# Towards Robust Transmission Grid with Uncertainty-tolerant Controls

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FIEEE, FIET, FInstMC and FAAIA

**Project Team: ORNL, SNL, PNNL, UNCC, BPA, Duke Energy, and Hitachi Energy**

U.S. Department of ENERGY | Office of Electricity

# Project Overview – Objectives/Impact

**Challenges:**

The power system dynamics faces **reduced inertia**, **more dynamic** and **uncertain** due to increased renewables penetration

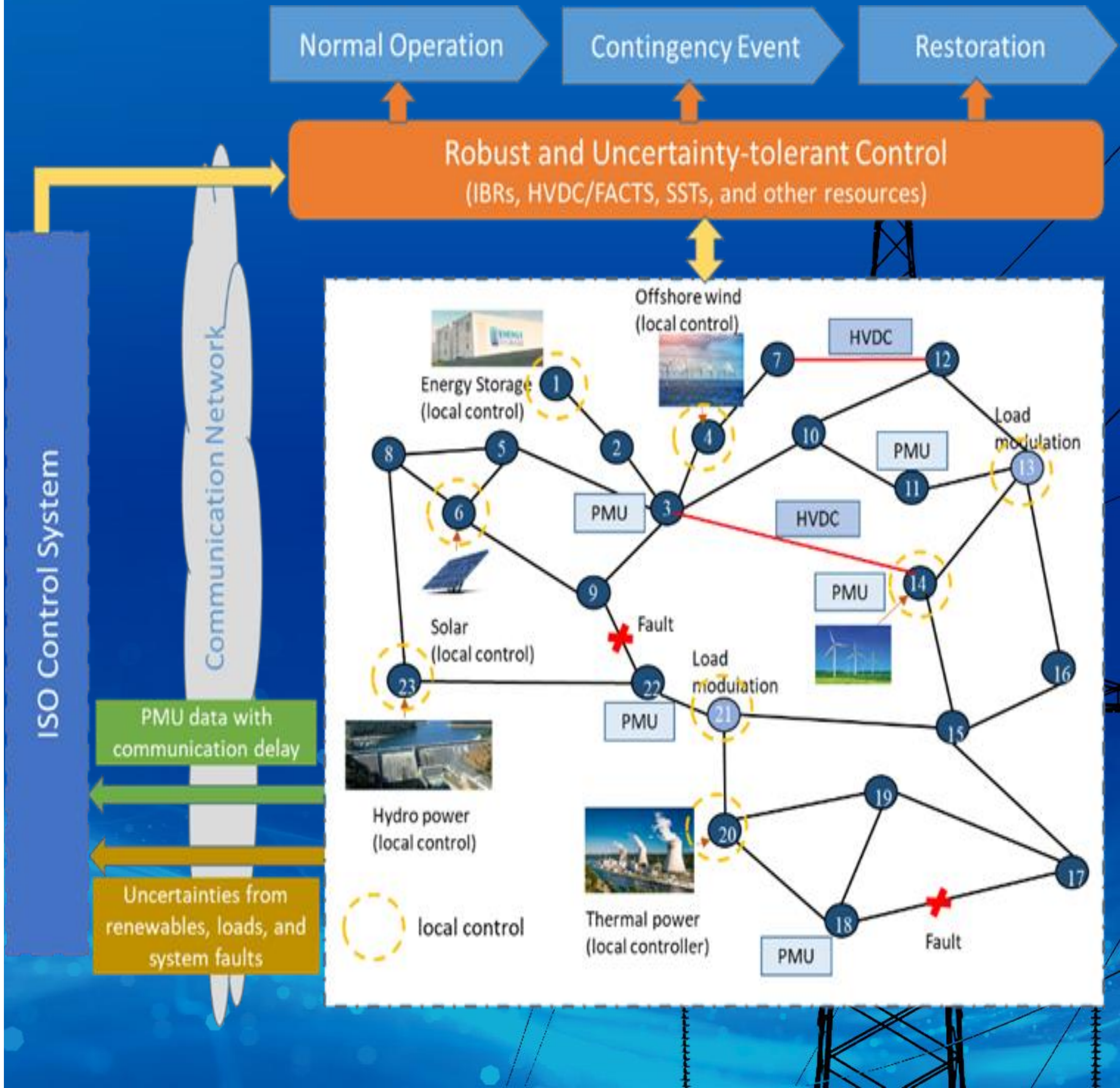
**Objective:**

To develop a set of advanced **fast**, **flexible**, **robust**, and **uncertainty-tolerant control technologies** for the transmission network systems in terms of novel stochastic distribution control, architecture communications and fast energy storage control

**Impact:**

Produce **a novel and next generation control suite** for transmission systems - integrating local, AGC and stochastic distribution control

