



The Control Room of the Future: AI Meets Digital Twin

Seong Choi, Engineering Lead

NREL, one of 17 National Labs under Department of Energy (DOE)

Office of Science Laboratories

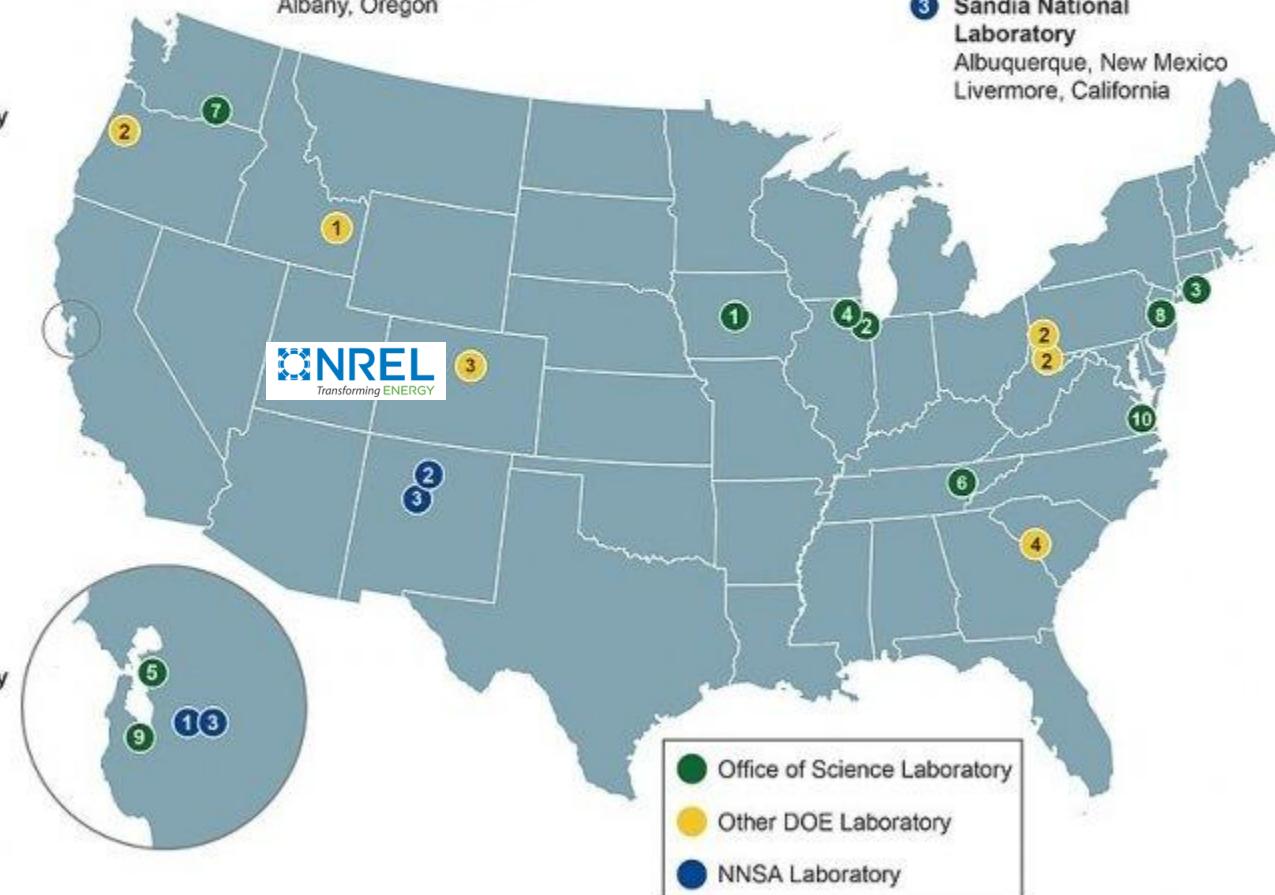
- 1 Ames Laboratory
Ames, Iowa
- 2 Argonne National Laboratory
Argonne, Illinois
- 3 Brookhaven National Laboratory
Upton, New York
- 4 Fermi National Accelerator Laboratory
Batavia, Illinois
- 5 Lawrence Berkeley National Laboratory
Berkeley, California
- 6 Oak Ridge National Laboratory
Oak Ridge, Tennessee
- 7 Pacific Northwest National Laboratory
Richland, Washington
- 8 Princeton Plasma Physics Laboratory
Princeton, New Jersey
- 9 SLAC National Accelerator Laboratory
Menlo Park, California
- 10 Thomas Jefferson National Accelerator Facility
Newport News, Virginia

Other DOE Laboratories

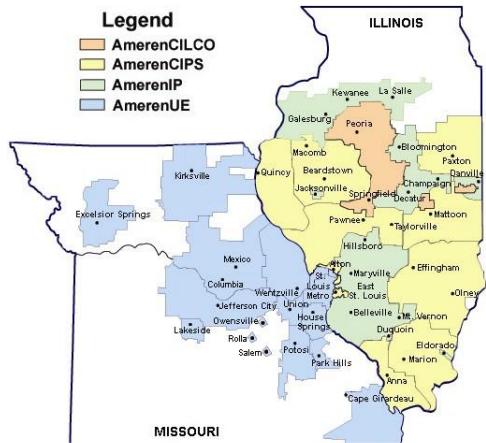
- 1 Idaho National Laboratory
Idaho Falls, Idaho
- 2 National Energy Technology Laboratory
Morgantown, West Virginia
Pittsburgh, Pennsylvania
Albany, Oregon
- 3 National Renewable Energy Laboratory
Golden, Colorado
- 4 Savannah River National Laboratory
Aiken, South Carolina

NNSA Laboratories

- 1 Lawrence Livermore National Laboratory
Livermore, California
- 2 Los Alamos National Laboratory
Los Alamos, New Mexico
- 3 Sandia National Laboratory
Albuquerque, New Mexico
Livermore, California



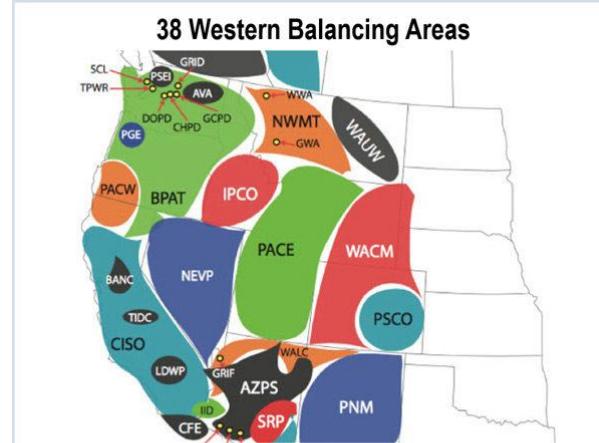
Who is Seong Choi



2000-2013:
Ameren

- Outage MS
- Customer IS
- Meter Data MS
- AMI

Distribution



2013-2019:
Peak Reliability

- Energy MS
- Wide area monitoring
- OSIsoft PI
- ESRI ArcGIS

Transmission



2019 – now:
NREL

- AI + Digital Twin
- Control room support
- National Resilience model
- Cybersecurity

