

Control Center of the Future

Challenges and Opportunities



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ESIG Fall Technical Workshop, October 28th, 2025

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- Increase your awareness of challenges that others are facing and alternate solutions to challenges you might be facing
- Save time and money troubleshooting problems EPRI and its stakeholders have seen before

Transmission Operations : Challenges and Opportunities

Control Center Operational Readiness

- Use of new technology in operations (VR, LLM)
- Managing IBRs in RT
- Advanced operator training

Transmission Utilization and Control

- Optimal operation of different power flow control device
- Voltage and Reactive Power Optimization
- De-centralized Control

Resilient Operations

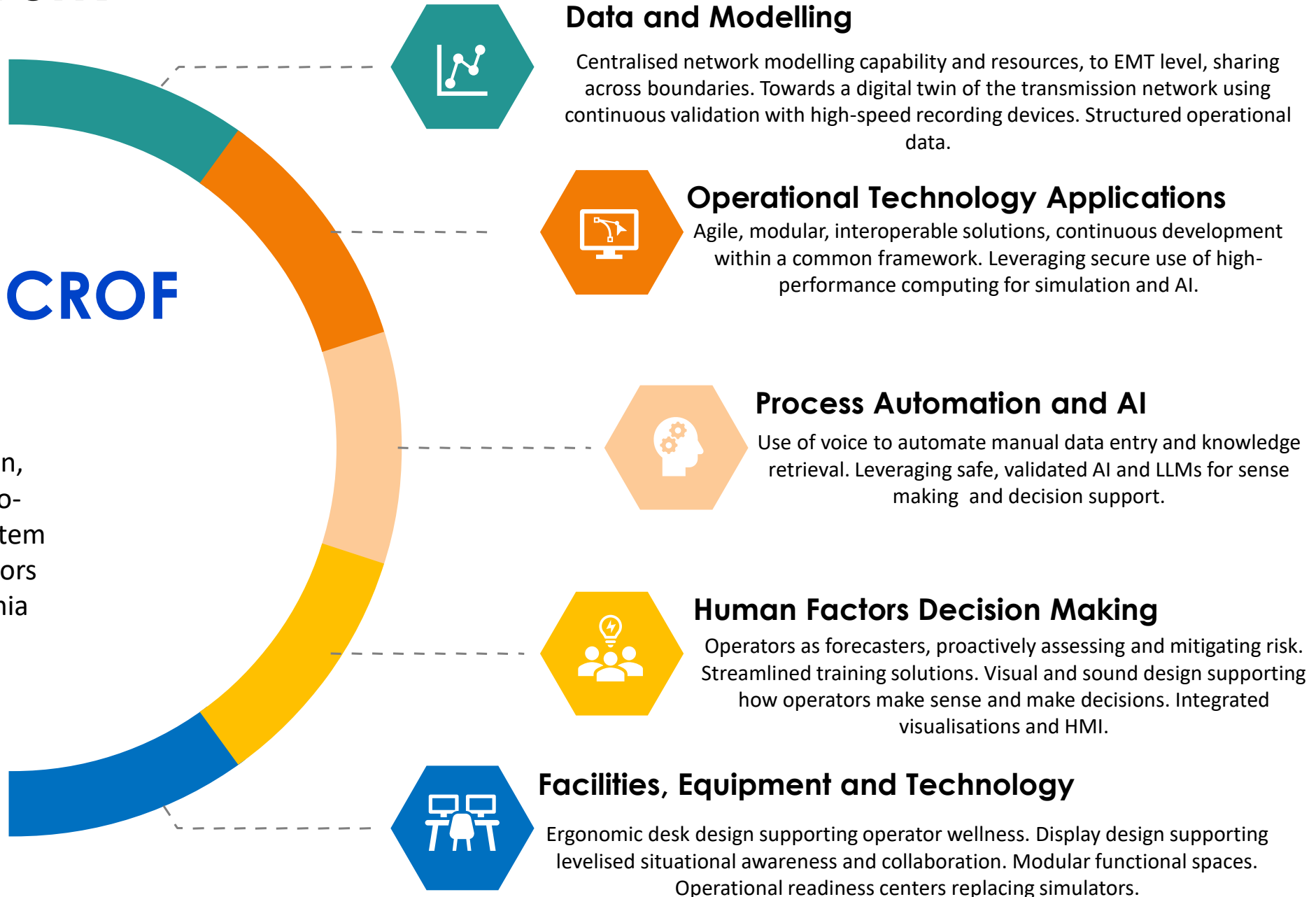
- Utilizing emerging technologies in Blackstart/Restoration
- Improve situational awareness
- Robust control center tools and applications

Leveraging AI, PMUs and Optimization Methods across all areas

CROF Framework

Realising the CROF Vision

This is an ambitious vision, requiring research and co-development between system operators, industrial vendors and research and academia