**Duration:** 2023 - 2026



# Novel Probability Density Function (PDF) Control – Next Generation Transmission Control

**First Phase Frequency Regulation (Primary):**

Up to 15 - 30 seconds - performed by local generation resources

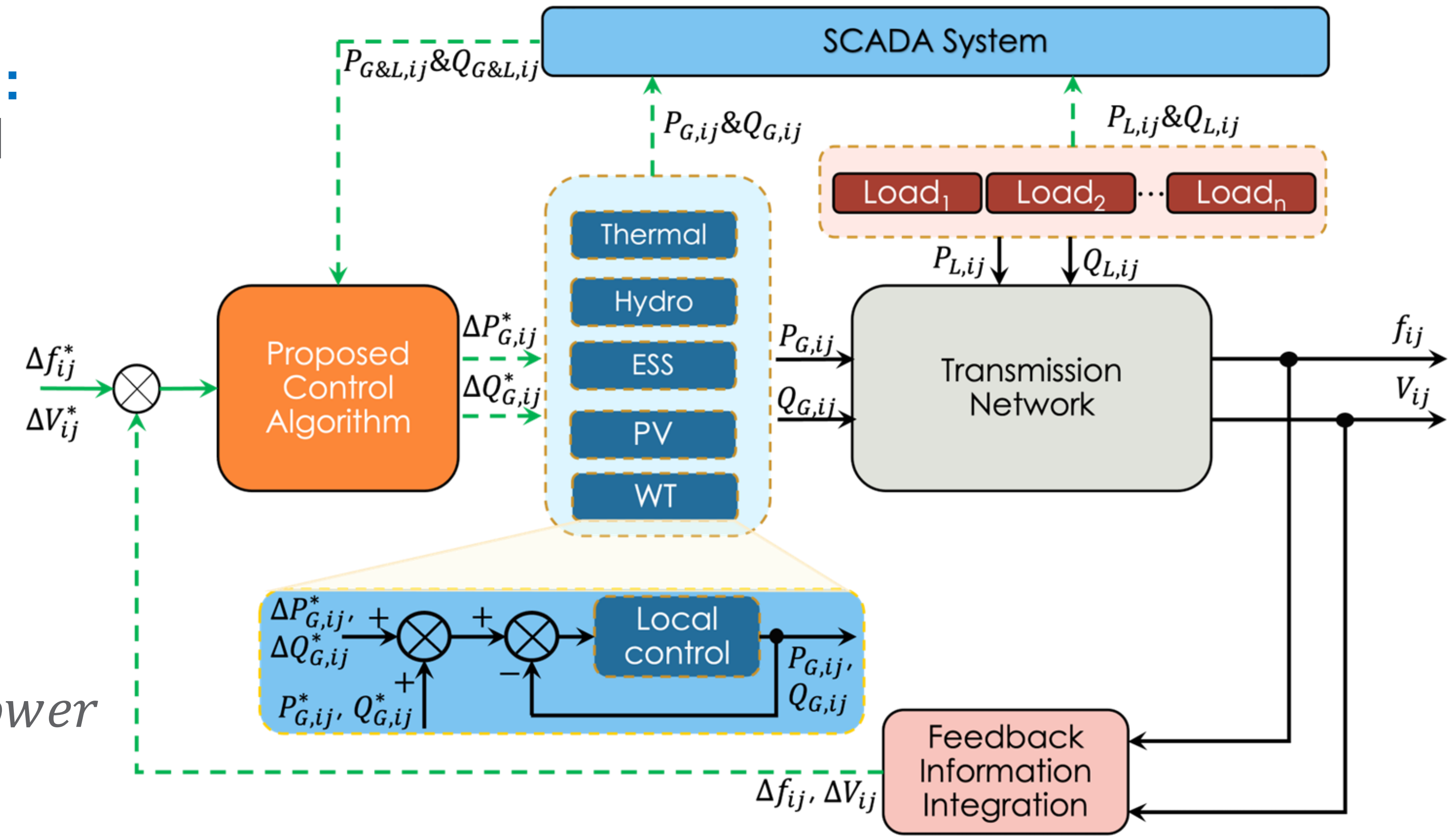
**Automatic Generation Control:**

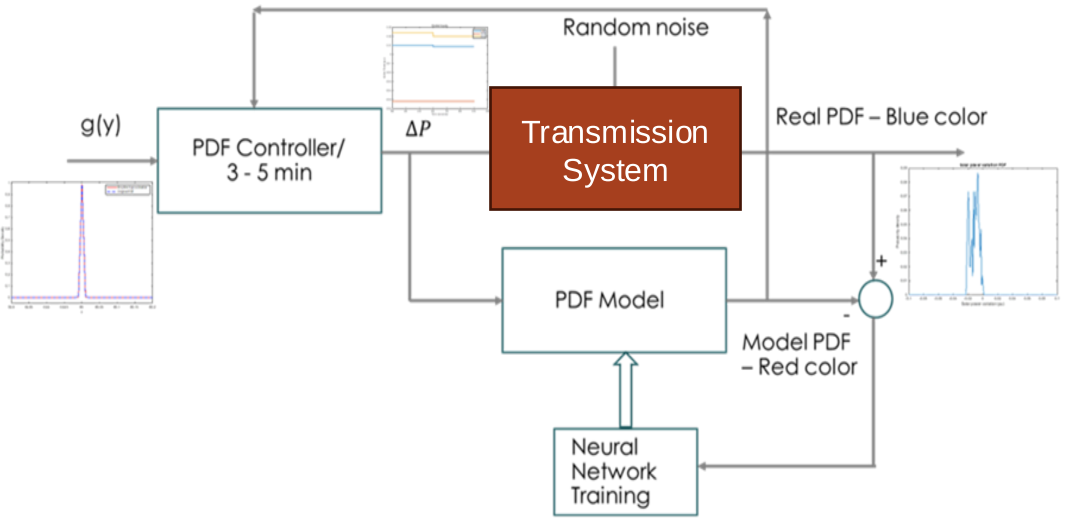
from 30 second to 10mins

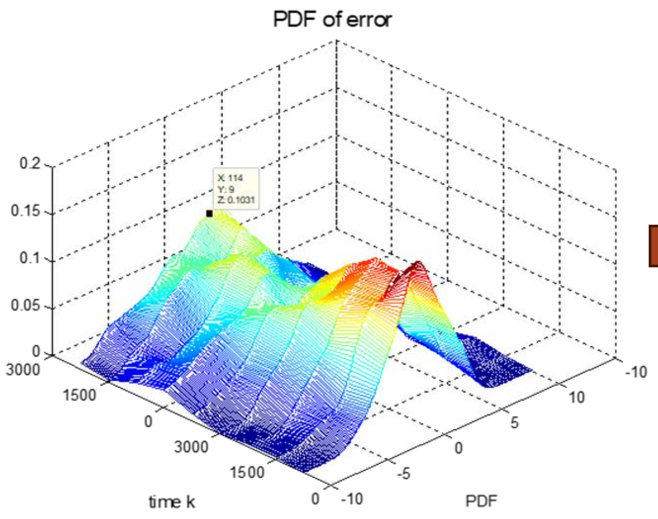
**Our Probability Density Function Control:**

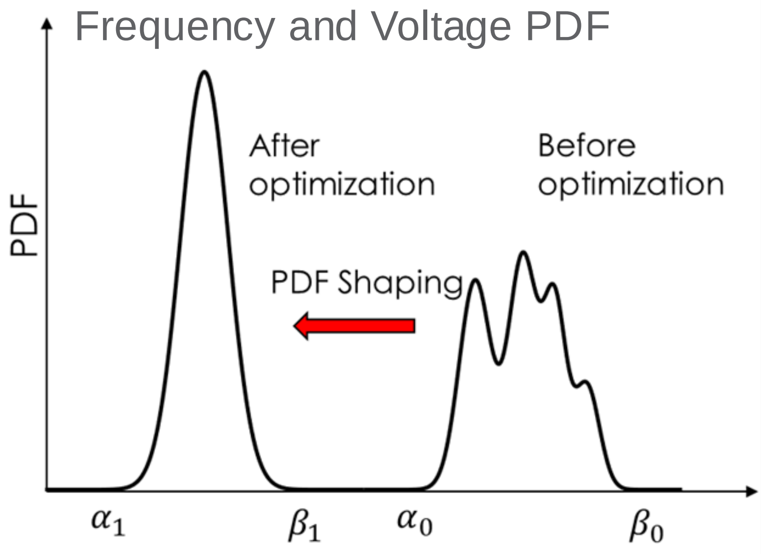
