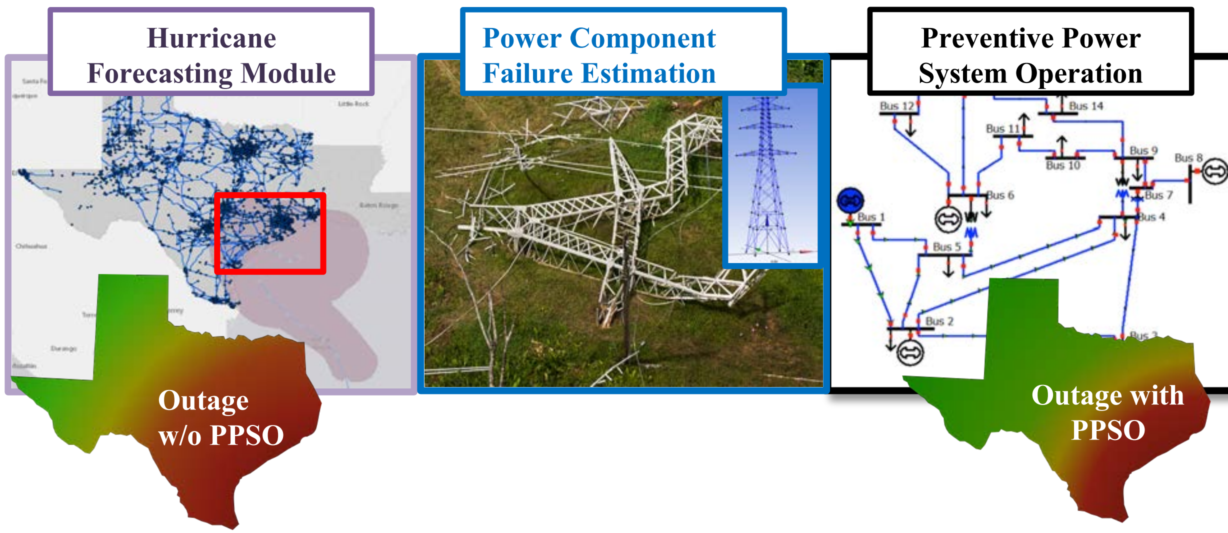
Preventive Power System Operation During Hurricanes



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Hurricane Impacts on Power Systems

- **Damage level:** Low
- **Main cause:** Flooding
- **Wind**: Rarely an issue

- **Damage level:** High
- **Main cause:** Wind force
- **Flooding**: May aggravate the situation

- **Damage level:** High
- **Main cause:** Wind force
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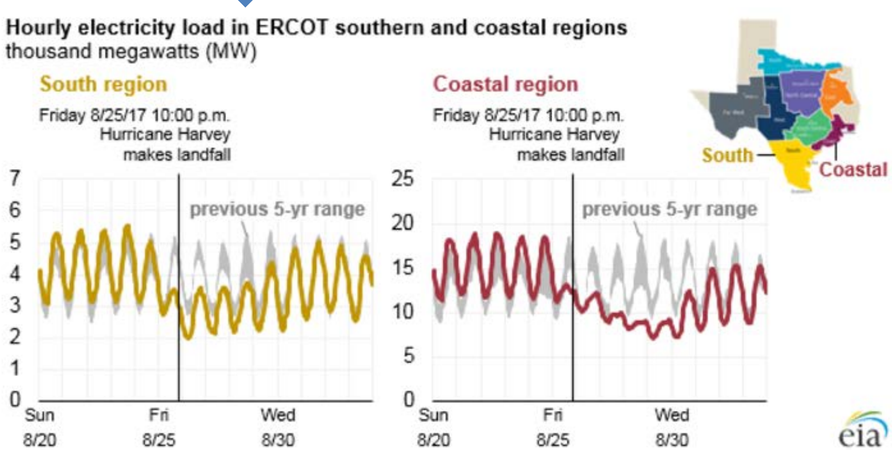
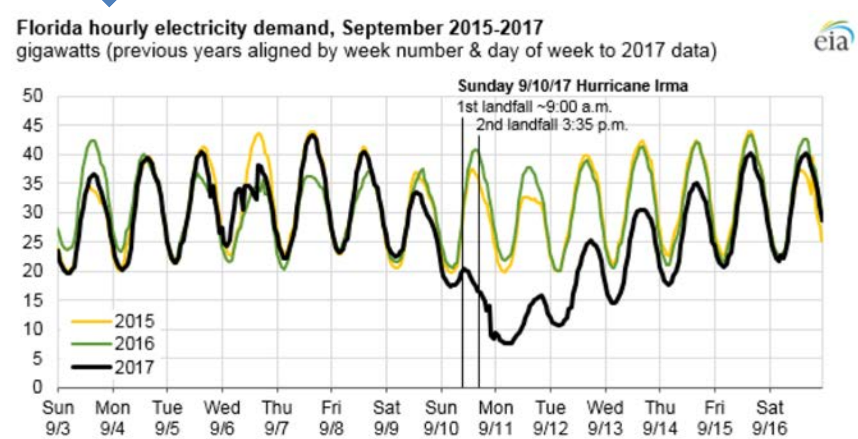
Power Outage Statistics