T&D + DERMS

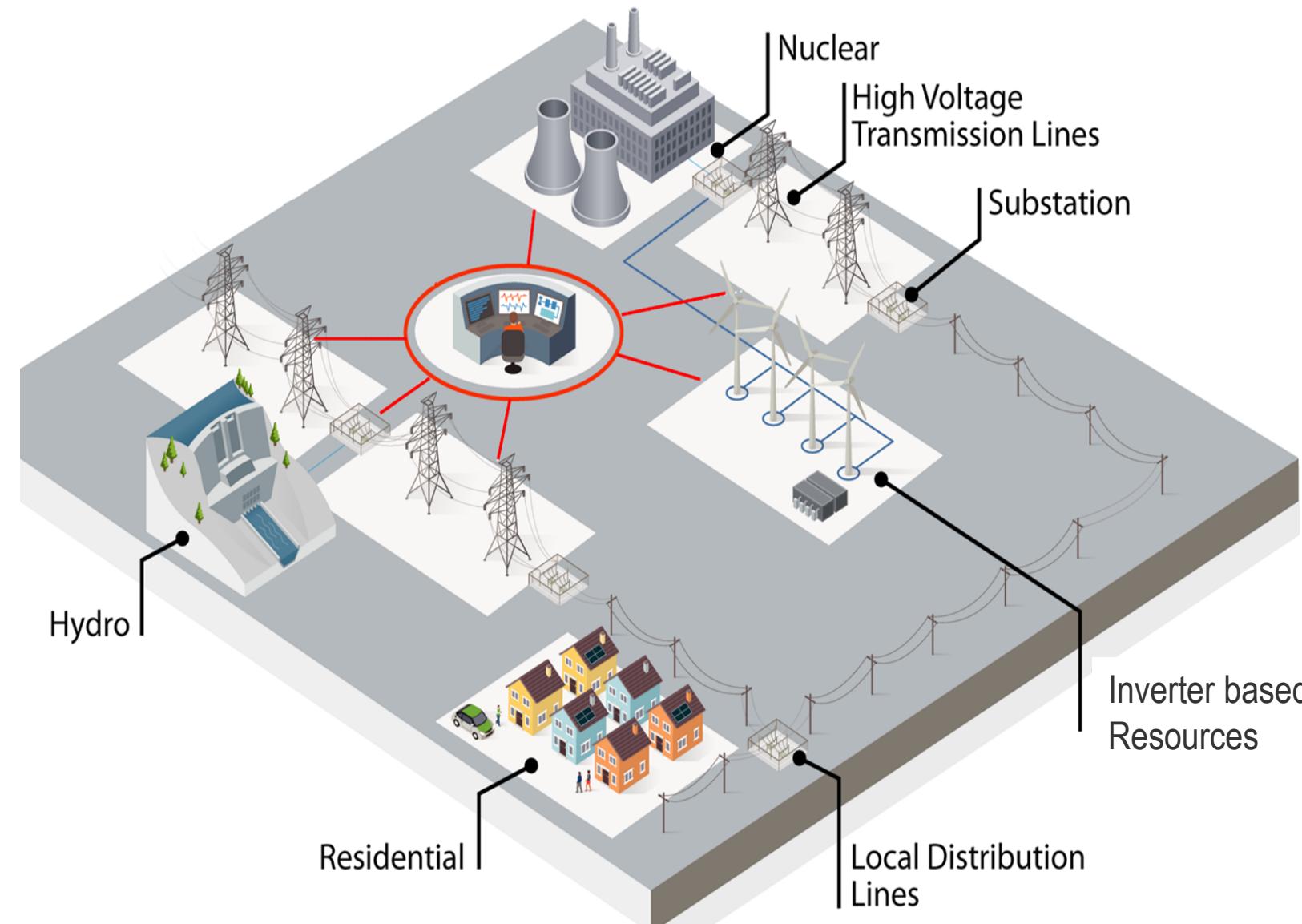
- MS in Technology and Human Affairs (focused S&T Policy), Washington University, St. Louis, MO
- Seoul National University (Graduate course work in Philosophy of Science), South Korea
- BS in EE, Korea Advanced Institute of Science and Technology (KAIST), South Korea

- Certified Information Systems Security Professional (CISSP) Licensed
- Former NERC Reliability Coordinator (RC) Holder
- Former Project Management Professional (PMP)

3 Key Topics to Discuss

1. AI understand your language
 2. Any concerns about using AI
 3. How NREL can help you to adopt AI
-

Grid: The World's Largest Machine Interconnection by synchronization



Interoperability is needed among different types of generation as more is interconnected.



1895

Large Waterpower



1939

Natural Gas



1916

Geo-Thermal



1954

Nuclear

The U.S. T&D system has been called the world's largest machine and part of the greatest engineering achievement of the 20th century (National Academy of Engineering, 2003).

NERC Electricity Stat



1,087,354 MW
2024 Summer Peak Capacity

The ERO Enterprise: NERC and Regional Entities



19 Reliability Coordinators

4 Interconnections

180 Transmission Operators

1,159 Generator Owners

107 Balancing Authorities

389 Distribution Providers

2024 BPS Inventory and Performance Statistics



5,840 Conventional Power Plants (>20MW)



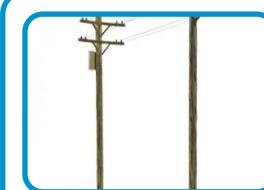
30,000 Transmission Substations (>100kV)



526,833 miles of transmission lines (>100kV)

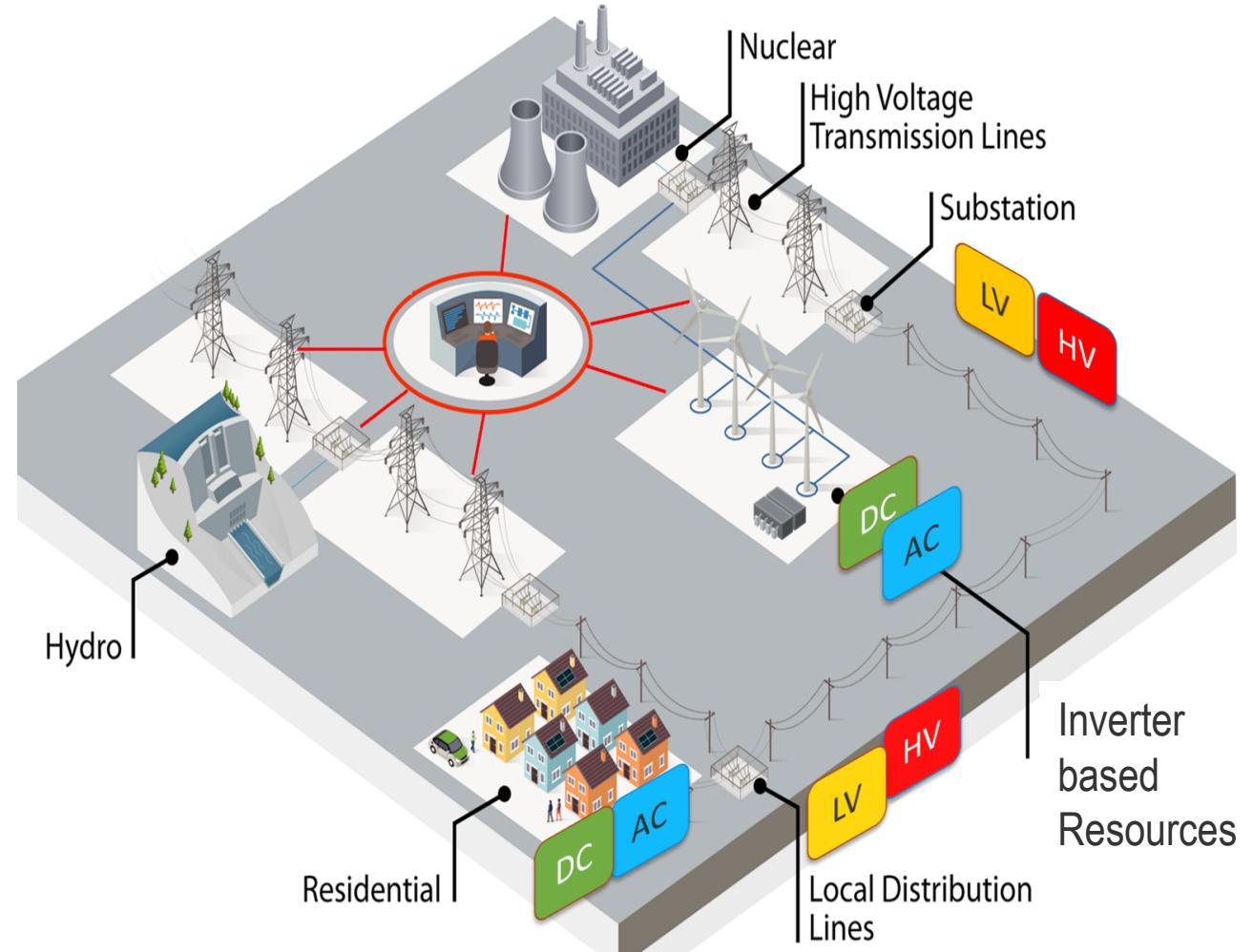
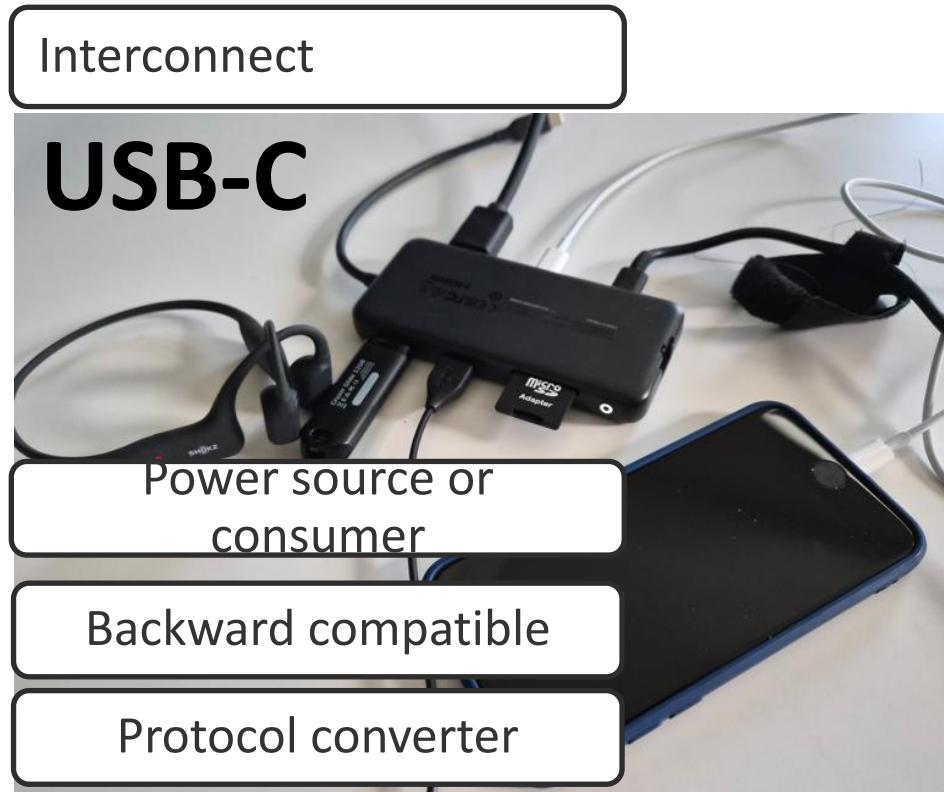