EPRI Control Room of the Future Vision

Ancillary Monitoring

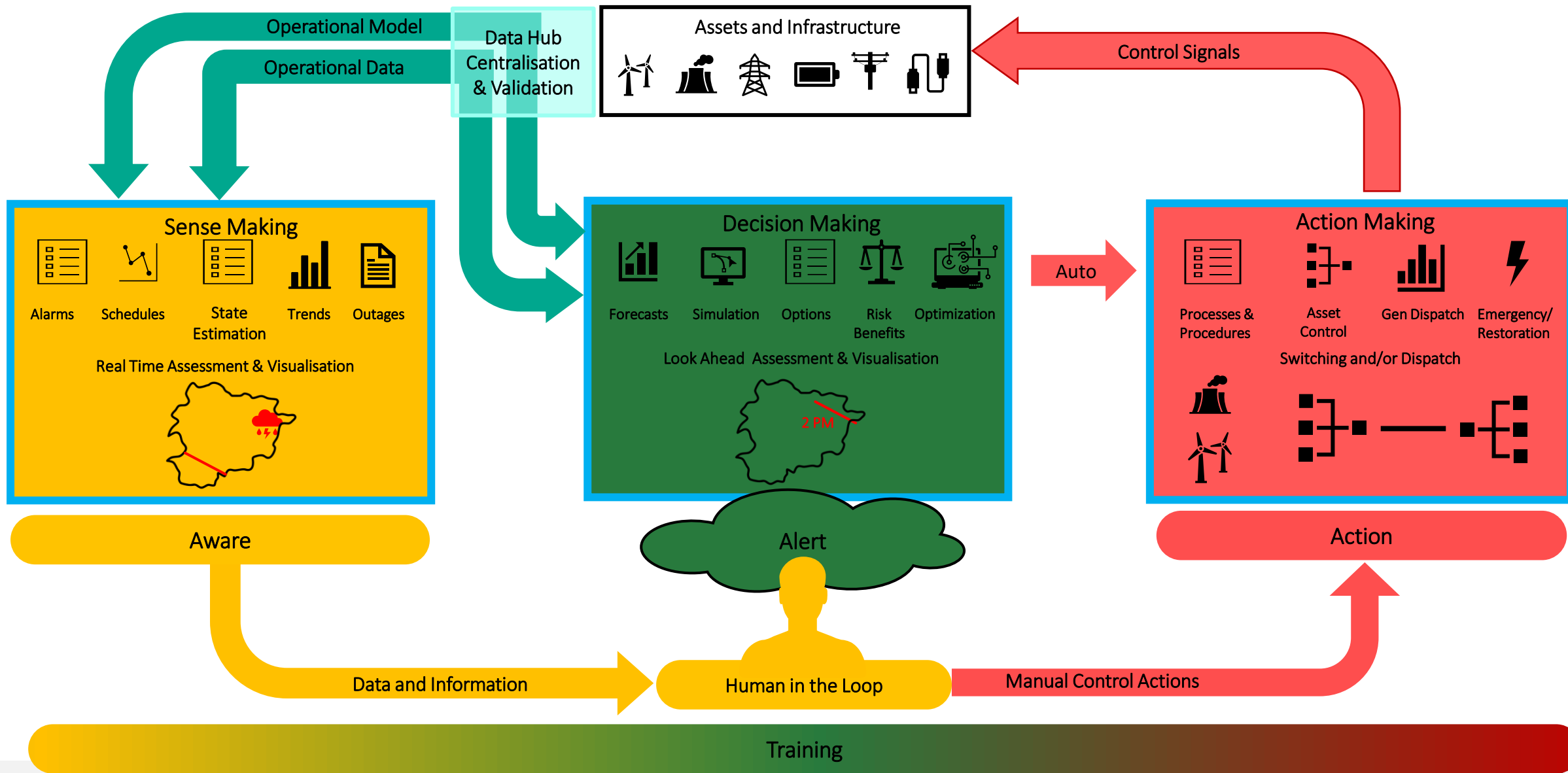
IT/OT Management

Telecoms Monitoring

Physical Security

Asset Health Monitoring

Cyber Security

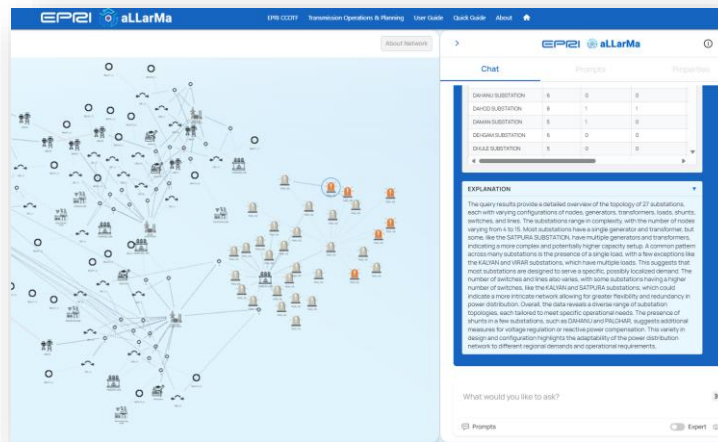




Leveraging AI in Operations

Concept – Can AI be Safely Used with Transmission Alarm and Operational Data

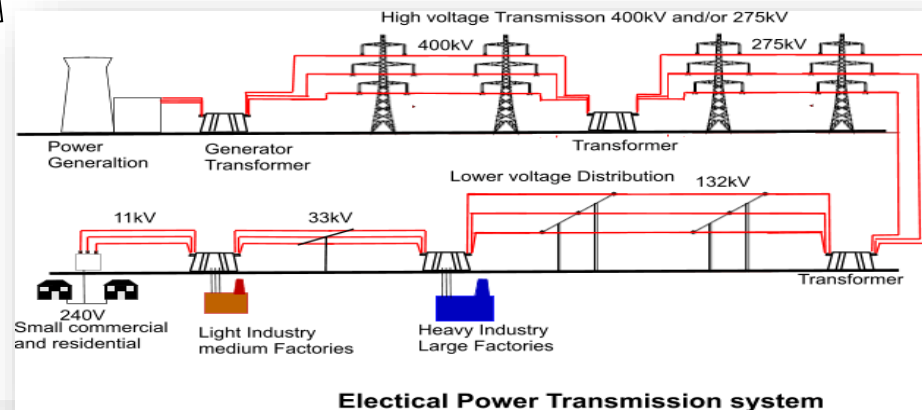
EPRI aLLarMa



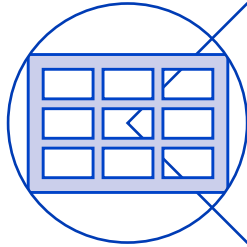
Alarm Data

EventTimeStamp	SCADA_Category	TOC	AOR	Priority_Code	Substation	DeviceType	Device	event_message
01/05/2017 00:00	MH	TMS	TOCMSDOC	3	Substation1317	STN	STA_SERVICE	Substation1317 STN STA_SERVICE AC SERV VOLTAGE NORMAL CHG-DET
01/05/2017 00:00	ML	TMS	TOCPB	4	Substation1265	BLKCAR	STUTR_PRI_UPLC	Substation1265 BLKCAR STUTR_PRI_UPLC CARRIER LEVEL LOW CHG-DET
01/05/2017 00:00	MH	TMS	TOCPB	3	Substation1459	BLKCAR	Device285	Substation1459 BLKCAR Device285 CARRIER LEVEL LOW CHG-DET
01/05/2017 00:00	MH	TMS	TOCPB	3	Substation1459	BLKCAR	Device285	Substation1459 BLKCAR Device285 SIGNAL RECEIVED NORMAL CHG-DET
01/05/2017 00:00	MH	TMS	TOCGR	3	Substation275	FIBOPT	LABAR_X_311L	Substation275 FIBOPT Device4576 PRI #2 OPTIC/CH NORMAL CHG-DET
01/05/2017 00:00	MH	TMS	TOCBM	3	Substation749	RELAY	L37_P2_SEL411L	Substation749 RELAY L37_P2_SEL411L RELAY FAILURE NORMAL CHG-DET
