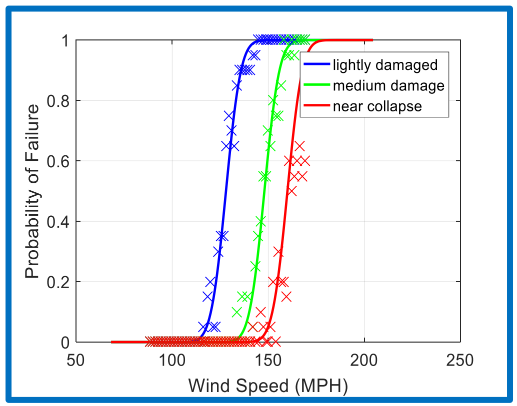
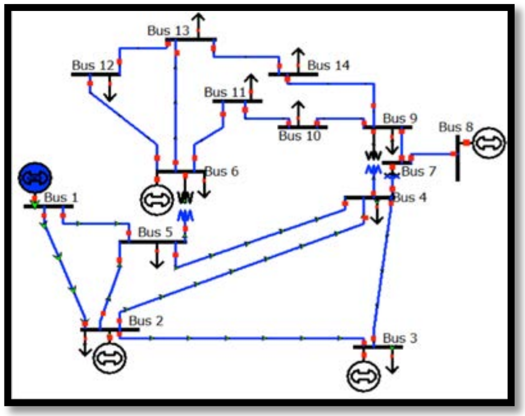
Scalable Preventive Unit Commitment for Operation during Extreme Weather

Hurricane
Forecasting Module



Power Component
Failure Estimation



Power System
Preventive Operation

Uncertainty Propagation

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Weather Forecast and Power System Operation

- Weather forecast is used for:
  - Load forecast
  - Renewable energy forecast (solar and wind)
- Extreme weather:
  - System operators have access to weather forecast
  - Some ISOs have meteorologists onsite
  - The forecast is not systematically used to adjust operation
  - **Most adjustments are made through engineering judgment**

Impacts of Extreme Weather

- Extreme weather
  - Windstorms: Hurricanes, Tornados
  - Ice storms and snow storms
- Impacts:
  - Load: load forecast models capture the impacts on load
  - Generation: the impacts are often minimal
  - **T&D systems: T&D failures**