2.7 M Transmission Towers (estimated)



170 M Wood poles (estimated)

Interconnection/Interchange Concept



Good Side of Interconnection Transmission Expansion by Substation Transformer

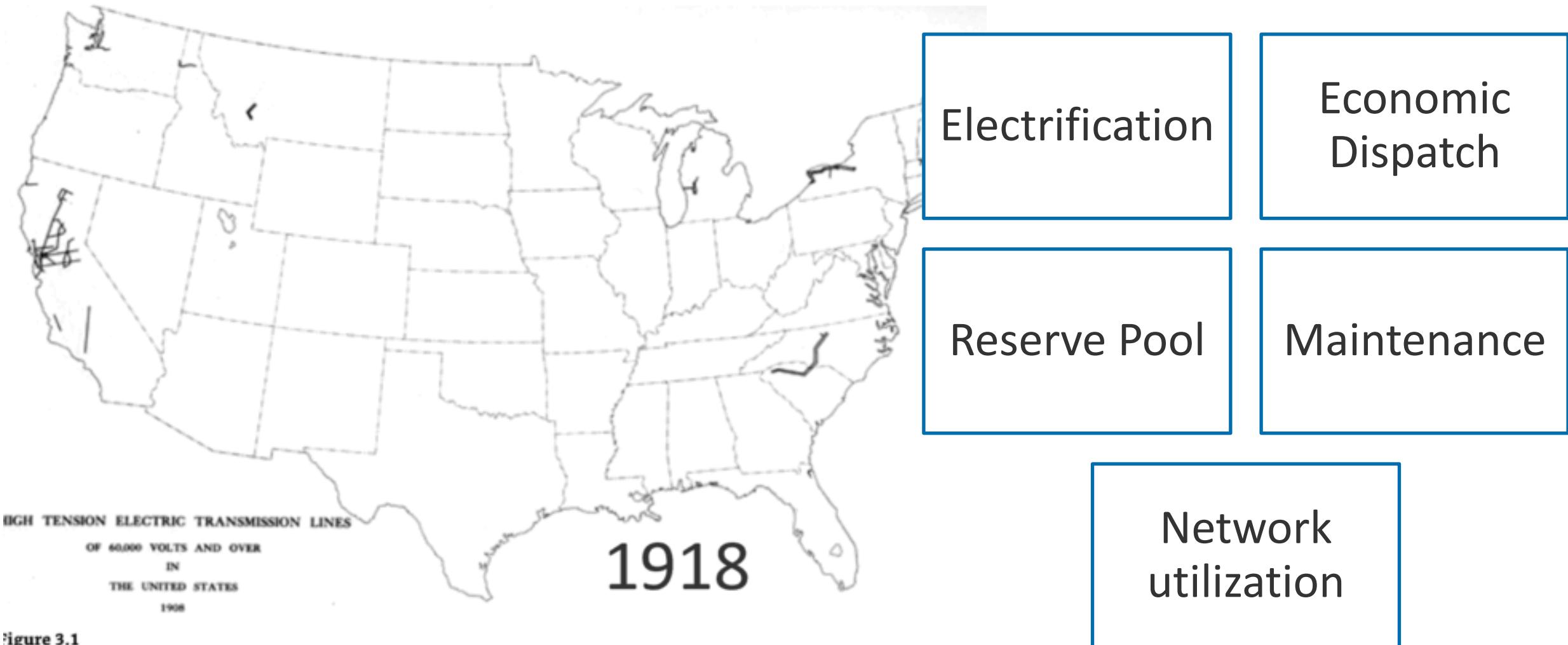


Figure 3.1

Map showing high-voltage transmission lines and related networks in 1918.

Other Side of Interconnection: Cascading Outage



<https://www.rcinet.ca/en/2016/11/09/history-nov-9-1965-the-great-northeast-blackout/>

Why should we be in the dark because of something that happened in Canada? **I've never even been to Canada.**

Electrical world 164, no 21 (1965): 31-34

System collapsed in 13 minutes

Uncontrolled Outages Cause Significant Grid Problems

Date	Location	Customers Affected	Collapse Time	Nature of Collapse
Nov. 9, 1965	Northeast	30,000,000 people 20,000 MW	13 min	Successive tripping of lines
Jul. 13, 1977	New York City	9,000,000 people 6,000 MW	1 hour	Successive tripping of lines and generators
Dec. 22, 1982	West Coast	12,350 MW	Few minutes	Successive line tripping, protection coordination scheme failure
Jul. 2, 1996	Western US	2,000,000 11,850 MW	36 seconds	Successive tripping of lines, generators and voltage collapse
Aug. 10, 1996	Western US	7,500,000 28,000 MW	> 1 min	Voltage collapse
Aug. 14, 2003	Northeast	10,000,000 customers in Ontario, 40,000,000 customers in US 61,800 MW	> 1 hour	Successive tripping of lines, generators and voltage collapse
Sept. 8, 2011	Western US	2.7 million customers out in AZ, S. CA, MX	11 min	Successive tripping of lines, generators, automatic load shedding, and operation of Remedial Action Scheme (RAS)



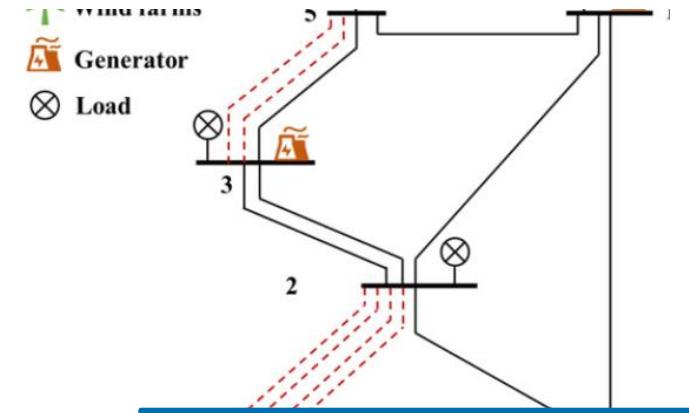
Understanding Outages - Planned vs Forced