from 1.5 – 5 mins

$$J\frac{d\omega}{dt} = Power\ Sources + Renewables\ - Load\ Power$$



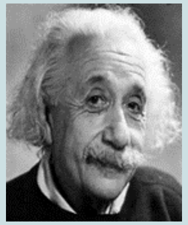




**Narrow PDF = Less Uncertainties**

# PDF Control vs Traditional Stochastic Control - What is new and some promising results

### Traditional Stochastic Control

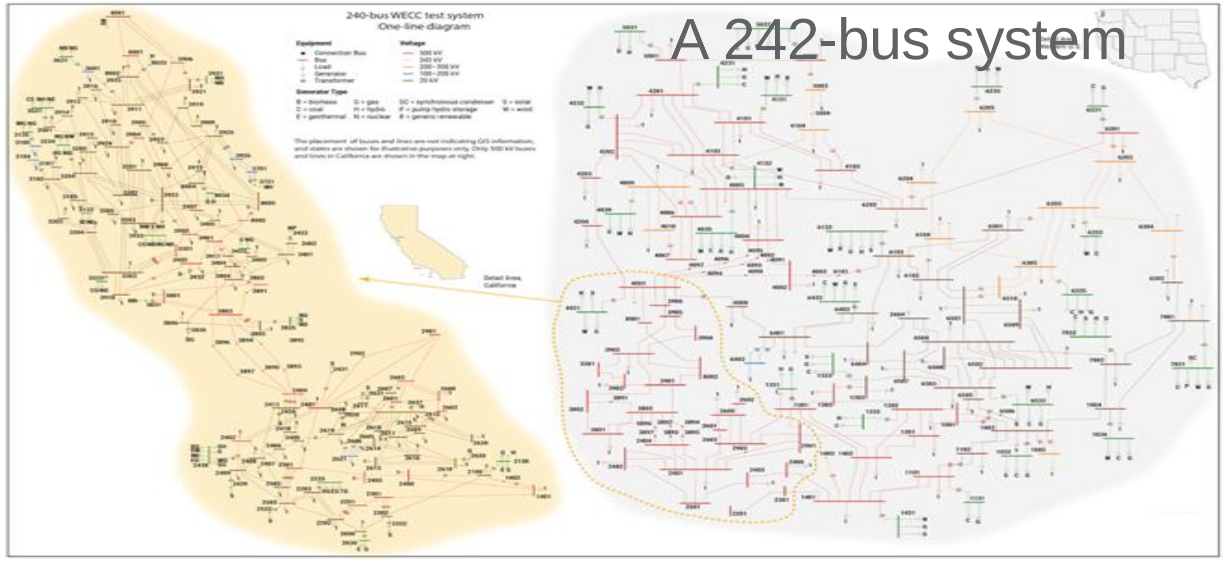
- Stochastic differential equations - Gaussian Driven Systems (**Einstein**, **Ito**, et, all , 1904, 1944, 1950) = Solving PDEs