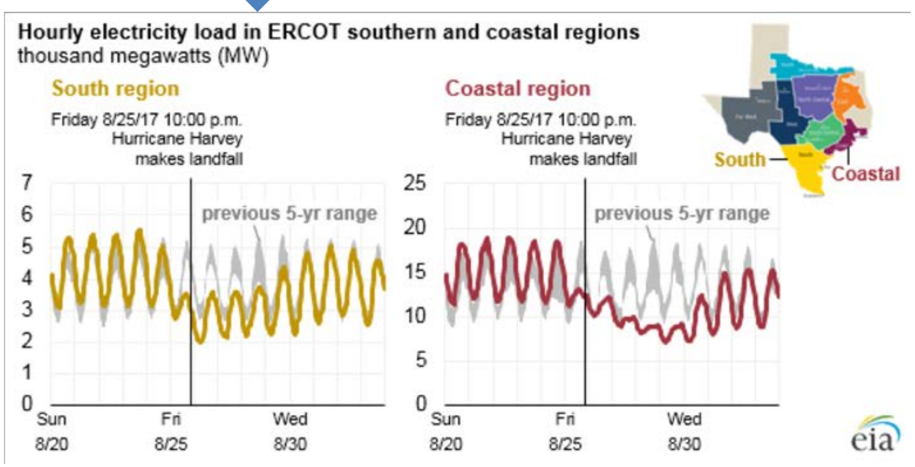
Example: Hurricane

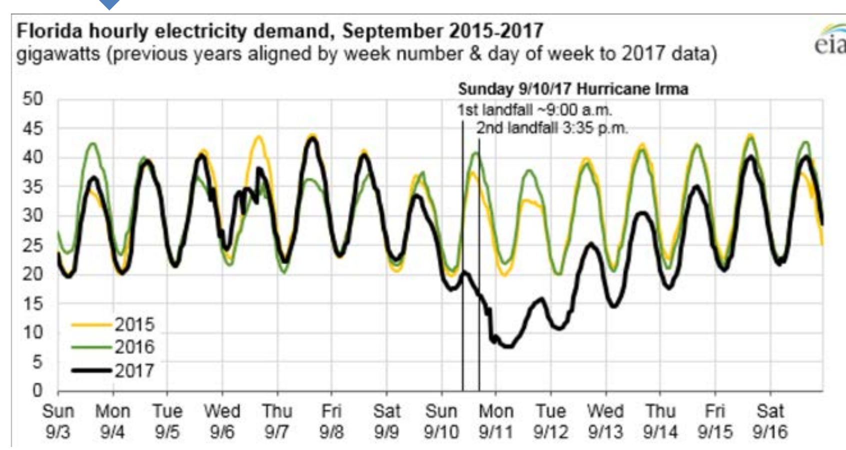
Generation	Transmission	Distribution
• **Damage level:** Low	• **Damage level:** High	• **Damage level:** High
• **Main cause:** Flooding	• **Main cause:** Wind force	• **Main cause:** Wind force
• **Wind**: Rarely an issue	• **Flooding**: May aggravate the situation	• **Flooding**: May aggravate the situation

Power Outage Statistics

- Hurricane season of 2017:

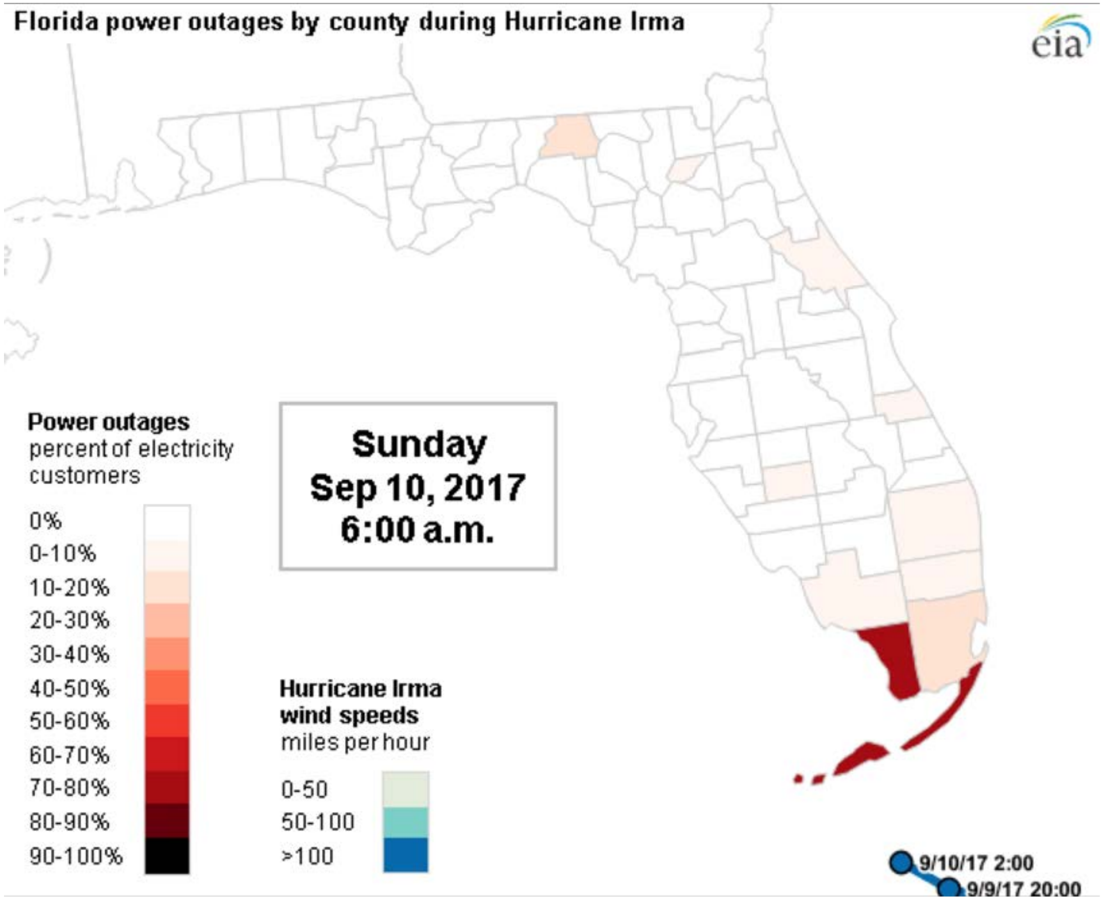
Harvey	Irma	Maria
August	September	September
• 300,000 customer outages in Texas	• 6 Million customer outages in FL (59%) • ~1 Million customer outages in GA (22%)	• 100% customer outage in PR