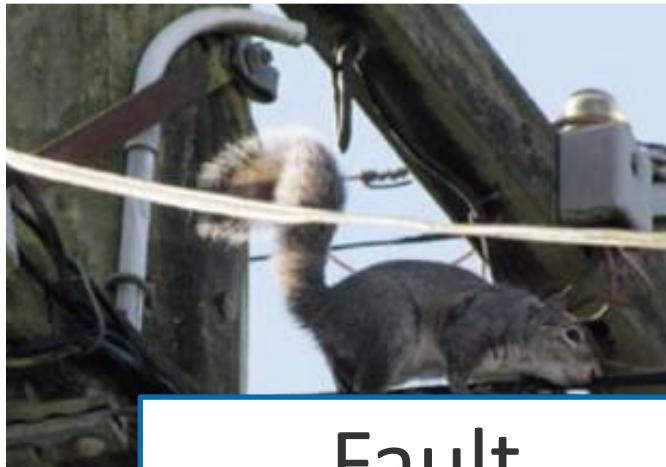
Vegetation



Maintenance



Line Upgrade



Fault



Tornado



Lightening

Number of Outages by ISO

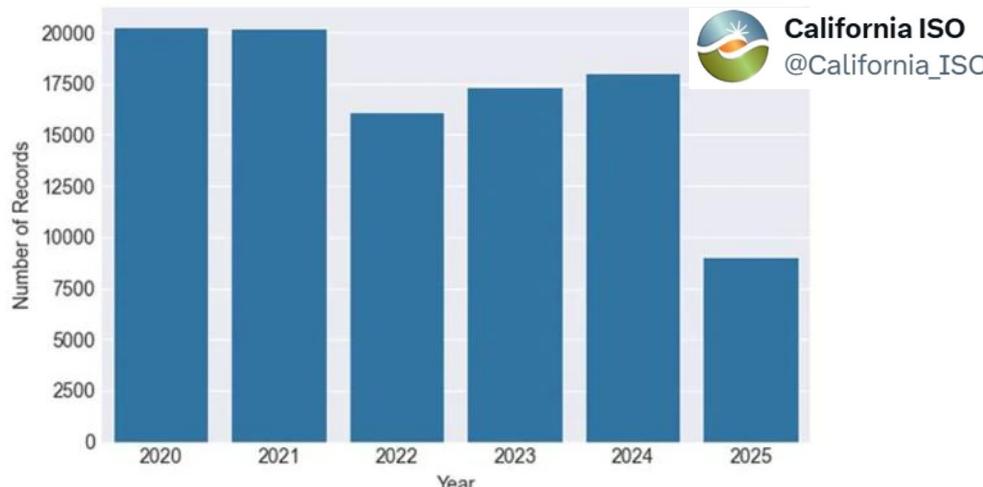
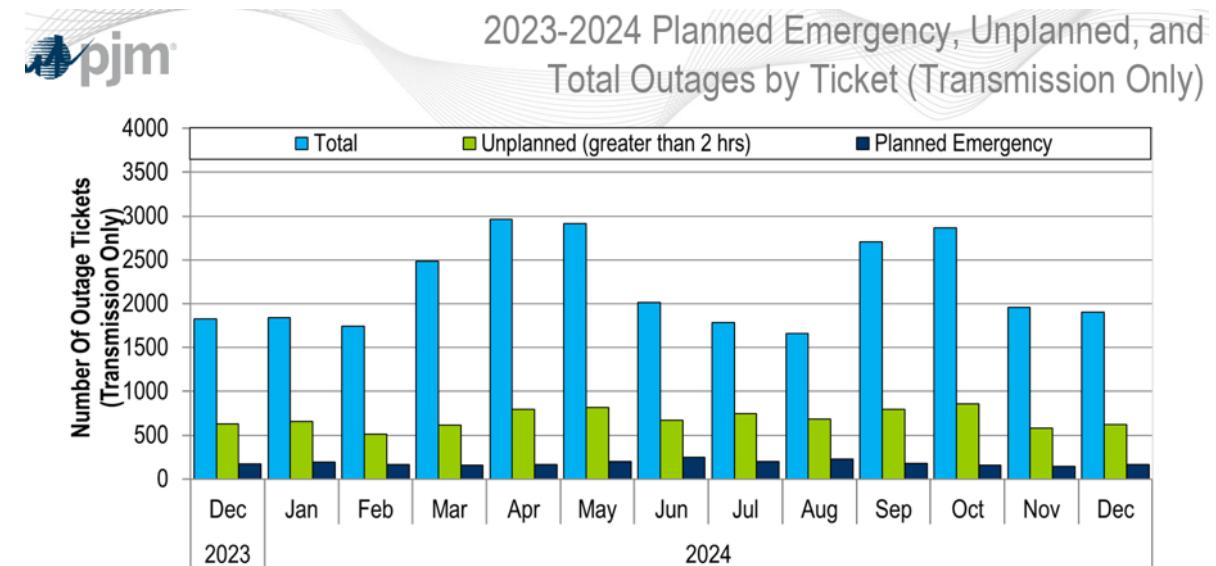
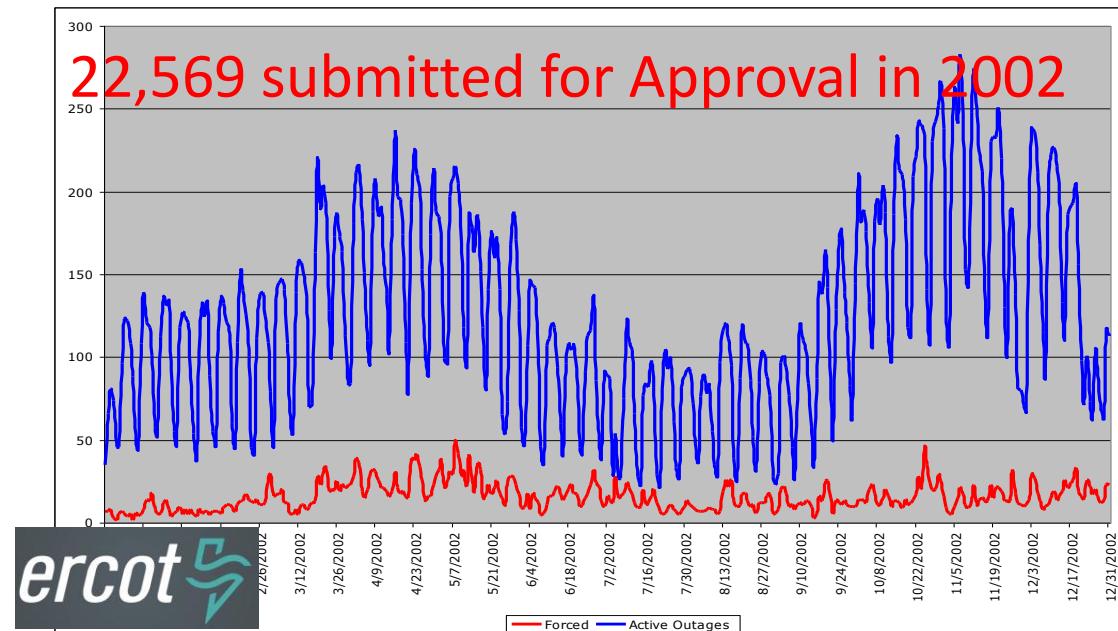
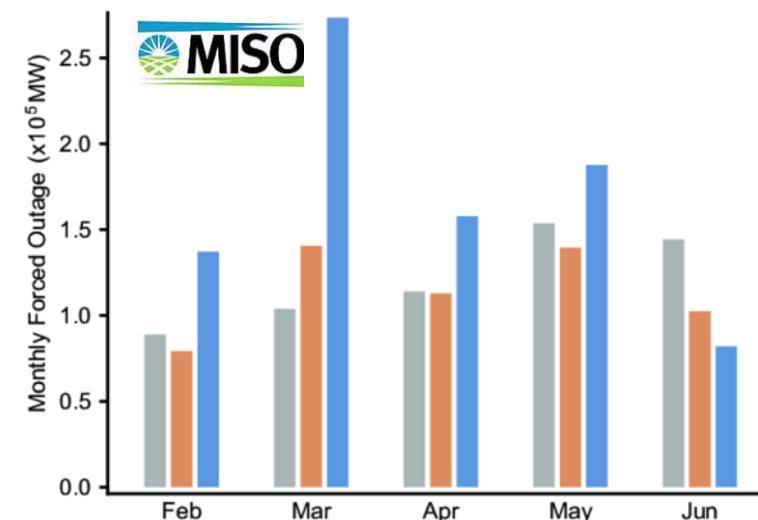


Figure 1. Number of records processed for the CAISO BA from 2020 – July 2025



Note: "Unplanned Outages" include tripped facilities. One tripping event may involve multiple facilities.

■ 2018 ■ 2019 ■ 2020



Minimize Risk by Cascading Outages: Outage Coordination

FERC Order 2000 & NERC reliability standards **TPL-001-4**

TOP submit
outage

ISO review
outage

If no issues

- Viability
- Reliability
- Mitigations available

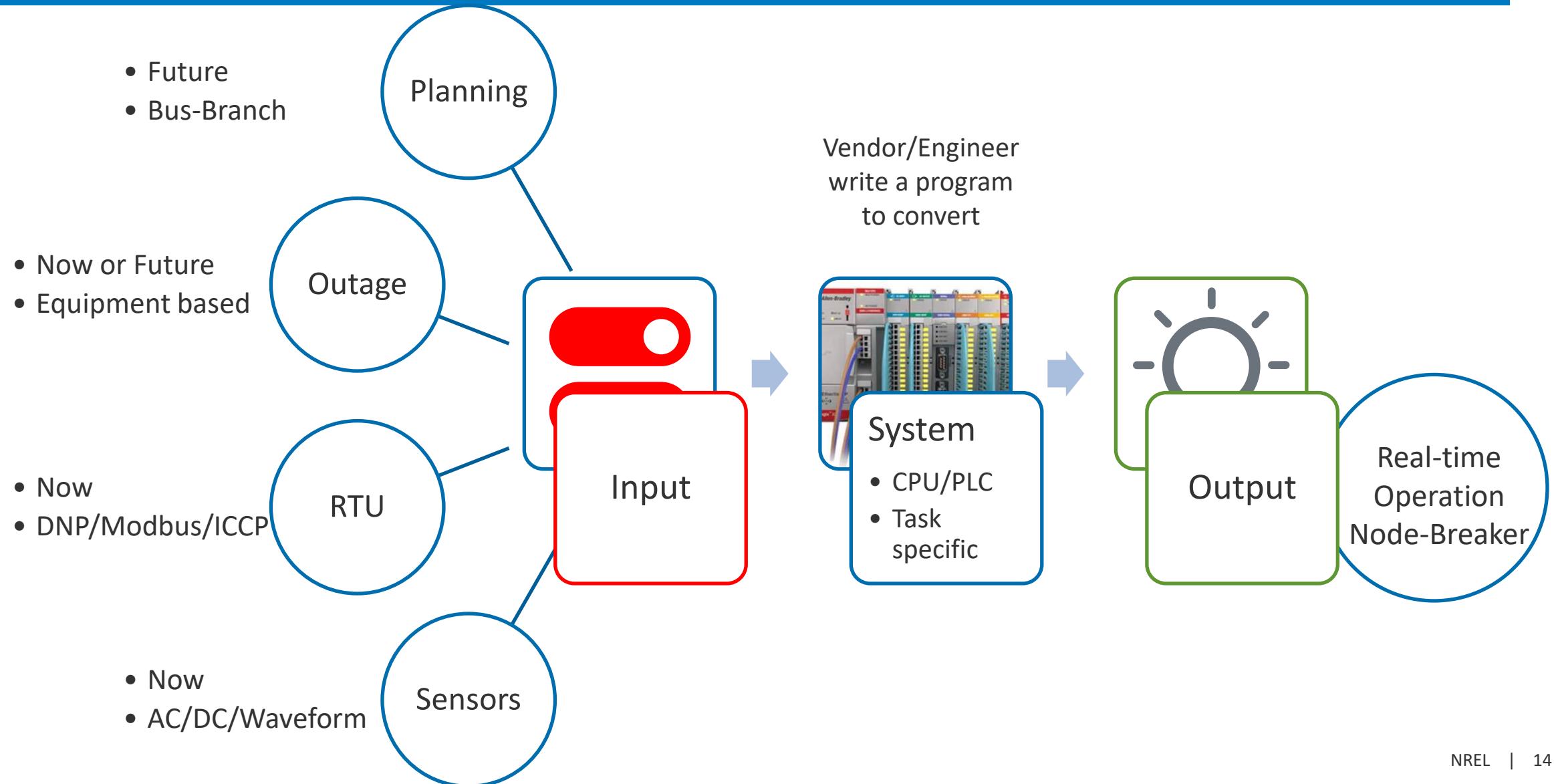
Mapping
outage device
name by TOP <-
> EMS in ISO