01/05/2017 00:00	MH	TMS	TOCBM	3	Substation256	RELAY	L532_SEL421313	Substation256 RELAY L532_SEL421313 SYSTEM NORMAL CHG-DET
01/05/2017 00:00	MH	TMS	TOCPA	3	Substation113	RELAY	L513_SEL411_P2	Substation113 RELAY L513_SEL411_P2 RELAY FAILURE NORMAL CHG-DET
01/05/2017 00:00	MH	TMS	TOCPA	3	Substation460	RELAY	L461	Substation460 RELAY L461 BKUP SYSTEM FAIL NORMAL CHG-DET
01/05/2017 00:00	ML	TMS	TOCED	4	Substation232	BLKCAR	Device689	Substation232 BLKCAR Device689 SIGNAL RECEIVED NORMAL CHG-DET
01/05/2017 00:00	MH	TMS	TOCGR	3	Substation1322	RELAY	Device1492	Substation1322 RELAY Device1492 #1 PRIMARY RELAY NORMAL CHG-DET

+ Network

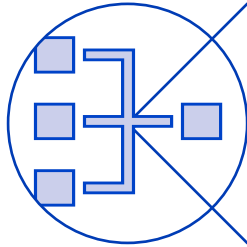


Challenges to the aLLarMa Concept



Lack of Transmission Ops Context –

- Alarm text is semi-structured.
- Standard LLMs don't recognise words and text acronyms,
- Different network data: Solution not generalizable



Lack of Network Context –

- The alarm text is separate from network model
- Asset data, protection, network, weather, outages also important



Hallucination –

- For high reliability organisations – cannot afford nonsense answers to important questions
- Need references to answers and an ability to verify



Security –

- Open weight LLMs are good but limited in capability.
- Cannot transfer network data to train frontier models