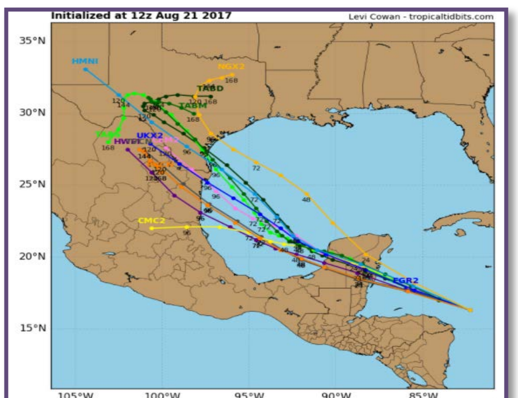
Why Focus on Transmission?

- Power outage in the areas, not in the hurricane track, is due to transmission-level damage.
- Such outages may be manageable, through weather-aware preventive operation.
- Transmission line outages in the past:
  - Harvey: 97 lines (>139 kV)
  - Sandy: 218 lines (>115 kV)

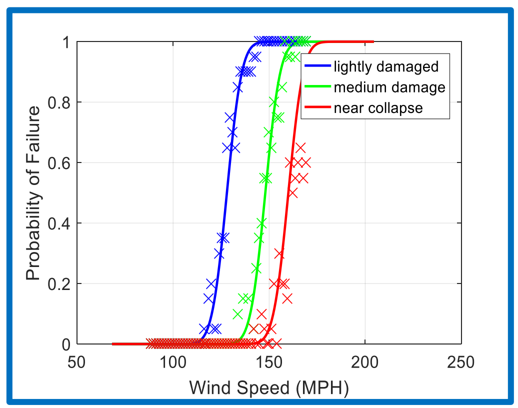


Preventive Operation

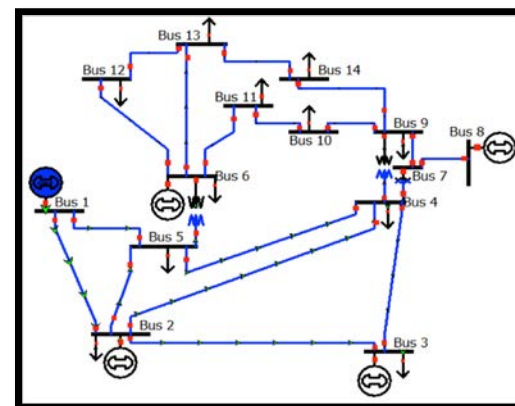
- Systematic integration of weather forecast data in power system operation
  - Conversion of weather data into useful information for operation: **component damage probability**



Weather Forecast Module



Power Component Failure Estimation

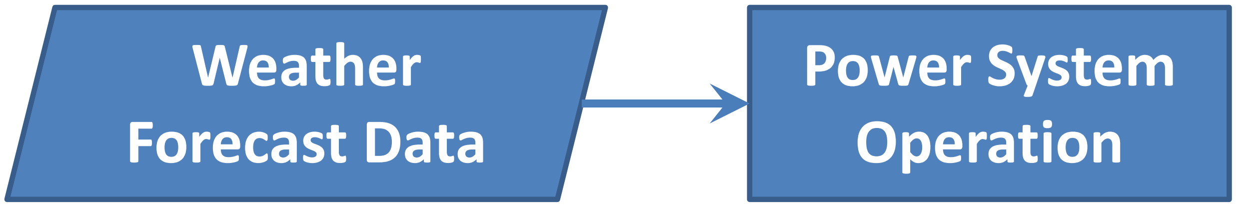


Preventive Power System Operation

Uncertainty Propagation

Employment of Weather Data

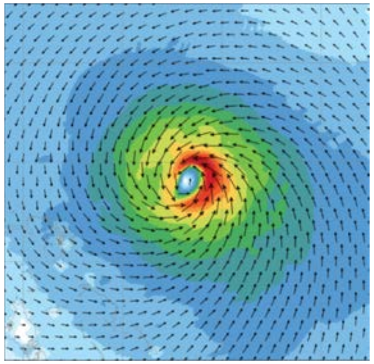
- Would integration of weather data in power system operation reduce the size and duration of power outages?