- 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





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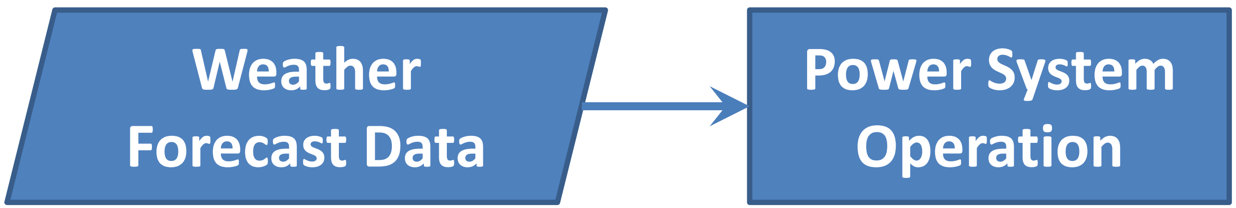
Employment of Weather Data

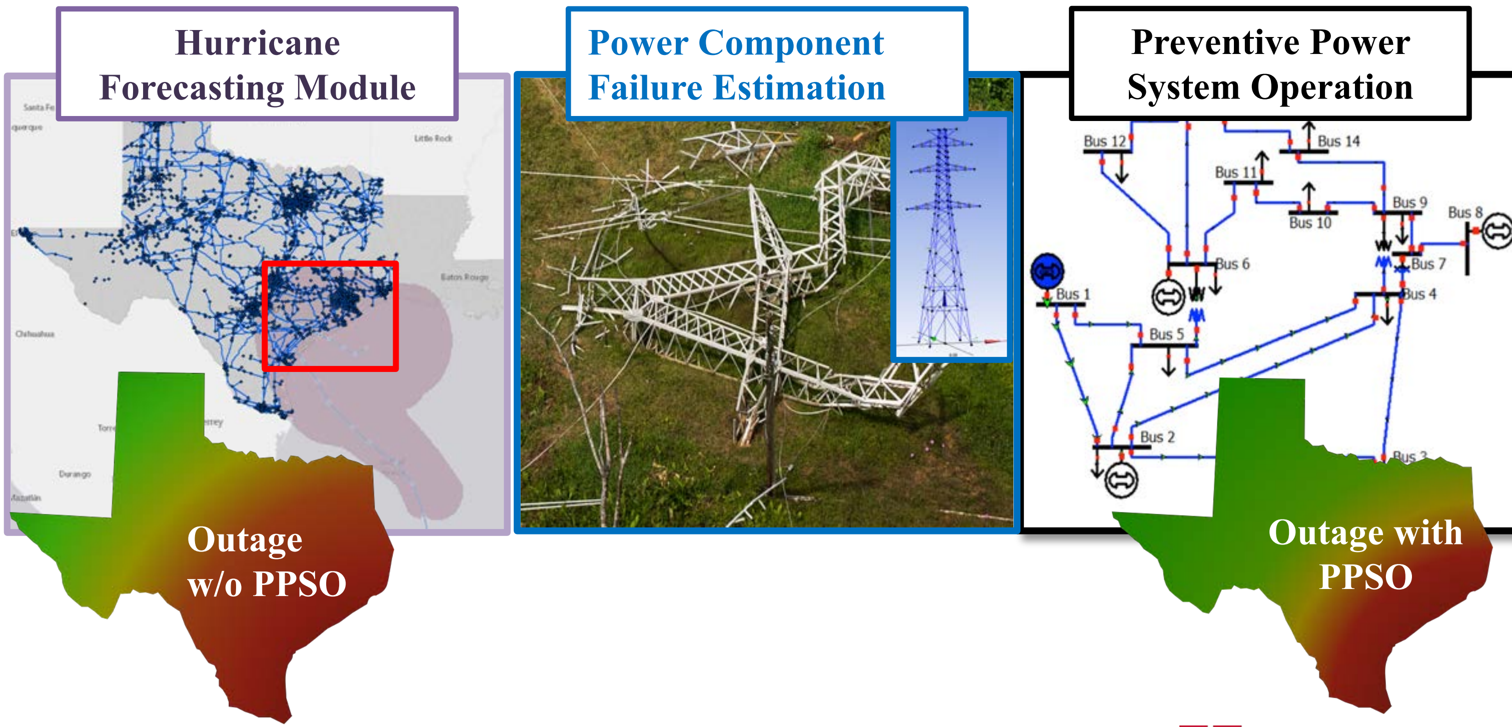
- Would integration of weather data in power system operation reduce the size and duration of power outages?