How We Built aLLarMa

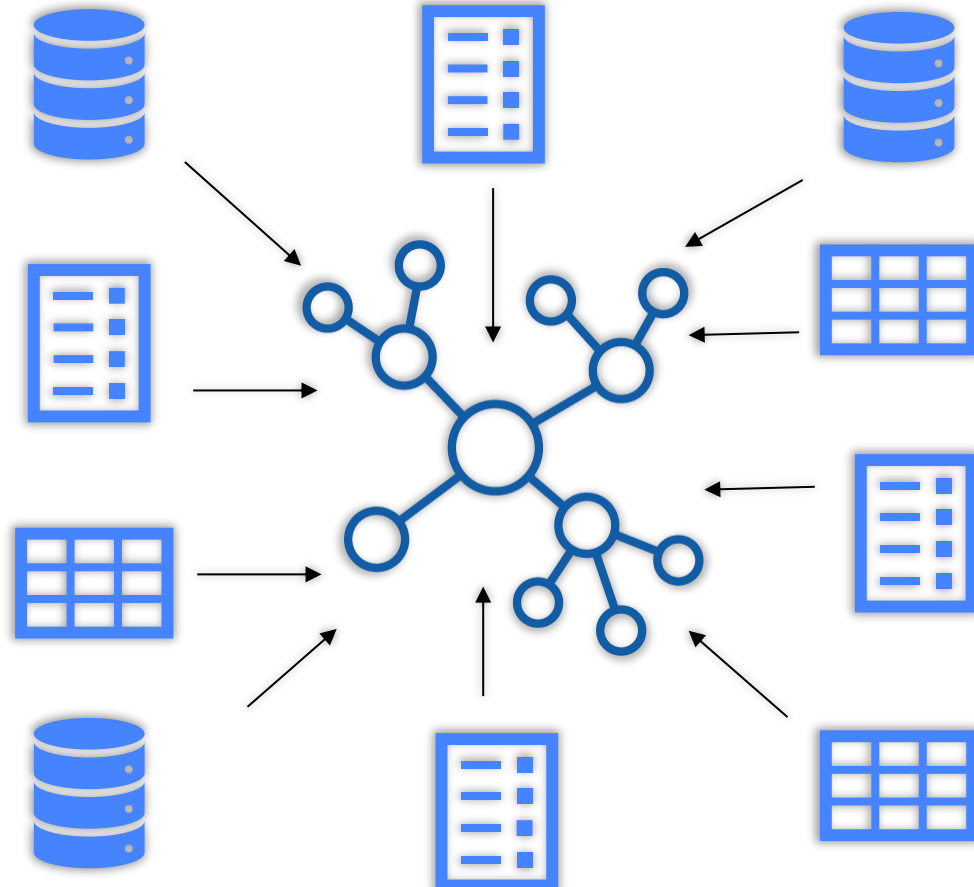
Traditional Database Approach

Multiple disperse operational databases
Complex queries required to relate data



aLLarMa Knowledge Graph

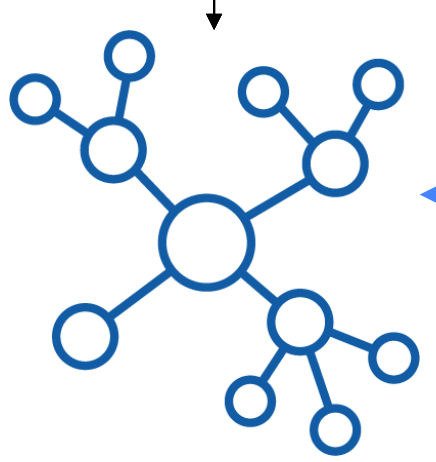
All data built into a single, large graph model, which is queryable by an LLM



High-Level Architecture of aLLarMa



LLM Converts Prompt to Database Query Based on Context of the Question



Query of the Graph

Query

Data

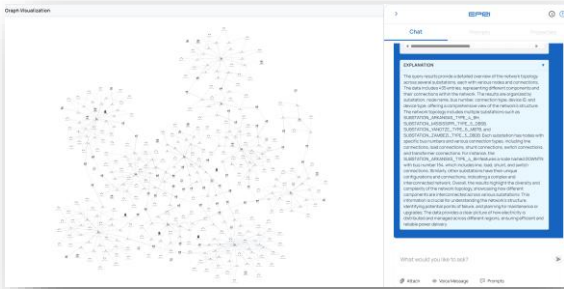
Extracted information from Graph



Natural Language Prompt input to LLM

LLM Response and Graph Update

Operator question in aLLarMa dashboard



LLM converts the results of the query into a concise readable format

Instantaneous text response with tables, graphics

Early Stage aLLarMa Online – Viewing Chattering Alarms

The interface displays a network diagram on the left and a chat window on the right. The chat window shows a query and its results.