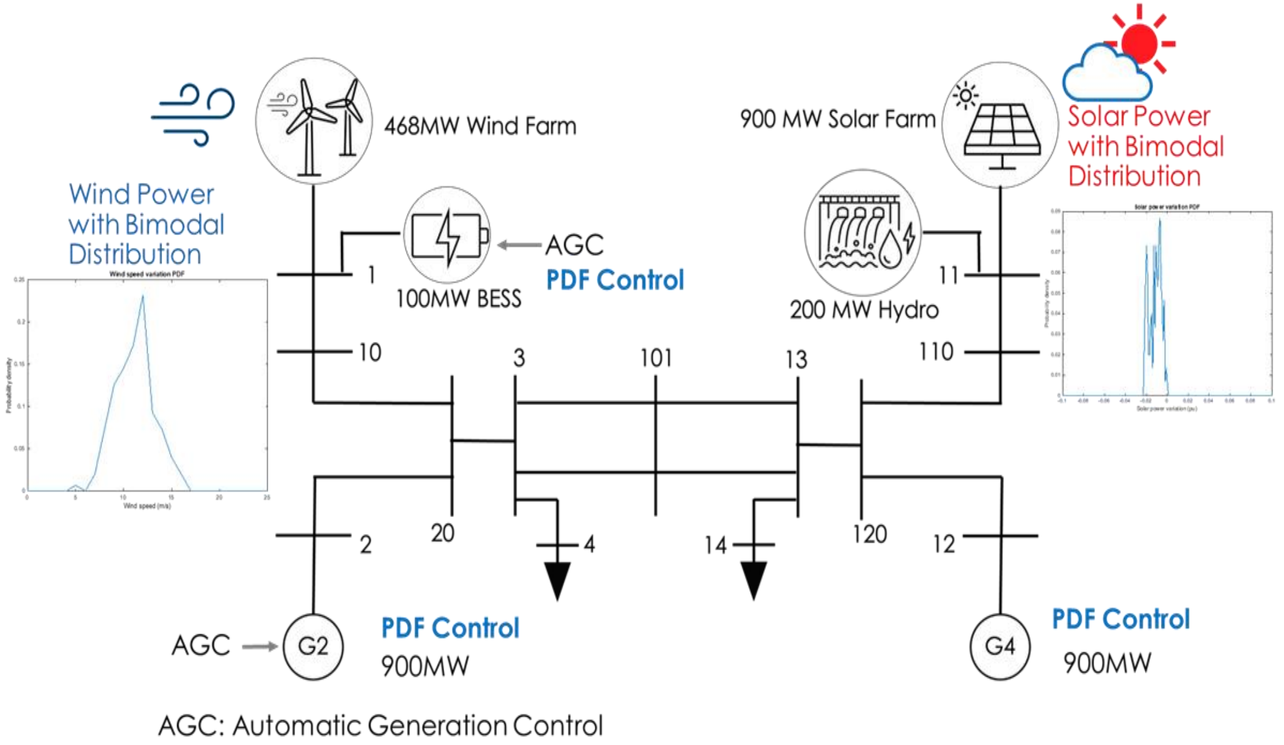


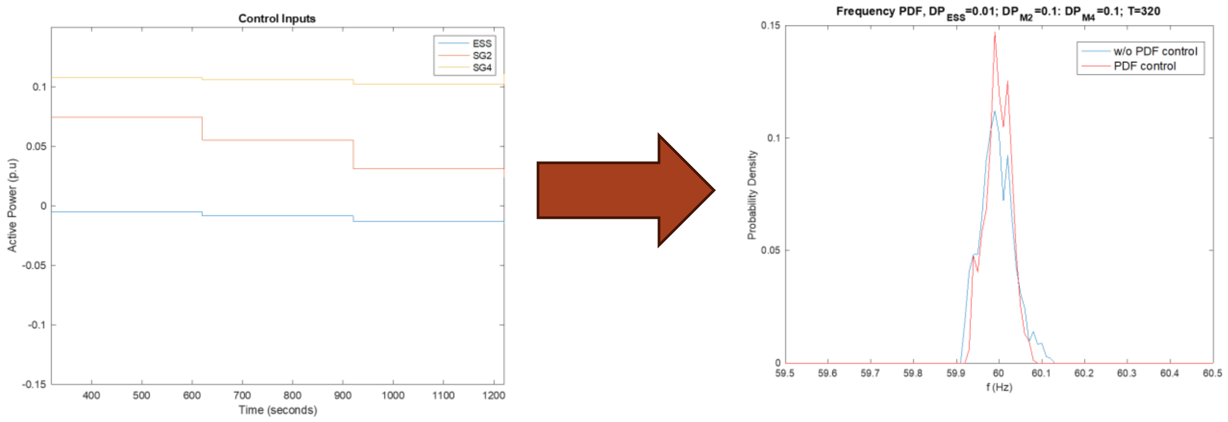
- Mean and Variance Control
- Largely Linear Systems
- Example:
  1. Minimum Variance Control (1970),
  2. Kalman Filter and
  3. LQG Control (1965),
  4. Neural Nets Modelling, etc

### My Stochastic Distribution Control

- Non-Gaussian Dynamic Systems
  - Some PDFs measurable for a lot of PDF shaping required processes!
- Total probabilistic control (controlling PDF means controlling all the aspects of a random variable)
- Wide applications:
  1. Modelling,
  2. Filtering and state estimation,
  3. Data miming,
  4. Stochastic optimization, etc



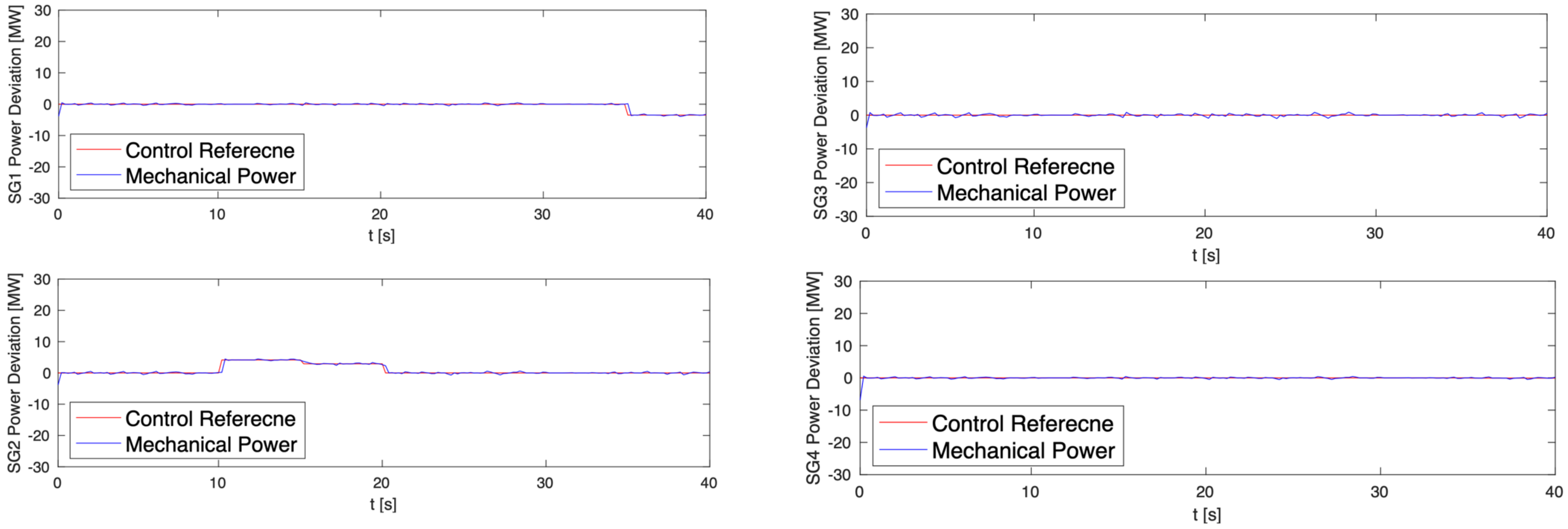

- Journal Publications
  - "Review of Challenges and Research Opportunities for Control of Transmission Grids," in IEEE Access, vol. 12, pp. 94543-94569, 2024, doi: 10.1109/ACCESS.2024.3425272. (**Published**).
  - "Probability Density Function (PDF) Control of Frequency Fluctuations in Transmission Grids," in IEEE Power Engineering Letters, (**Under Review**).
- Conference Publications
  - “Towards the Flexibility of HVDC-Interconnected Systems: A Novel Emergency Frequency Response Model”, 2024 IEEE Power & Energy Society General Meeting (PESGM), (**Accepted**).
  - S Wang, W Du, G Zhang, H Wang and Z Huang, Model Gap Quantification and Evaluation, 2024 UKACC 14th International Conference on Control (CONTROL) 10-12 April, 2024. Winchester, UK