- **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

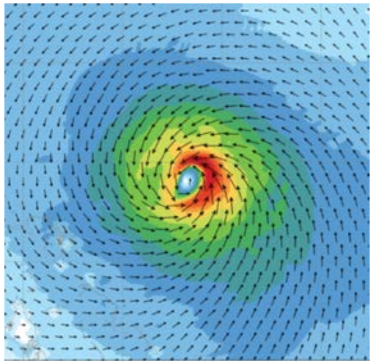
Proposed Integrated Platform

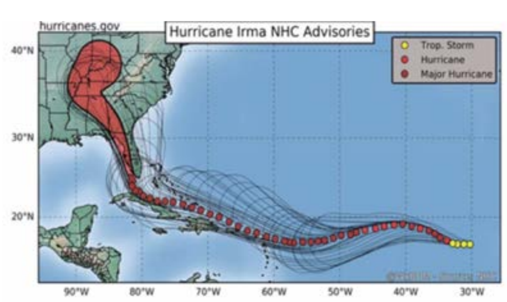
- Systematic integration of weather forecast data in power system operation
  - Translation of weather data into useful information for operation: **component damage probability**

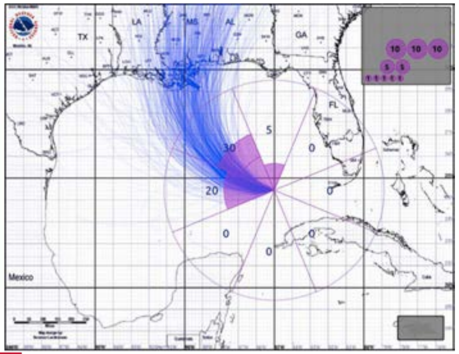


Weather Forecasting (Atmospheric Sciences)