Chat Prompts Properties

TABLE CYPHER QUERY

GRAPH CYPHER QUERY

RESULTS

Substation Name	Device Name	Device Type	Event Msg	Event Time
SUBSTATION_TIGRIS_TYPE_1_SB	SS_TIGRIS_SWD_1_3_1	RELAY	SYSTEM	1 May 2017 10:00:00
SUBSTATION_TIGRIS_TYPE_1_SB	SS_TIGRIS_SWD_1_3_1	RELAY	SYSTEM	1 May 2017 10:00:00
SUBSTATION_YANGTZE_TYPE_6_MBTB	LINE_29	LN	CARRIER	1 May 2017 10:00:00
SUBSTATION_YANGTZE_TYPE_6_MBTB	LINE_29	LN	CARRIER	1 May 2017 10:00:00
SUBSTATION_TIGRIS_TYPE_1_SB	SS_TIGRIS_SWD_1_3_1	RELAY	SYSTEM	1 May 2017 10:00:00
SUBSTATION_TIGRIS_TYPE_1_SB	SS_TIGRIS_SWD_1_3_1	RELAY	SYSTEM	1 May 2017 10:00:00
SUBSTATION_TIGRIS_TYPE_1_SB	SS_TIGRIS_SWD_1_3_1	RELAY	SYSTEM	1 May 2017 10:00:00
SUBSTATION_TIGRIS_TYPE_1_SB	SS_TIGRIS_SWD_1_3_1	RELAY	SYSTEM	1 May 2017 10:00:00

EXPLANATION

The query results indicate that there have been multiple chattering events related to diagnostic statuses in the last two hours, specifically on May 1, 2017. These events are primarily associated with two substations: SUBSTATION_TIGRIS_TYPE_1_SB and SUBSTATION_YANGTZE_TYPE_6_MBTB. The majority of the events (six out of eight) are linked to the device SS_TIGRIS_SWD_1_3_1, a relay device at the Tigris substation, with event messages labeled as "SYSTEM." The remaining two events are associated with the LINE_29 device at the Yangtze substation, with event messages labeled as "CARRIER." The chattering events are characterized by a high number of status changes within a short period, indicating potential configuration or measurement issues rather than direct electrical faults. For instance, the number of status changes ranges from 7 to 10 across the events, suggesting rapid toggling of alarms. This pattern is consistent with the typical behavior of chattering alarms, which can lead to operational challenges such as operator fatigue and cluttered alarm systems. Addressing these issues would involve adjusting alarm thresholds, introducing hysteresis, and possibly conducting a root cause analysis to prevent future occurrences. Overall, while these events do not pose an immediate physical risk, they highlight the need for system adjustments to maintain effective monitoring and safe operations.

What would you like to ask?