Identify
equipment to
be open in EMS

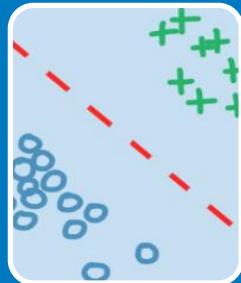
- Various dispatch condition



Mapping/Conversion/Translation /Interchange

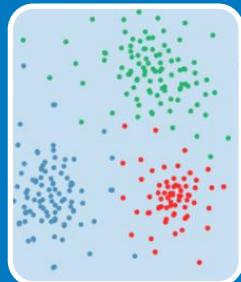


Mapping/Translating by AI?



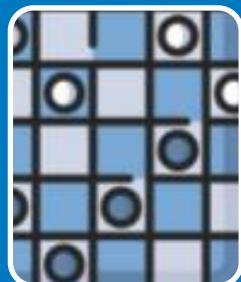
Supervised

- Unknown function
- Known input & output



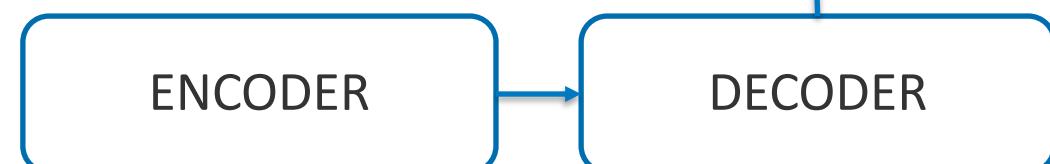
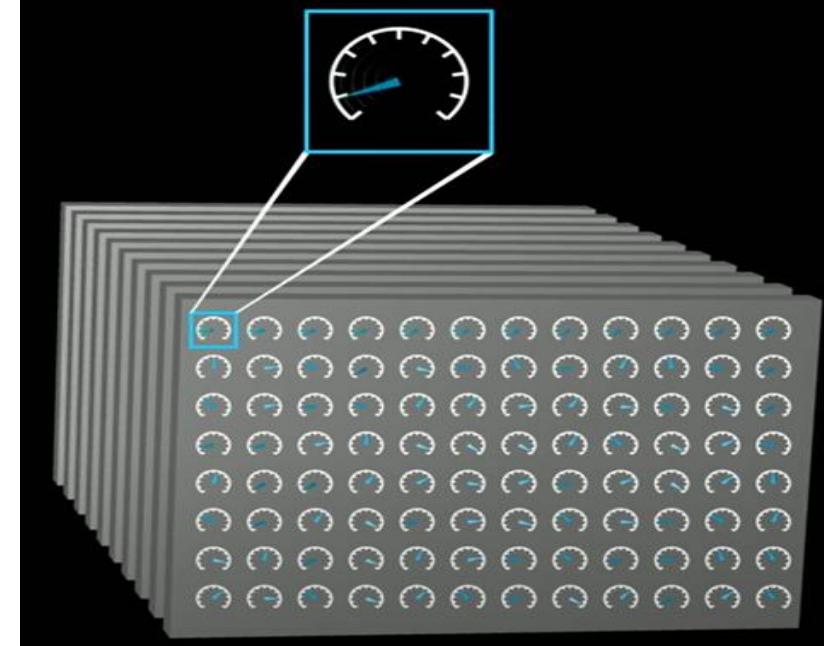
Unsupervised