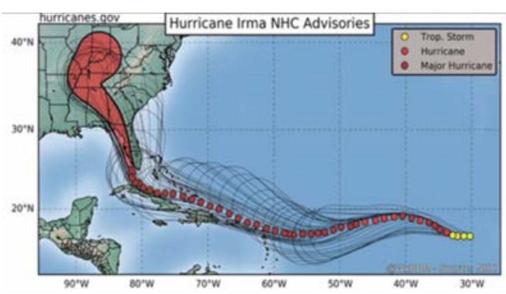


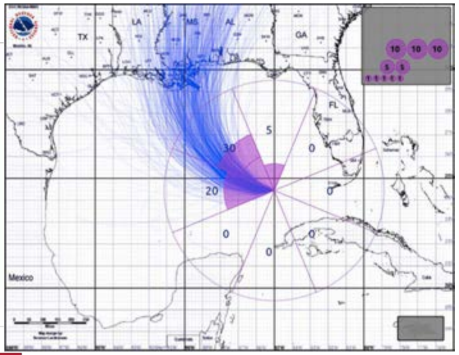
- **Availability of weather data:**
  - System operators have access to weather forecast services
  - In some cases, they also have access to meteorologists onsite
- **Existing technologies:**
  - Pre-storm outage forecast
  - Post–storm restoration planning
  - Long-term grid hardening
  - Emergency operation based on engineering judgement

Weather Forecasting (Atmospheric Sciences)

- High-resolution wind field modeling
  - 1 Km horizontal
- Hurricane track and movement speed estimation
- Ensemble forecasting
  - Multiple tracks with different probabilities
- Forecast at different time scales
  - 5-day ahead, 48-hr ahead, day-ahead, hour-ahead