# MPC-based Multi-time Scale Frequency Regulation (UNCC)

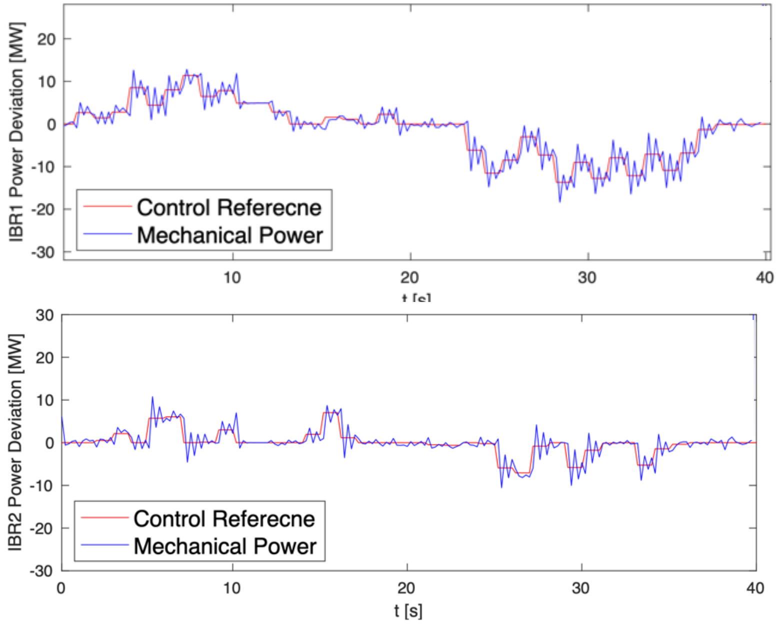
- Developed a model-predictive control (MPC)-based multi-time scale coordinated AGC controls for fast-responding IBRs and slower-responding synchronous generators (SGs)
- The approach prioritizes the resources with higher ramping capability and lower costs for providing frequency support – **form effective selection of generation resources for PDF control.**

## Numerical experiments

- SGs with lower ramp rates are not selected (SG3 and SG4) – priority selection
- IBRs with more control flexibility contribute more to regulation (validated by the comparison between IBR and SG) – multi-time scales