- Unlabeled input
- Similarity/Pattern recognition



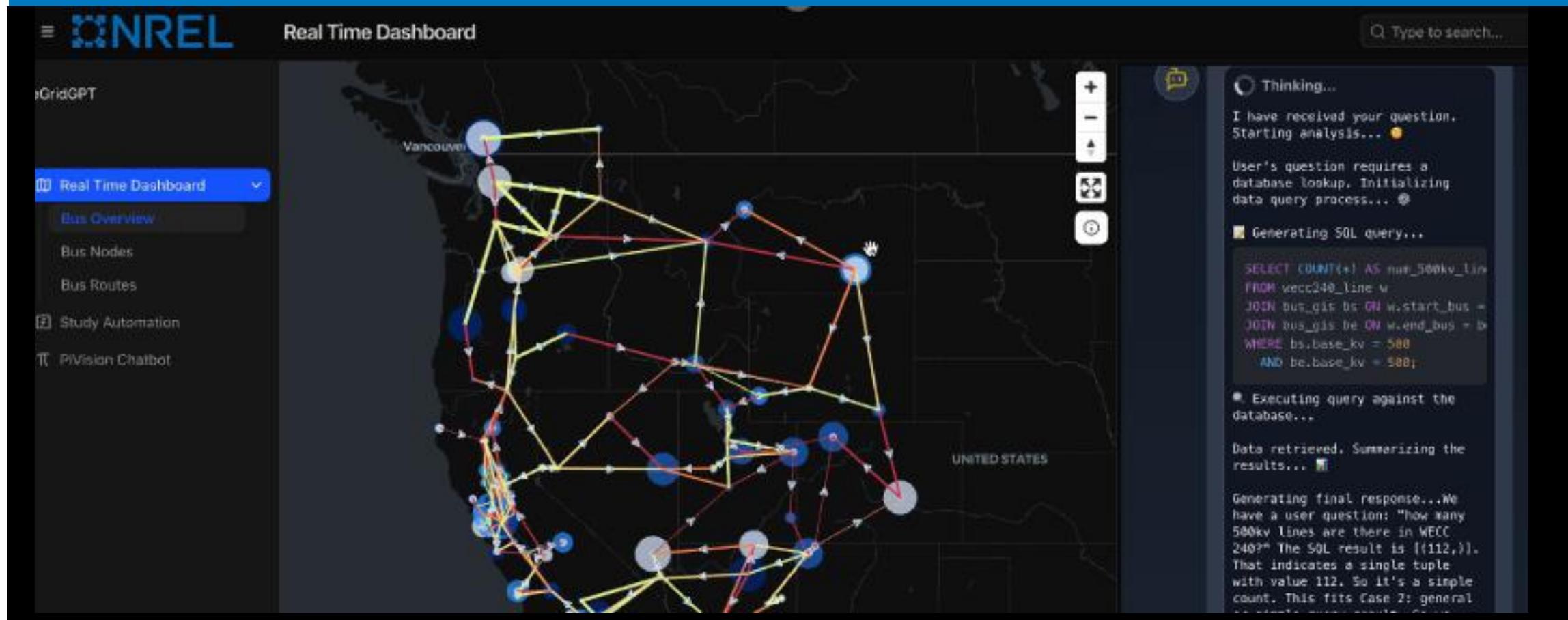
Reinforcement Learning

- Ground truth
- Policy gradient

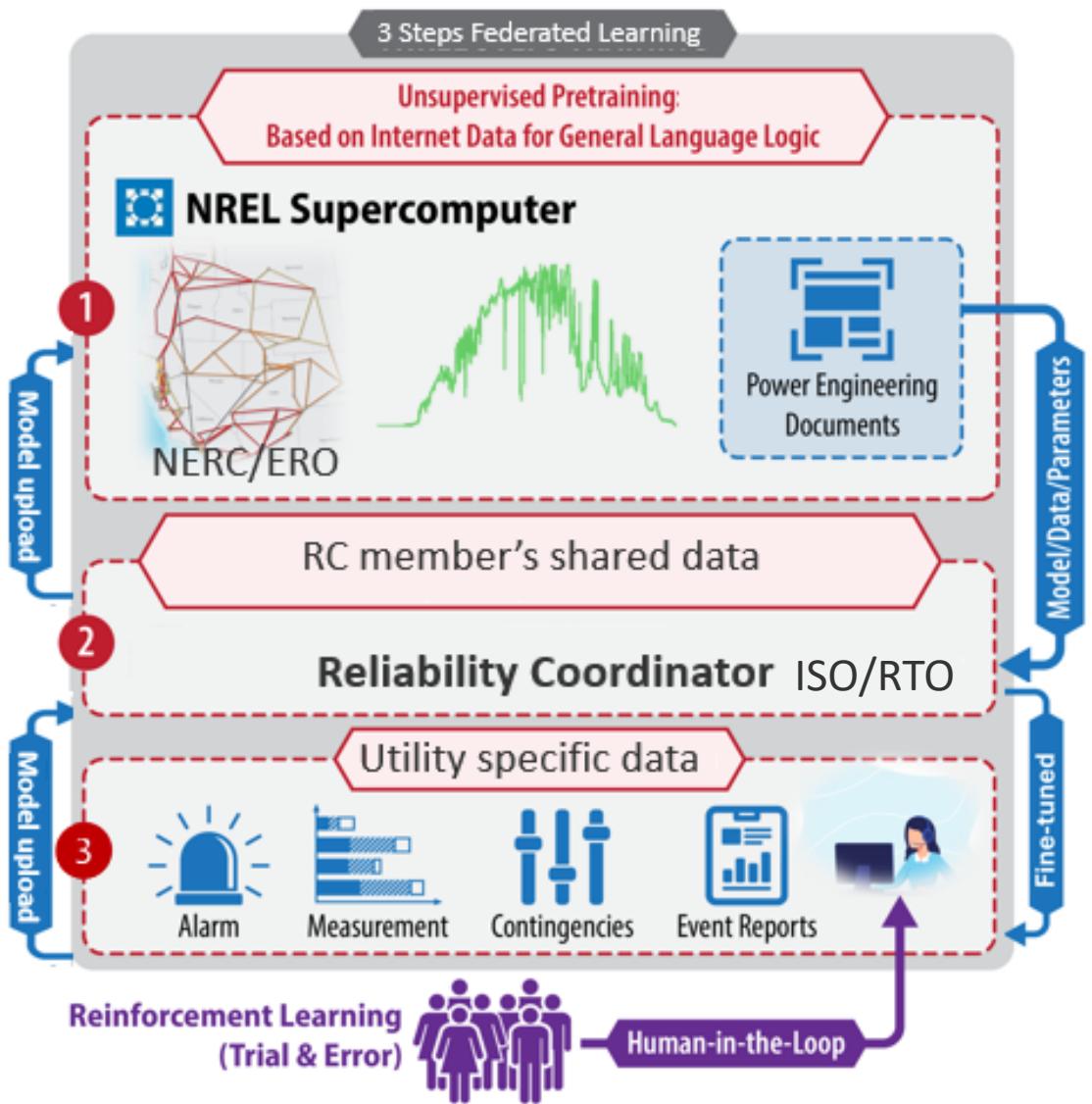


Line XYZ trip
Line 123 overloading

eGridGPT: Trustworthy



Collaborate with Us



eGridGPT
Trustworthy AI



Secure, Reliable, Affordable & Resilient Operations

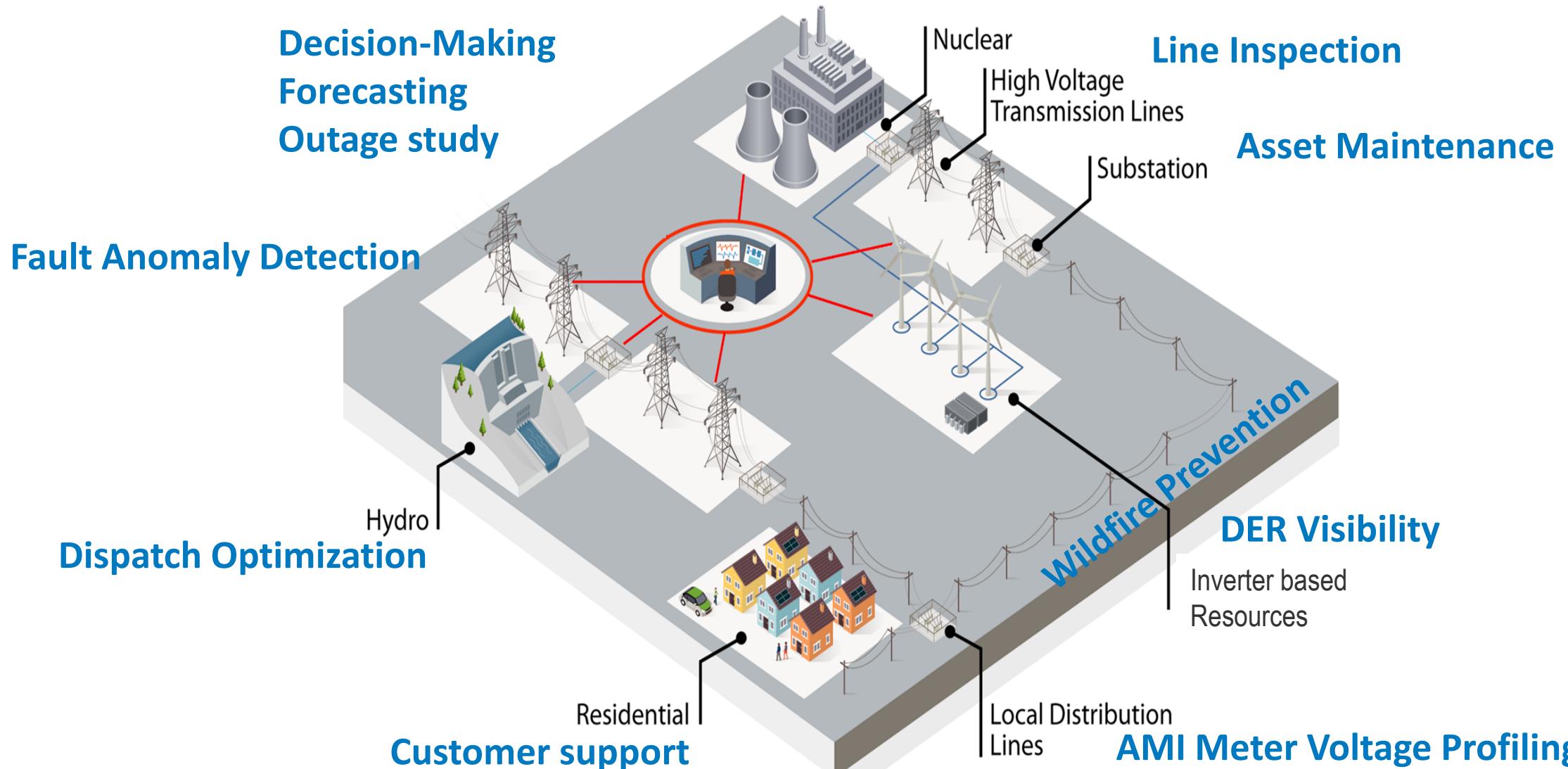
Assist at All Scales,
T&D + DER

On-premise &
To run on a laptop

Cyber secure &
NERC Compliant



There Are Lots Of Use Cases AI Can Do



AI Use Cases by Functions

Grid Operation

- Load/Gen/Price Forecasting
- Outage Prediction
- Workforce Training
- Anomaly/Patterns Recognition

Grid Planning

- Capacity Expansion Planning
- Resource Planning
- Asset Inventory
- Storm Restoration

Grid Modeling

- Optimal PowerFlow
- Transient & Dynamic Stability
- System Security/Fault Detection

Business Operations

- Rate Case Documentation
- Policy Development
- Company Performance Data

Cybersecurity

- Anomaly Detection
- Vulnerability Assessment
- Incident Response

Customer service

- Interactions Analysis
- Data Support for Call Center
- Billing Dispute

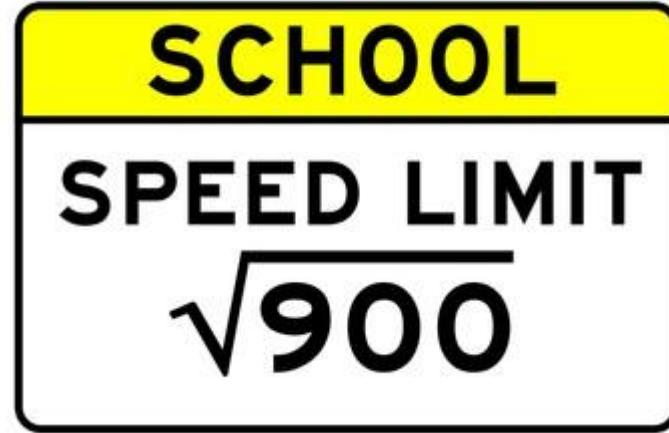
3 Key Topics to Discuss

1. AI understand your language

2. Any concerns about using AI

3. How NREL can help you to adopt AI

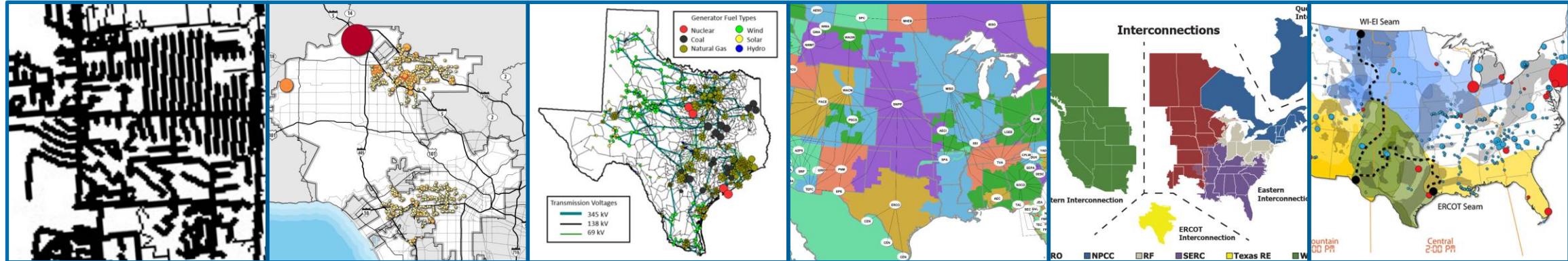
Seong's Thought: Utility Mind Set of a New Tool