Attach Voice Message Prompts

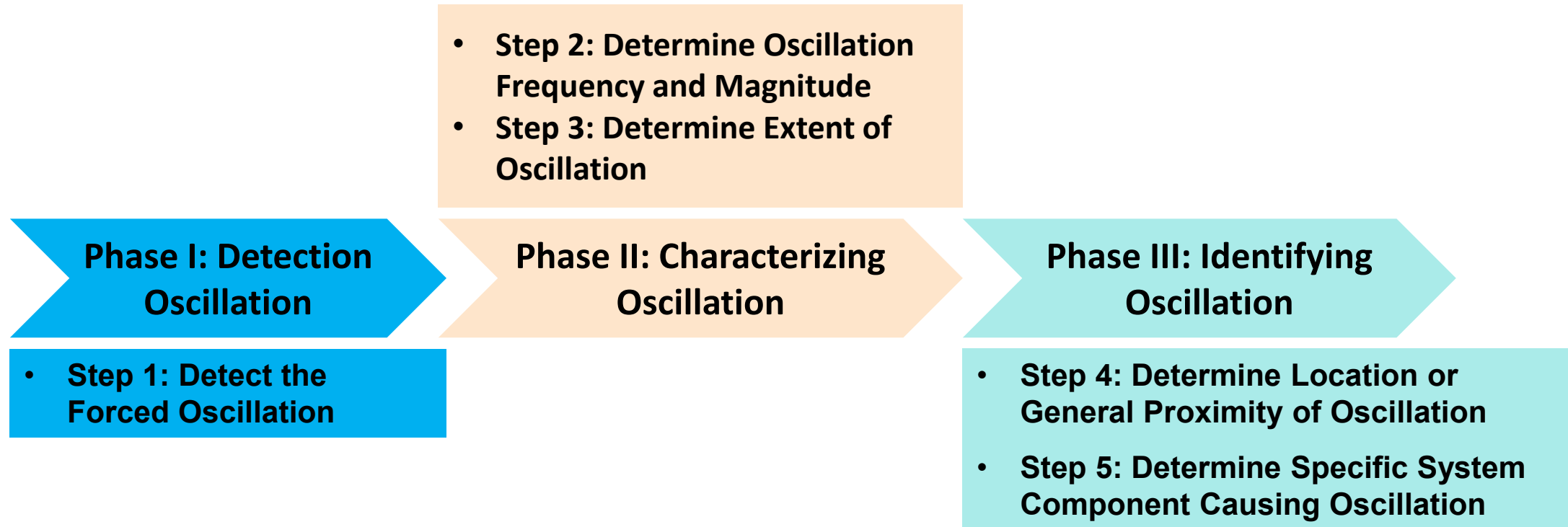
....Coming Soon to allarma.epri.com



Oscillation Detection, Monitoring and Mitigation using PMUs

NERC Recommended Practices & Mitigation Measures

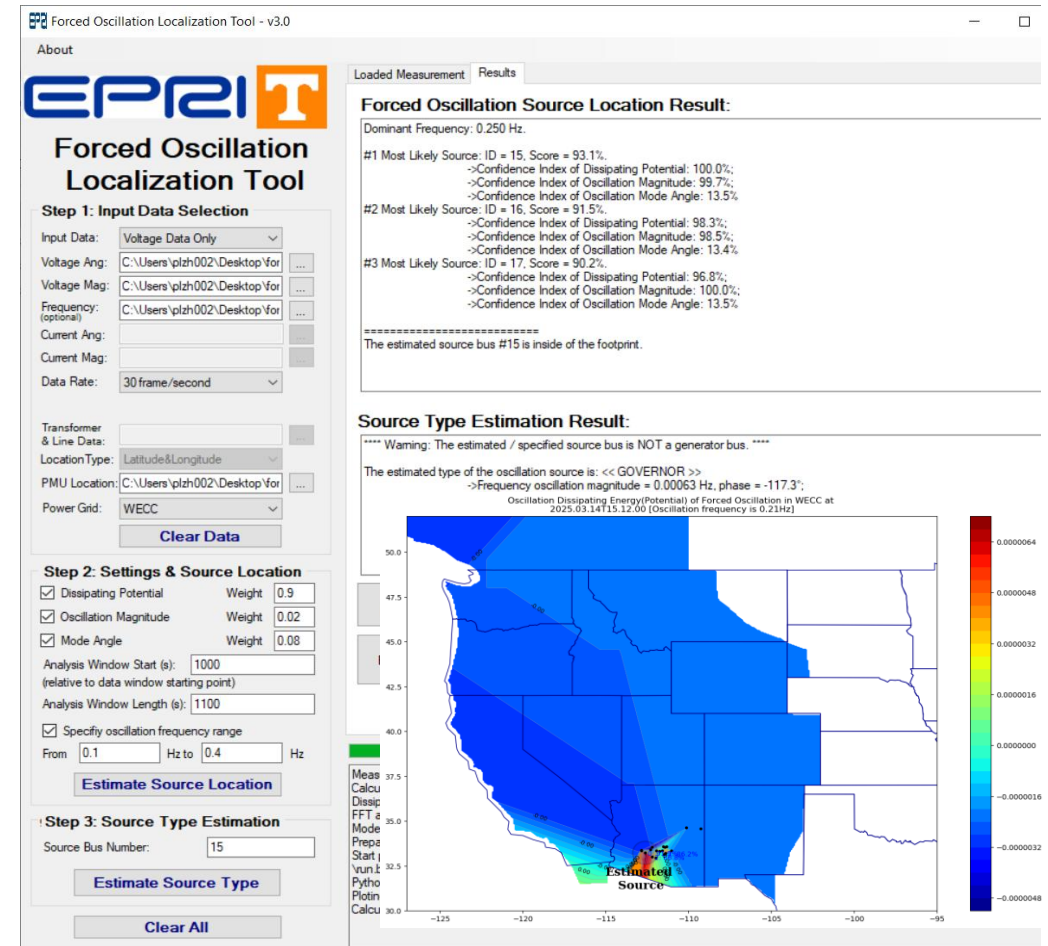
- Three-phase, five-step approach to mitigate forced oscillations
- Source location and source type estimation are critical for system operators to mitigate forced oscillations



Source: NERC Reliability Guideline: Forced Oscillation Monitoring & Mitigation Sept. 2017

Forced Oscillation Localization Tool (FOLT)

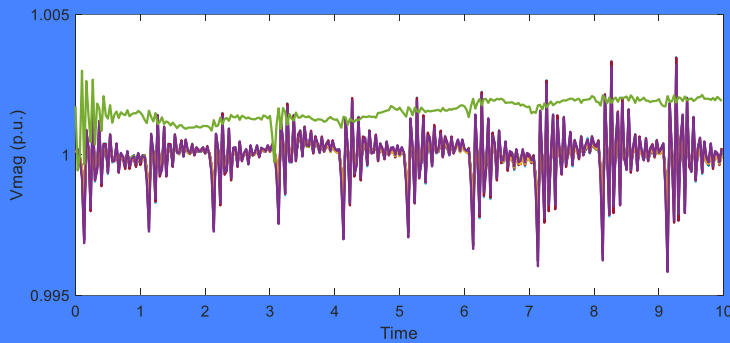
- Wide-band frequency oscillations (< 0.1 Hz to 15 Hz)\
- Three different methods for oscillation source location
 - Dissipating Potential method
 - Oscillation Magnitude method
 - Oscillation Mode Angle method
- **Source location estimation** with confidence index
- **Source type estimation:** Active or reactive power control issue
- **Inside/outside territory identification**
 - Usually for interconnection wide forced oscillations
- **Does not rely on system topology**
- **Does not require full grid PMU observability**
- **Online version implemented using *OpenPDC***