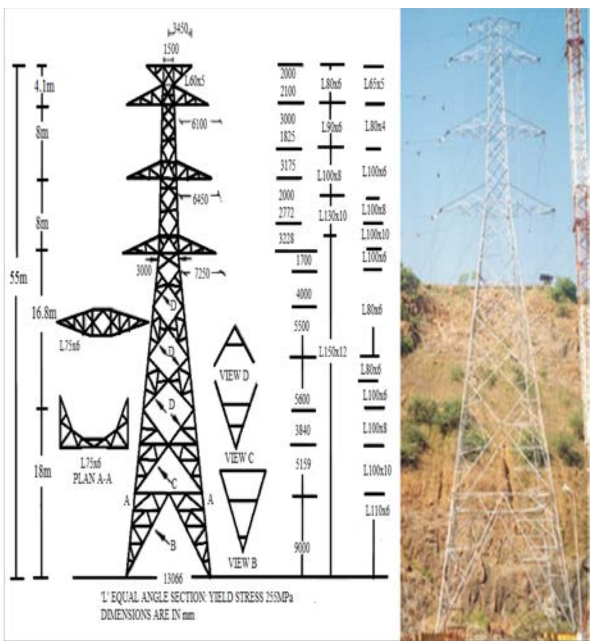




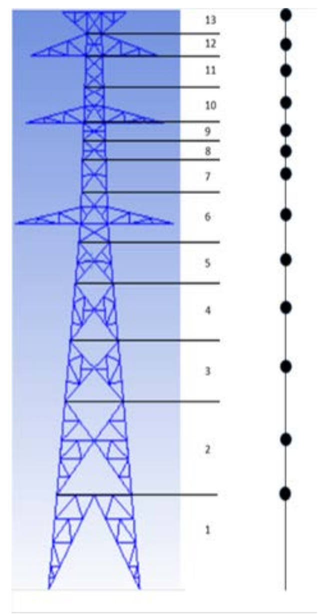


Transmission Failure Estimation

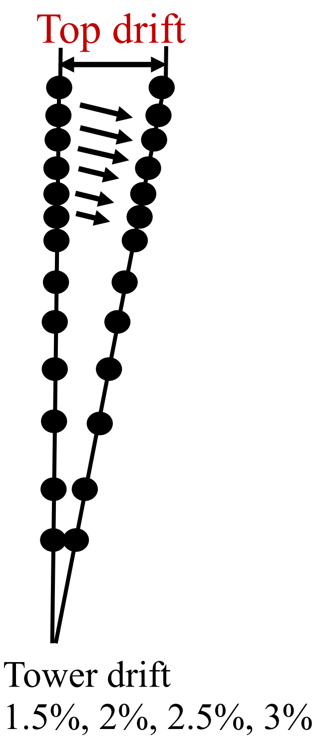
Structural Drawings



Finite Element Modeling

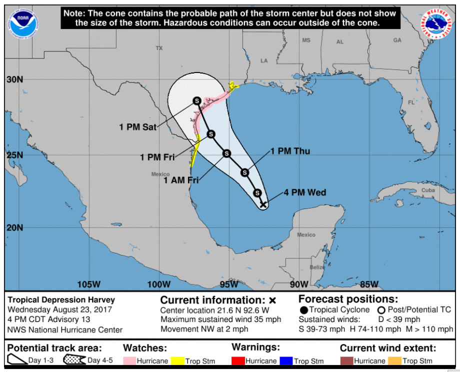


Stability under Dynamic Wind Loading

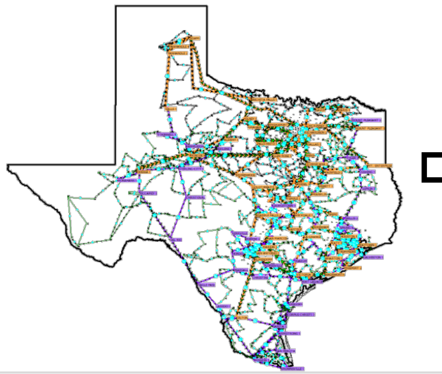


Transmission Failure Estimation cnt'd

Transmission line outage is estimated based on tower failure likelihood.



Hurricane Harvey Path



Texas System

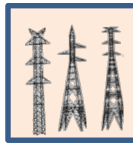
$$P[FL,k] = 1 - P[SL,k]$$
$$= 1 - \prod_{m=1}^{NT} F_{R,m}(V_m)$$

$P_m = F_{R,m}(V_m)$: m^{th} individual transmission line's failure probability

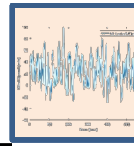
$P[SL,k]$: k^{th} transmission line's survival probability

NT: number of the tower

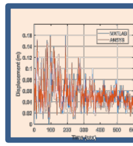
V_m: Wind Speed at the m^{th} tower



Transmission Tower Modeling



Wind Speed and Load Simulation

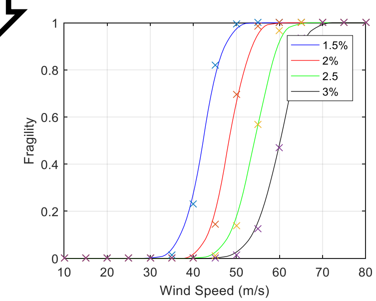


Dynamic Response of Transmission Tower Finite Element Model and Lumped Mass Model

Monte-Carlo Simulation to generate wind speed and set the limit state of transmission tower

$$F_R = P[l > LS | V_{10} = V]$$

- $l > LS$: Top drift of the transmission tower exceed the limit
- V : 10m/s-70m/s