Output of SGs

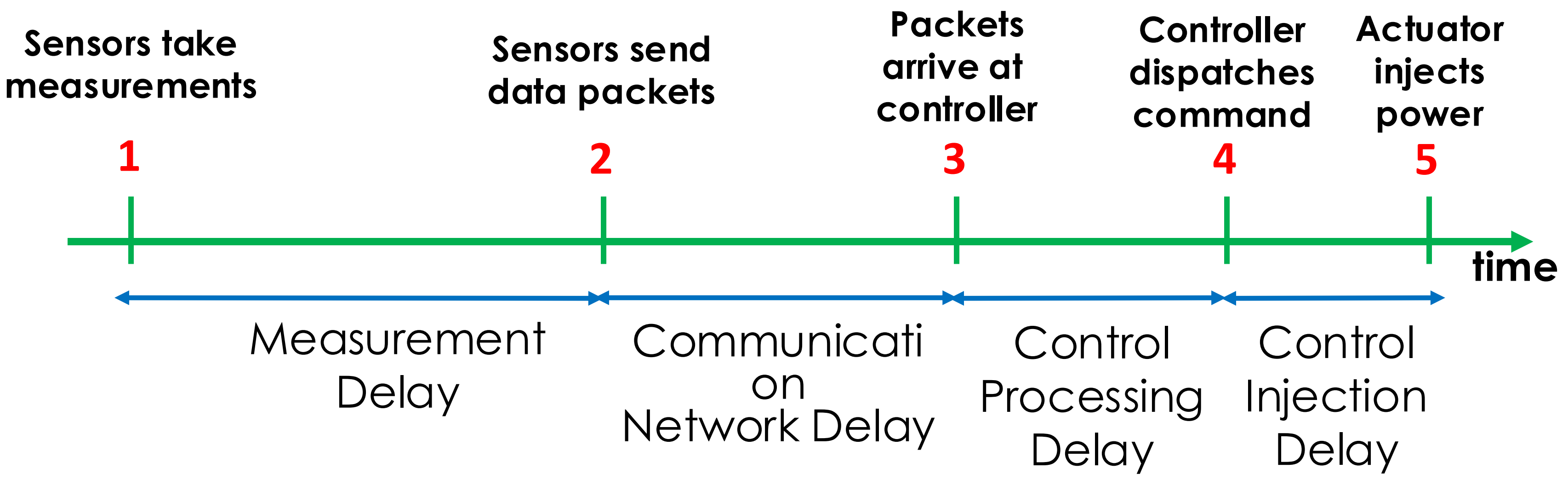


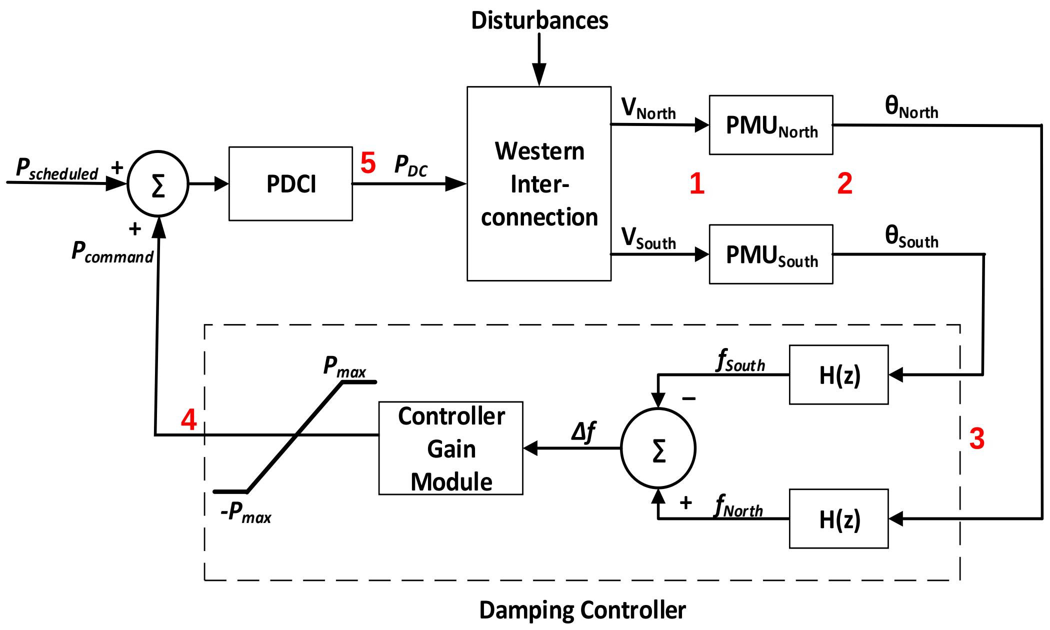

Output of IBRs

# Fast, Robust Controls Tolerant to Communications Uncertainties (SNL)

## Objective:

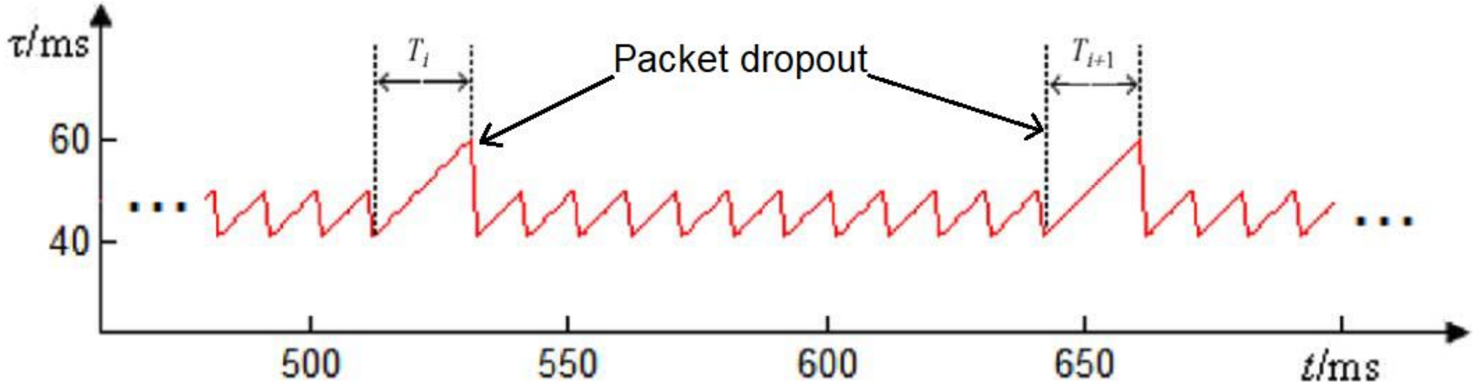
- develop distributed control solutions by leveraging wide-area information to achieve system-wide objectives using control architecture developed in Task 1.
- consider communication constraints such as delays and data package drops/corruption.



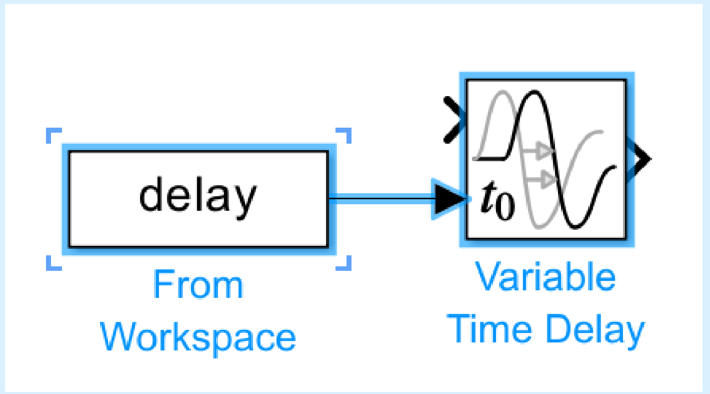



# Analysis, Modelling, and Simulation Communication-Induced Uncertainties (PNNL)

- ❖ Uncertainties in networked communication
  - ➢ Communication Delays
  - ➢ Data Packet Dropout
  - ➢ Data Packet Disordering