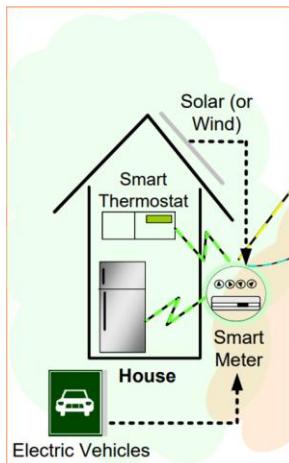
If it ain't broke, don't fix it

Reliability is the top priority, not reducing O&M cost

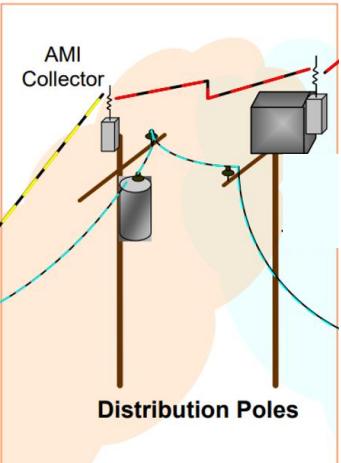
Grid is a National Critical Infrastructure NERC Compliance



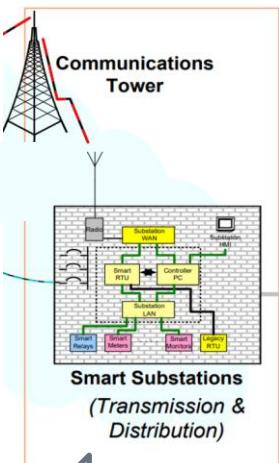
Home



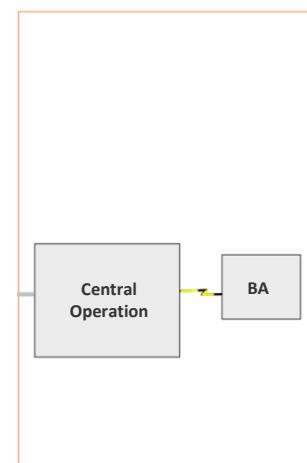
City



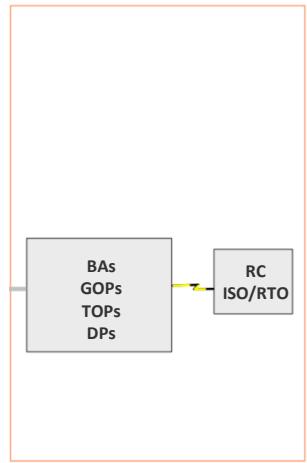
State



Regional



Interconnection



National

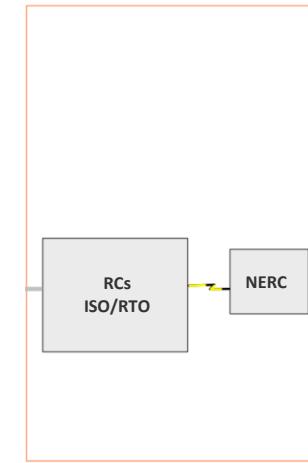


Image credit: PJM, NERC , Texas A&M & NREL

Currently, no cloud service allowed

Utilities' Grid Modernization: Why?

Vision:

- To become the leading ...

Goals:

- Improve ...
- Enhance ...

Functions:

- Reliability
- Customer satisfaction

Process:

- Contingency analysis
- Customer support

Technology:

- Energy management system
- Call center IVR

Data Center

- Aging infrastructure
- Transmission upgrade
- Capacity expansion

AI

- Baby boomer retiring
- Big data
- Productivity

Control Room

- Uncertainty
- Low visibility
- Extreme weather

Urgent Utilities' Grid Modernization

Vision:

- To become the leading ...

Goals:

- Improve ...
- Enhance ...

Functions:

- Reliability
- Customer satisfaction

Process:

- Contingency analysis
- Customer support

Technology:

- Energy management system
- Call center IVR

Technology Toolbox for achieving future goals

Measuring Technology Maturity

Technology Trend

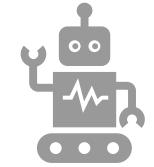
Mapping future goals to Technologies



Generative AI



Digital Twin



Robot/Drone



eGridGPT
Trustworthy AI



3 Key Topics to Discuss

1. AI understand your language

2. Any concerns about using AI

3. How NREL can help you to adopt AI

eGridGPT Use Cases

Manual to Automation

- Outage study automation
- Many scenarios / 30 min

Integration

- Different tools talk to each other
- Reduce number of displays

Big Data: Hard to process or never been used

- Flood of alarms
- 1,000 alarms / hour

NREL eGridGPT Supports Control Room Operator Transition by Integrating AI + Digital Twin



LADWP

Past
No computer/Analog



PeakRC

Present
Computer/Digital



NREL

Future
Digital transformation

Importance of the Control Room Operator



System Reliability

- What happens if something goes wrong?

Stability

- Secure power flow to prevent abnormal conditions

Affordability

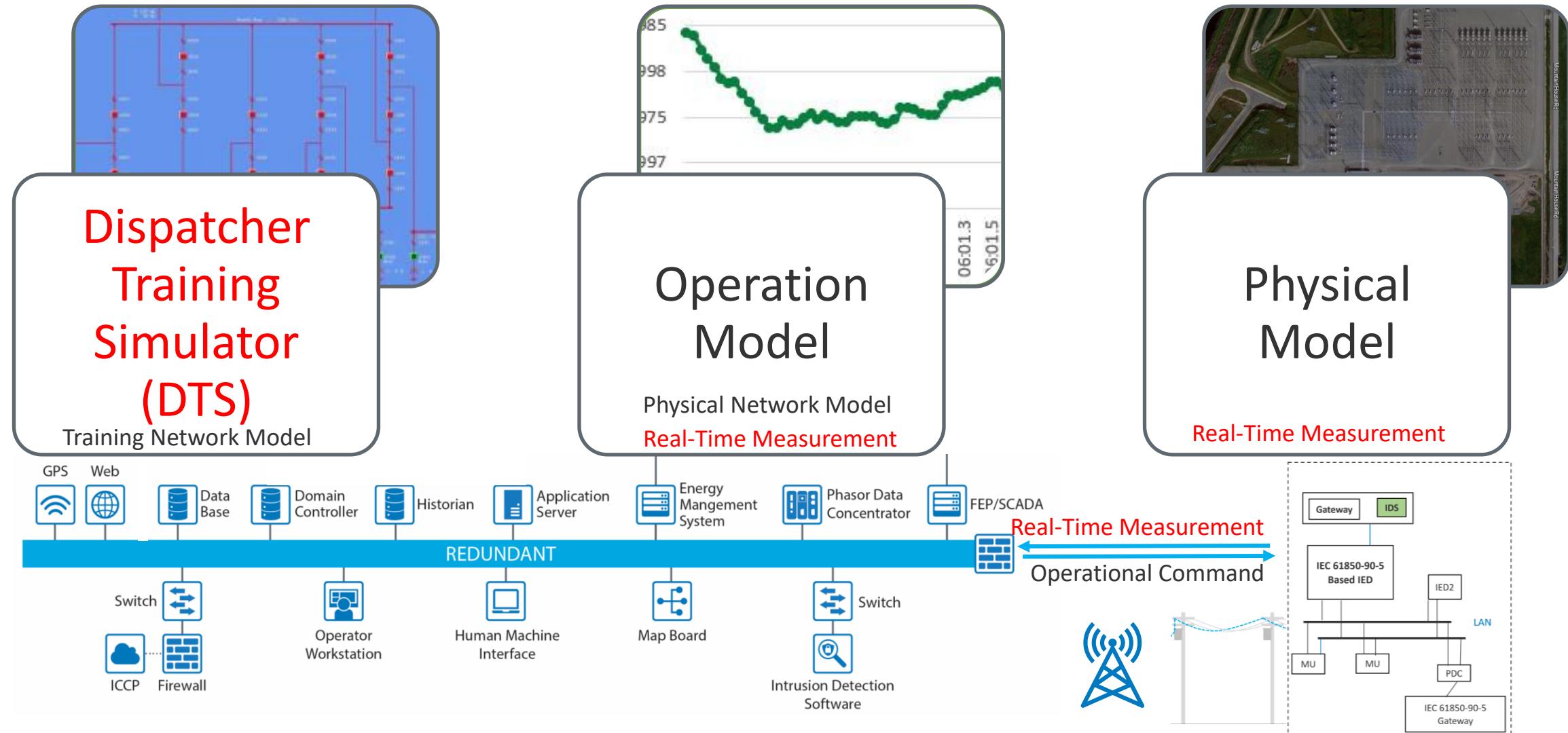
- Optimal cost

Resilience

- Quickly restore

Why Digital Twin?