Testing and validation of the tool done using actual events and utility systems

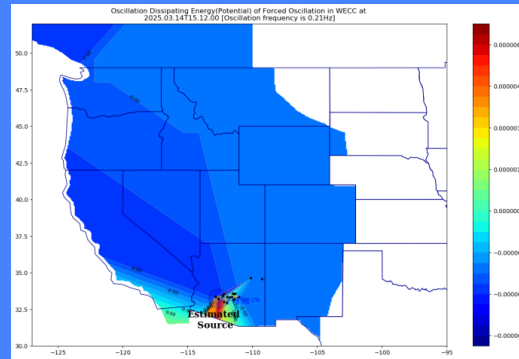
FOLT : Use Cases

Utility #1 SSO Event



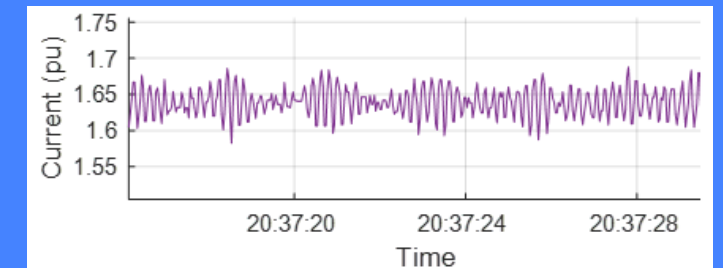
- Source: Data center
- Oscillation observed by PMUs in 5 substations
- ~ 11 Hz, ~5% damping ratio
- Reinitiated every ~1s

Utility #2 BESS-Induced Forced Oscillation Events



- PMU data for 09/20/2023 (0.21 Hz) and 11/03/2023 (0.25 Hz) events
- Source: Hybrid plants (PV with BESS)

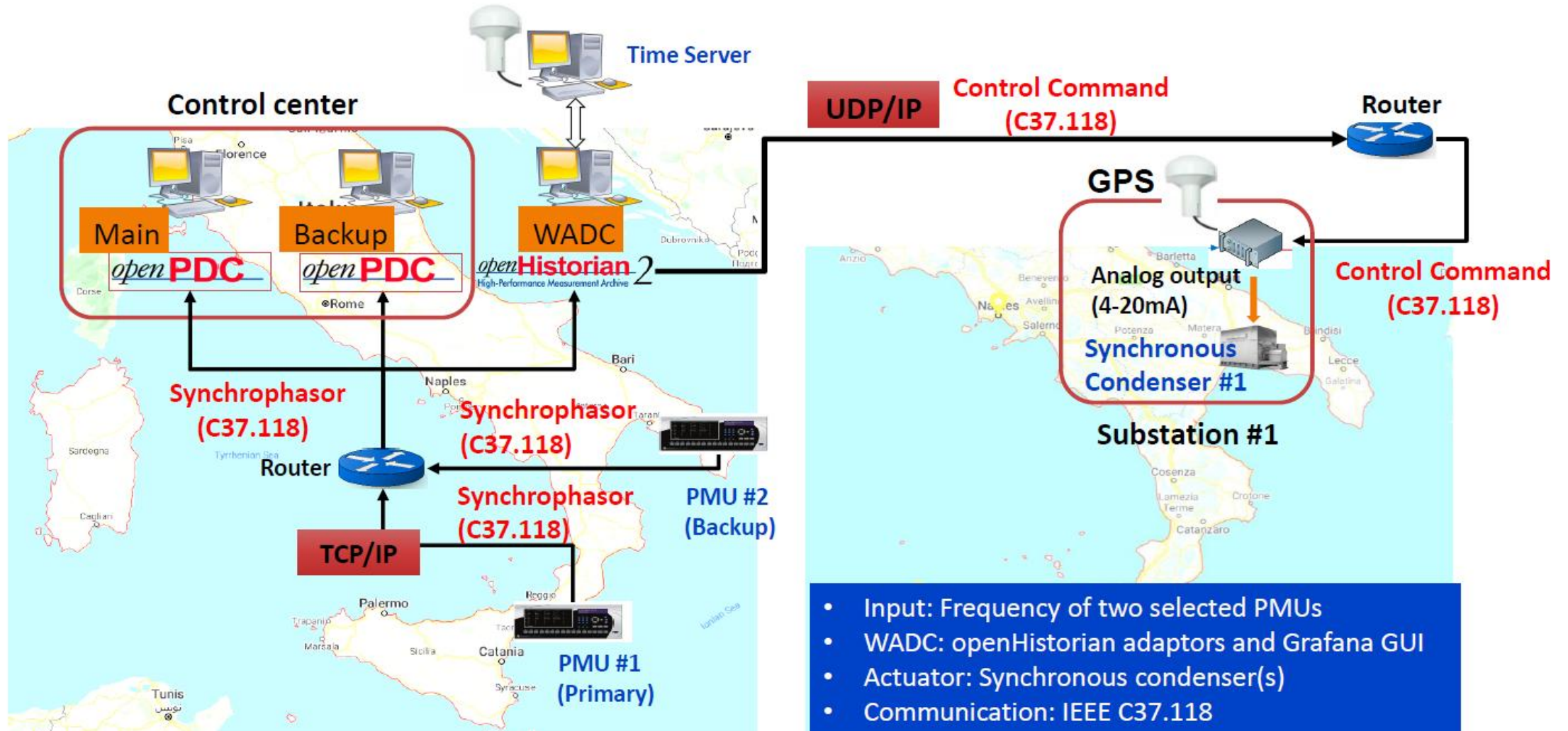
Utility #3 Load-Induced Forced Oscillations