Fragility Curve

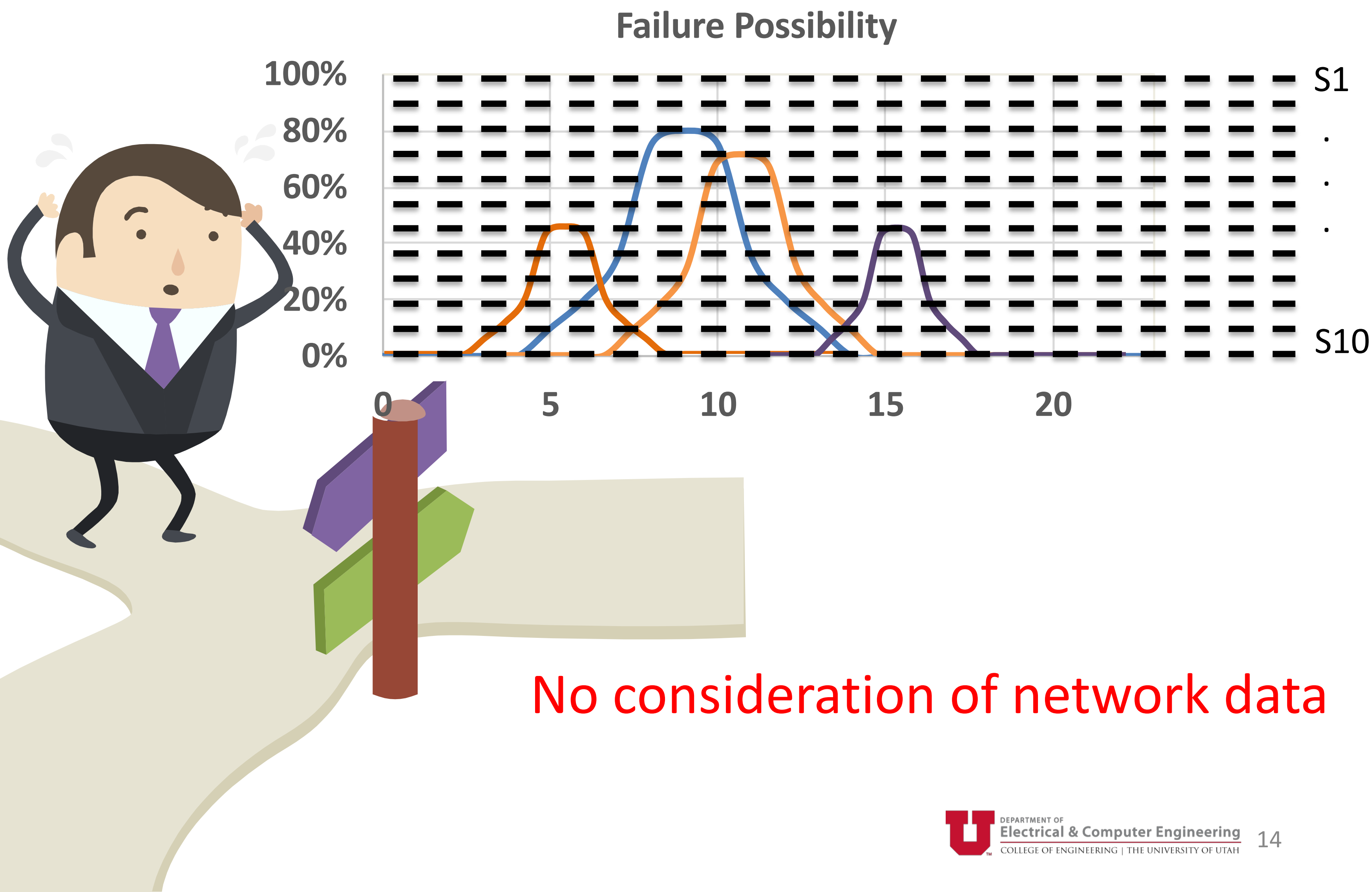
Uncertainty Management in Unit Commitment

- Stochastic Programming
- Robust Optimization
- Engineering Judgment
- Deterministic Rules (Reserves)

Challenges of Stochastic Unit Commitment

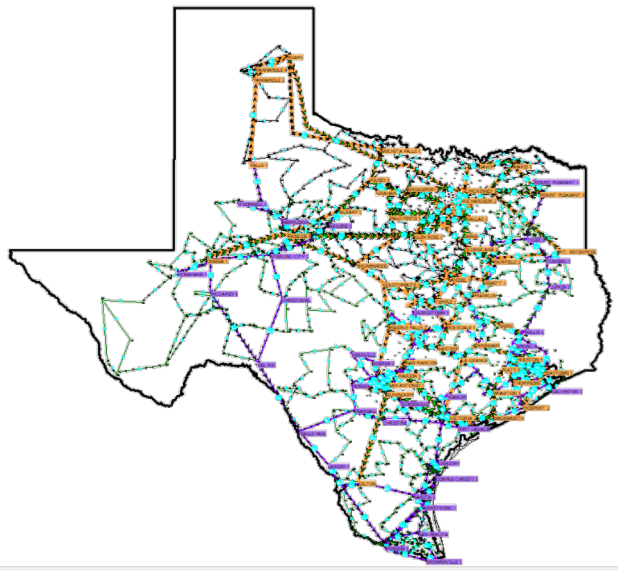
- Large uncertainty set:
  - With only 36 lines affected, for a 24-hour UC, the number of scenarios can be larger than the number of atoms in earth!
- Changing network topology:
  - Original shift factors are no longer valid
- Computational tractability is a challenge for large systems