- ❖ Uncertainties Modelling:
  - ➢ Communication system: Data packet, discrete signal
  - ➢ Power grid dynamic: input signals, continuous
  - ➢ Use ZOH (zero order hold) to connect the discrete communication network with continuous power grid network
- ❖ Uncertainties Simulation
  - ➢ Matlab Simulink
  - ➢ Model time-varying delay in m.file
  - ➢ then feed the time-varying delay to Simulink to perform the whole closed-loop system (hybrid system) simulation





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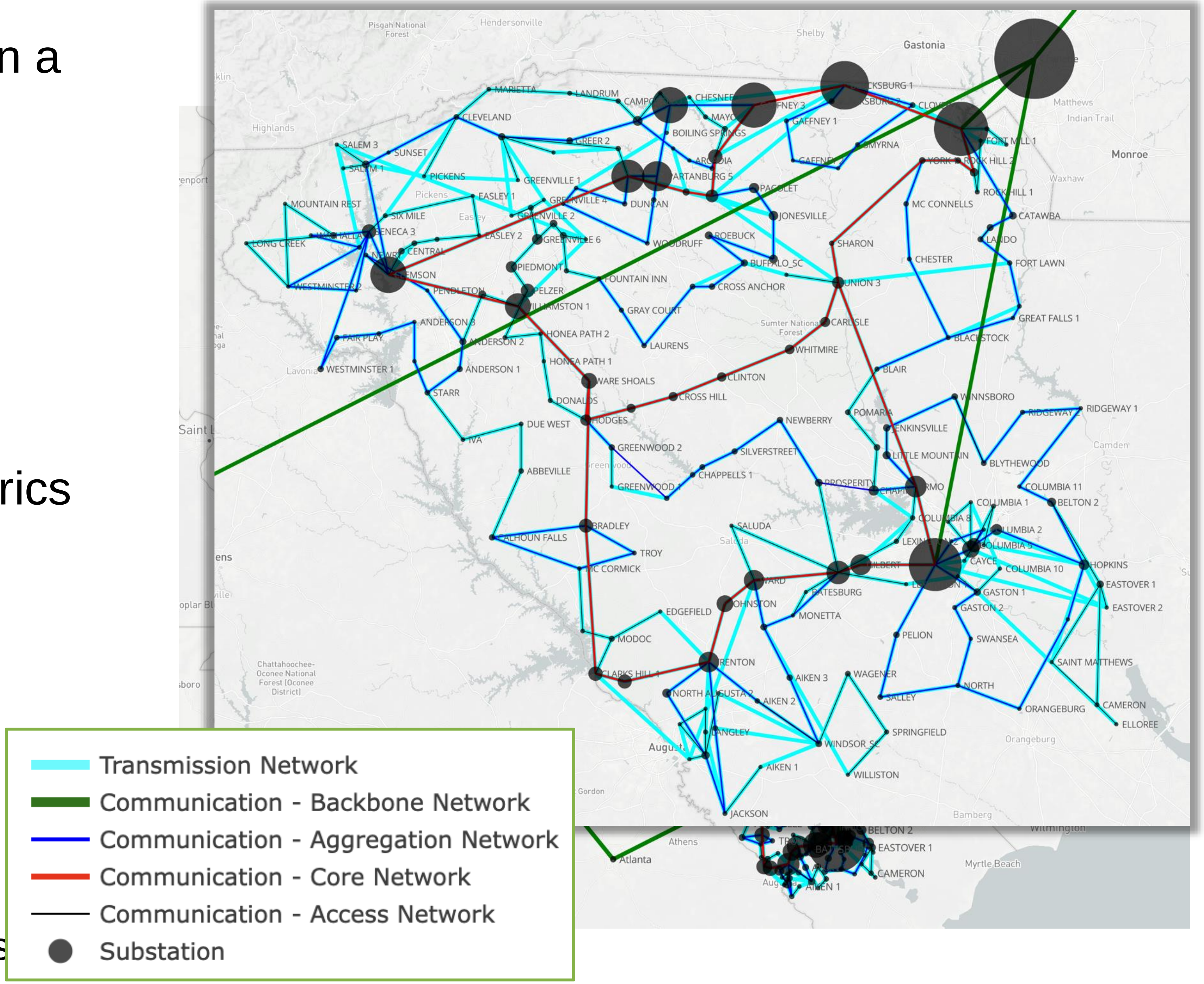
# Modeling of Communication Architecture (PNNL)

- Modeled communication network in a weighted graph
- Developed delay-based weights
  - Propagation delay
  - Transmit delay
  - Switching delay
  - Queueing delay
- Computed the graph theoretic metrics to analyze the communication efficiency
  - Closeness Centrality
  - Betweenness Centrality
  - Efficiency Drop
- Next steps
  - Verification with simulations
  - Siting of PMUs, PDCs and controllers



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# Thank you

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