Automation, Accuracy & Many Simulations



Expanding eGridGPT Automation

The screenshot shows the eGridGPT web application interface. At the top, there's a header with the NREL logo, a search bar, and a 'Study Automation' button. On the left, a sidebar lists 'Real Time Dashboard', 'Bus Overview' (which is selected), 'Bus Nodes', 'Bus Routes', 'Study Automation' (which is also selected), and 'PiVision Chatbot'. The main content area has a blue header 'Digital Twin Simulation: eGridGPT' with the sub-instruction 'Ask questions and get responses from a Power System Simulator (OpenDSS)'. Below this, a green banner says 'Connected - 3 servers available'. A message box displays a timestamp '7:13:51 PM' and the heading 'MCP Client: eGridGPT + OpenDSS'. It states 'Your questions are processed by a Power System Simulator (OpenDSS)' and lists two features: 'Filesystem - Read and write files' and 'Sequential Thinking - Step-by-step problem solving'. At the bottom, a yellow callout box contains the text 'eGridGPT automates study process by leveraging digital twin!'. At the very bottom, there's an input field 'Ask a question...' and a 'Send' button.

eGridGPT

≡ **NREL** Study Automation Type to search...

Real Time Dashboard

Bus Overview

Bus Nodes

Bus Routes

Study Automation

PiVision Chatbot

Digital Twin Simulation: eGridGPT

Ask questions and get responses from a Power System Simulator (OpenDSS)

Connected - 3 servers available

7:13:51 PM

MCP Client: eGridGPT + OpenDSS

Your questions are processed by a Power System Simulator (OpenDSS)

- **Filesystem** - Read and write files
- **Sequential Thinking** - Step-by-step problem solving

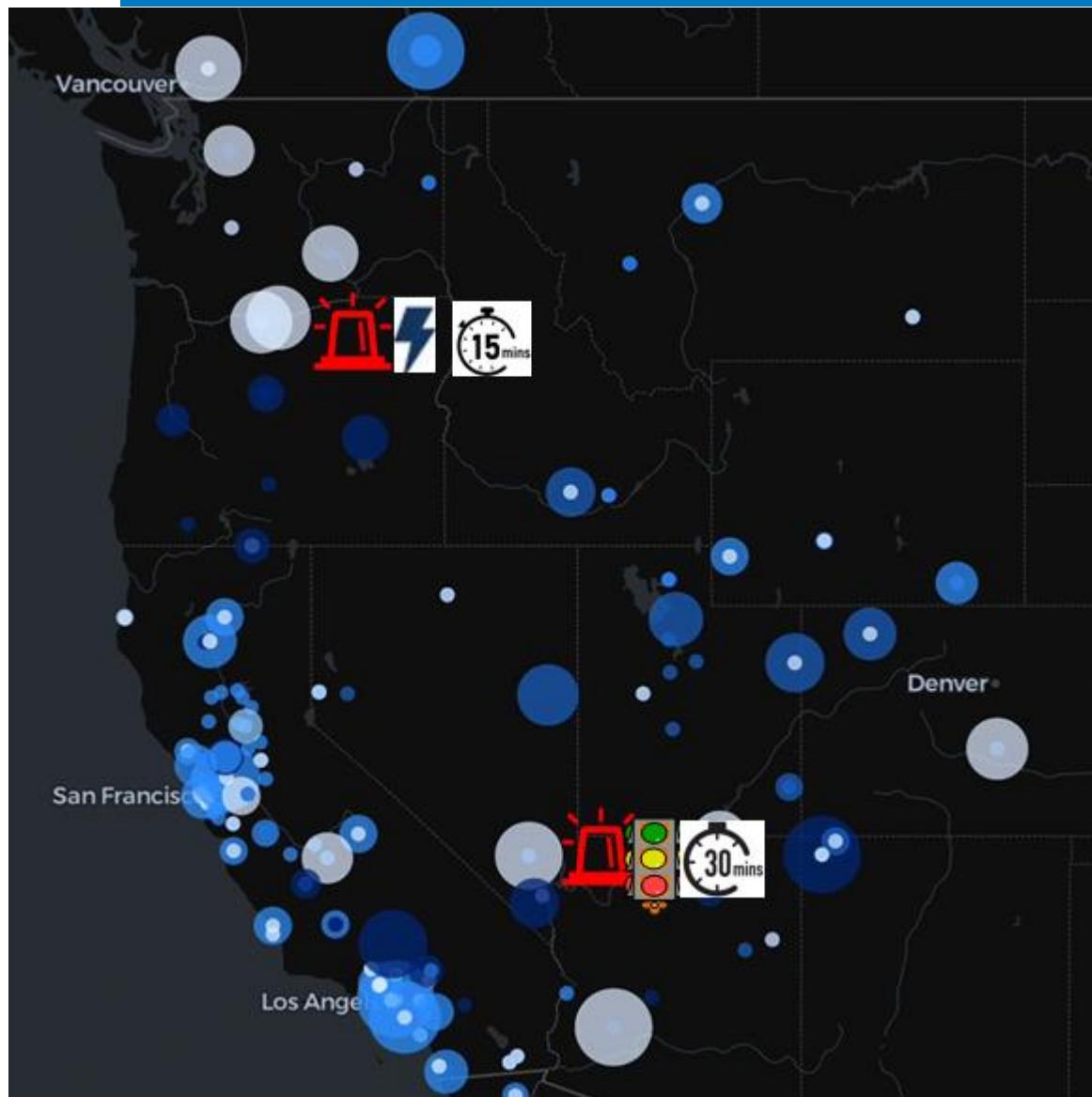
eGridGPT automates study process by leveraging digital twin!

W wecc@nrel.gov WECC

Ask a question...

30

eGridGPT Alarm Dashboard



All: 120

2
Critical

15
Time to Act (min)

4
Alarm Rate/hr

Alarm Summary

Time

State

Message

17/09/22:55

ACK

PSCO LINK UP

17/09/22:25

ACK

PSCO LINK DOWN

CALL BA TO CYCLE ICCP LINKS

17/08/33:47

ACK

RTNET SOL WITH MISMATCH ALARM RETURNS TO NORMAL

17/08/32:48

ACK

RTNET SOLVED WITH MISMATCH ALARMS

17/08/19:29

ACK

WALC DCS EVENT ROC -0.09

17/07/58:44

ACK

BHPL LINK UP

17/07/47:40

ACK

BHPL LINK DOWN

CALL BA TO CYCLE ICCP LINKS

17/07/42:47

ACK

RTNET SOL WITH MISMATCH ALARM RETURNS TO NORMAL

17/07/41:48

ACK

RTNET SOLVED WITH MISMATCH ALARMS

17/07/13:01

ACK

NVE_ LINK UP

Ack: 20

Unack: 100

Level

Critical 2

High 18

Medium 30

Low 70

Time	State	Message	Actions
17/09/22:55	ACK	PSCO LINK UP	UNACK
17/09/22:25	ACK	PSCO LINK DOWN	CALL BA TO CYCLE ICCP LINKS
17/08/33:47	ACK	RTNET SOL WITH MISMATCH ALARM RETURNS TO NORMAL	
17/08/32:48	ACK	RTNET SOLVED WITH MISMATCH ALARMS	
17/08/19:29	ACK	WALC DCS EVENT ROC -0.09	
17/07/58:44	ACK	BHPL LINK UP	
17/07/47:40	ACK	BHPL LINK DOWN	CALL BA TO CYCLE ICCP LINKS
17/07/42:47	ACK	RTNET SOL WITH MISMATCH ALARM RETURNS TO NORMAL	
17/07/41:48	ACK	RTNET SOLVED WITH MISMATCH ALARMS	
17/07/13:01	ACK	NVE_ LINK UP	

SCADA Enhanced Alarm Intelligence Tool



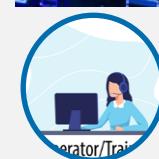
2
Hmmm DCS event...Can you check the alarms & run simulations?



Alarm DB



Mitigation



Operating instruction

5

Agentic AI
MCPs

6

Tools

LLMs

7

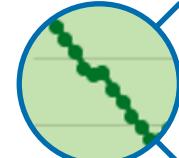
It maybe we are heading EEA 1. Here is why



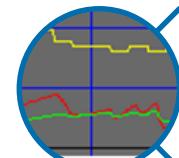
Many substations' lines are down. No measurement coming in. (R1) Recycle the link? Y/N



Transmission lines are overloading.
(R2) Re-run power flow? Y/N



Frequencies are decreasing. (R3)
Redispatch AGC? Y/N



Forecasting shows demand increase in 2 hours. 95% Probability considering weather predicted



EEA 1 is possible. Here is the procedure of NERC EOP-011

eGridGPT: Control Room of the Future



Thank You

Seong Choi (Engineering Lead)
Email: Seong.Chi@nrel.gov



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