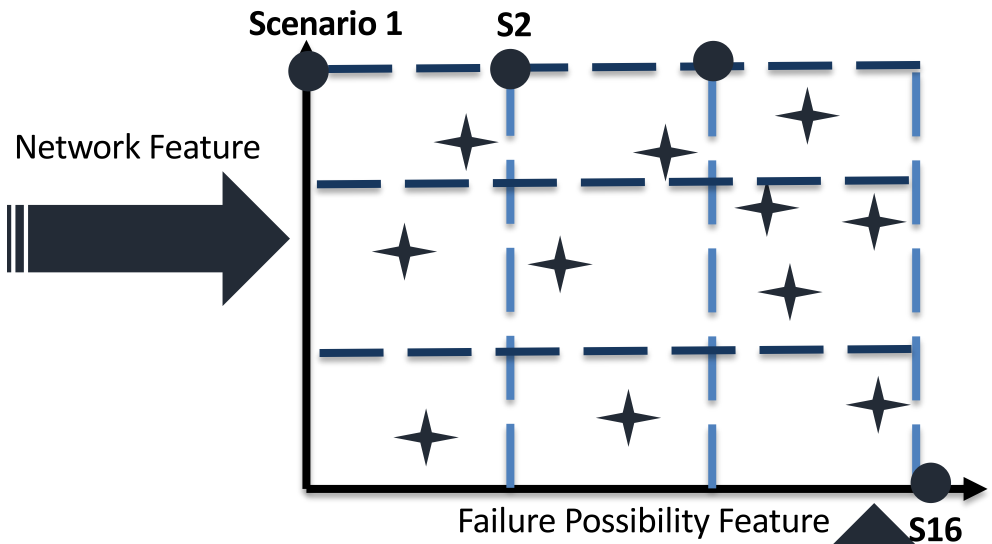
Scenario Selection: Failure Likelihood

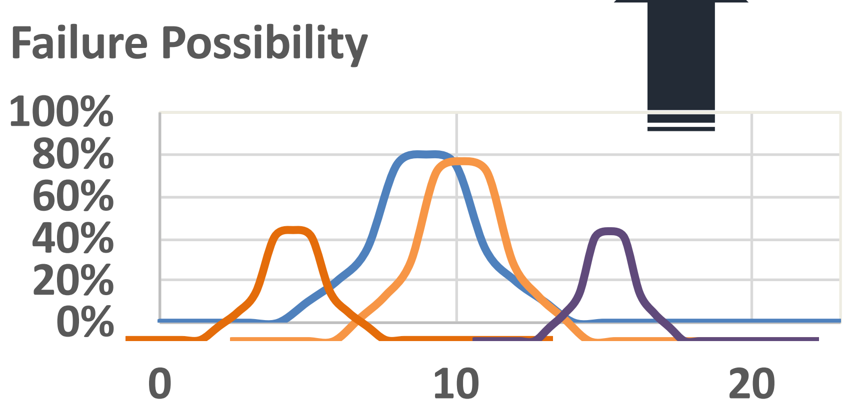


No consideration of network data

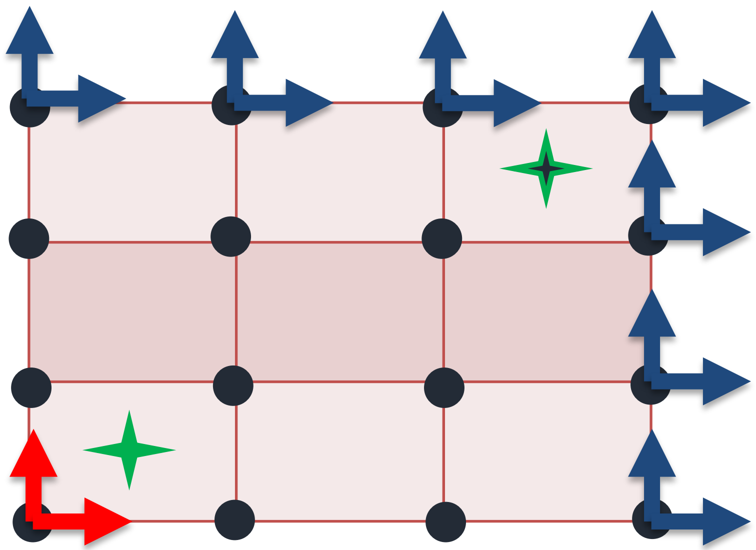
Scenario Selection: Criticality of the Element







Scenario Reduction



Represent the Same Scenario (Best Case or Business as Usual)