- 3-7Hz oscillations
- Source: Synchronous motors driving reciprocating compressors

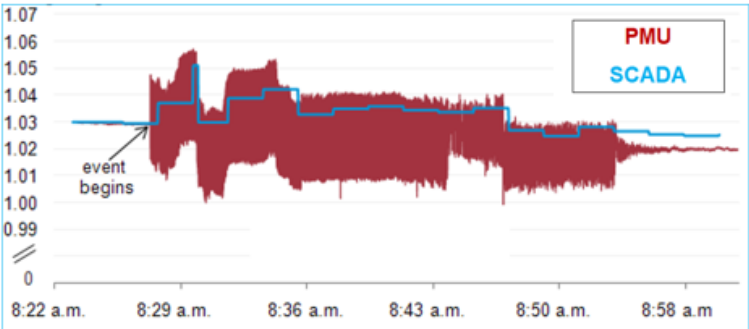
Mitigation of Natural Oscillations : Wide Area Oscillations Damping Control

TERNA Field Deployment

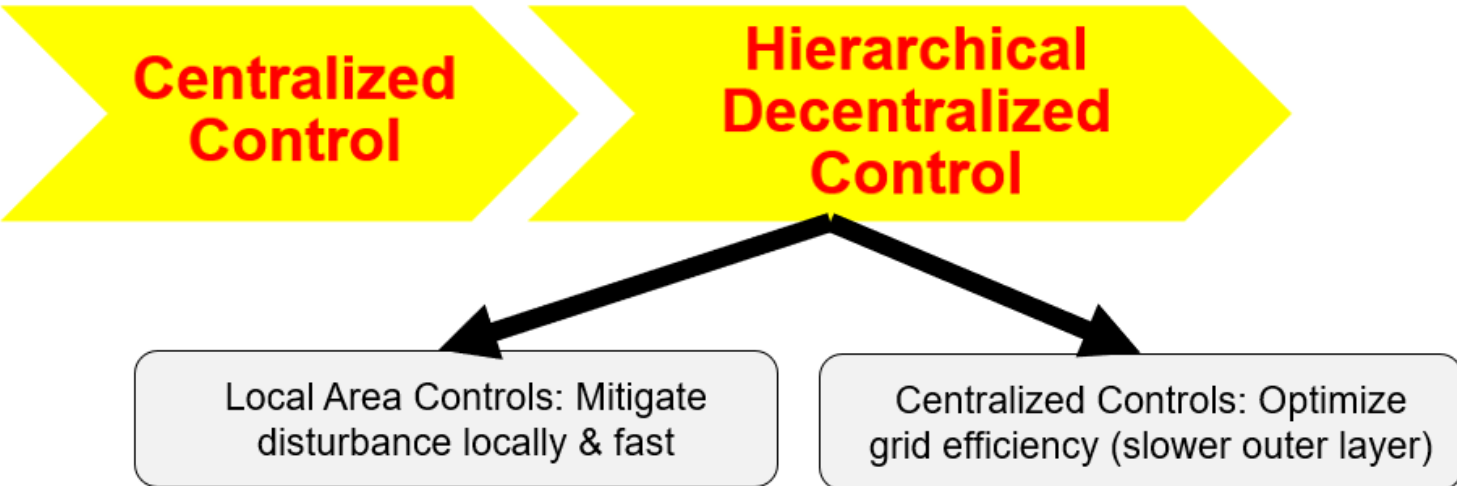
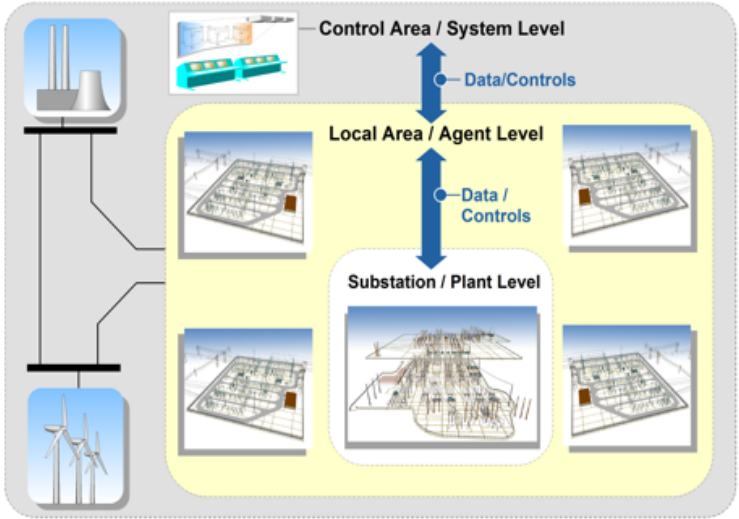


Next Generation Grid Monitoring & Control for IBR Dominated Grids

Monitoring



Control



Control Room Operations: Human Control → Supervision of Automated Systems



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