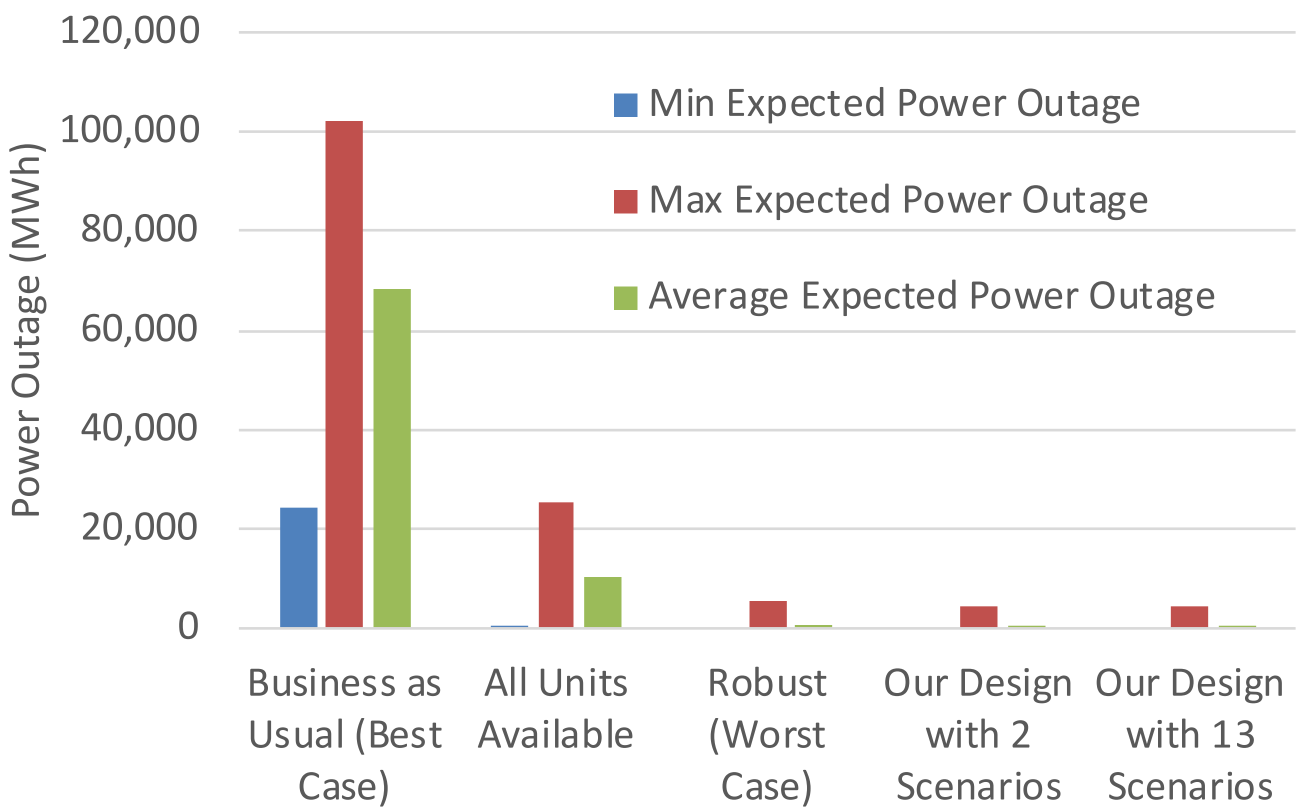
Represents the Worst Case Scenario

More Important Elements are repeated in more scenarios

Multiple Outage Handling

- Shift factors are used in UC for flow modeling
- Shift factors change as the topology of the network changes
- Single line outages can be modeled by Line Outage Distribution Factors (LODF)
- LODFs are not valid for multiple line outages
- We use flow canceling transactions or generalized LODFs
  - Iterative constraint selection for security constraints

Simulation Results: Hurricane Harvey–Texas 2000 Bus System



Computational Time:

Less than 4 hours

Conclusions

- Predictable weather-related natural hazards are the cause of about half of the blackouts in the US.
- Weather forecast data can be used to estimate component damage likelihood.
- Component damage estimations can be used to guide preventive operation.
- The simulation results confirms the effectiveness of our integrated platform in substantially reducing power outages.
- Appropriate integration of weather forecast data within power system operation can enhance system reliability.

Discussion and Future Work

- Stochastic optimization was used in this work:
  - Computationally demanding
  - Power system operation software by in large use deterministic models
  - We are currently working to develop proxy deterministic rules that:
    - Capture the majority of stochastic optimization
    - Do not substantially add to the computational burden
- The framework is general and can be applied to other weather hazards such as ice storms.

Acknowledgement

Our Research Team

Principal Investigators

Atmospheric Sciences

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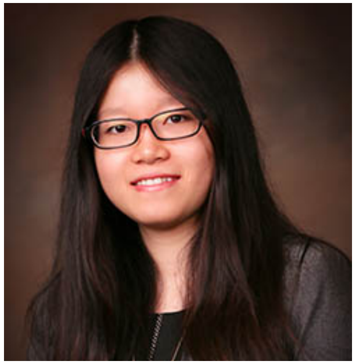
Civil Engineering



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References and Further Reading

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Thank You!