- 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







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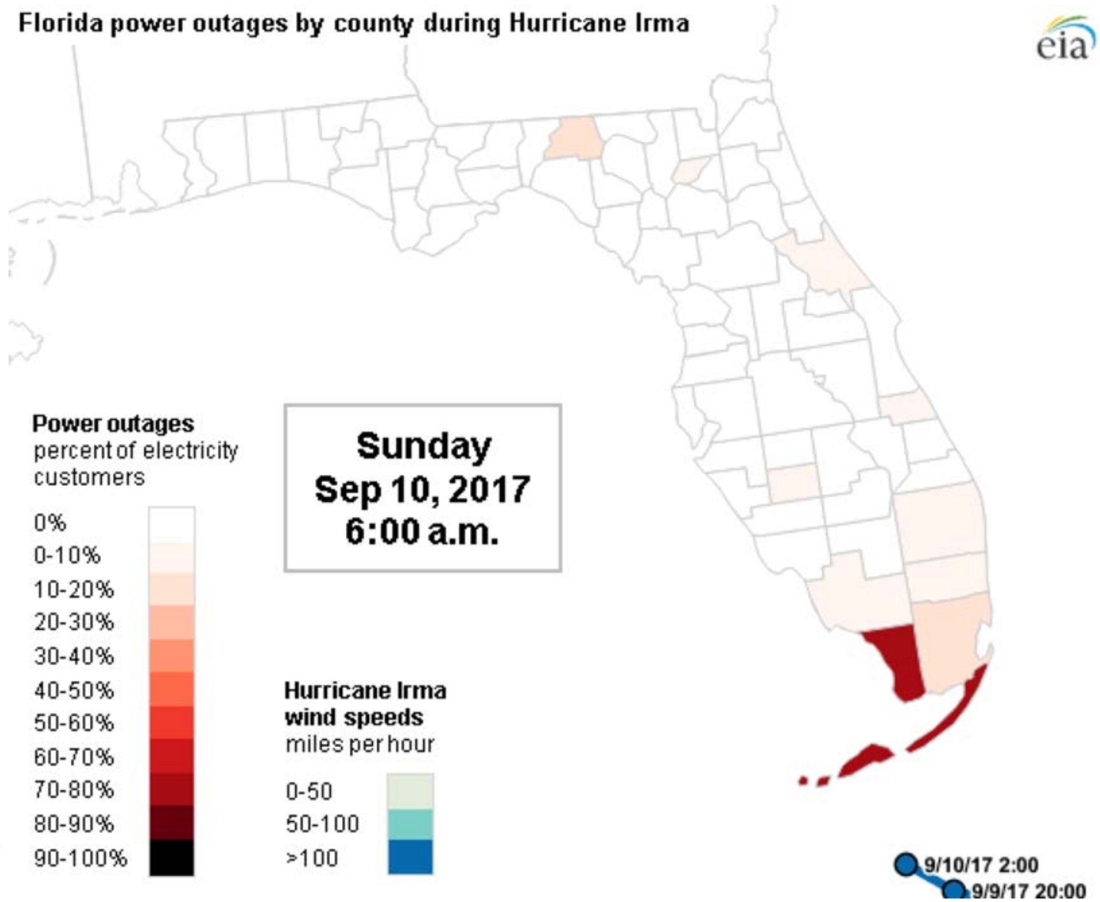
Component Failure Estimation

- Vulnerable components:
  - Transmission lines
  - Distribution lines
- We ignore distribution, because:
  - Distribution network is often radial, which makes preventive operation ineffective
  - Distribution-level damage causes local power outage
  - Transmission-level damage can cause power outage in areas, not directly affected by the hurricane
- Transmission failure is estimated based on:
  - The dynamic loading of the wind
  - Likely important factors that are neglected in our existing model:
    - Debris modeling
    - Flooding and precipitation

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)



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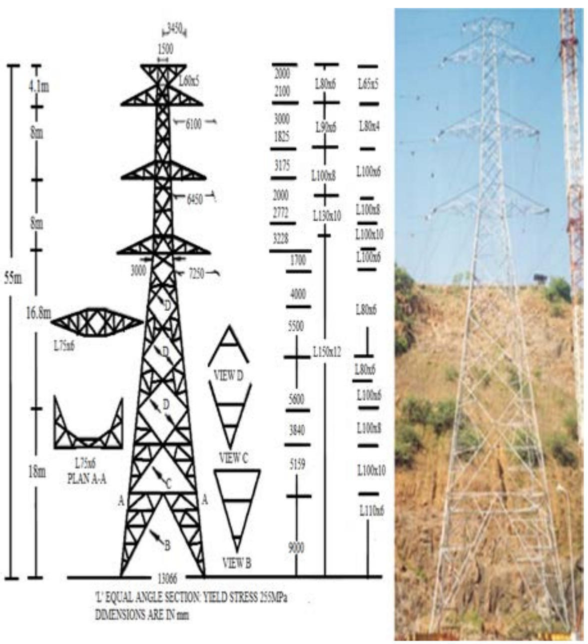
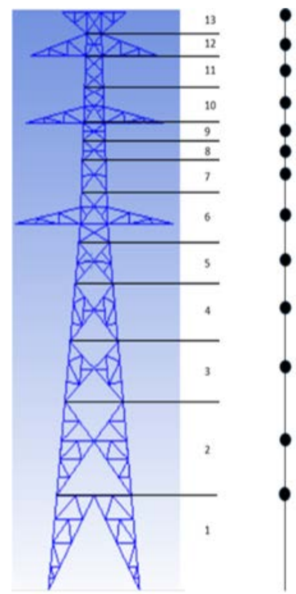
Transmission Failure Estimation I

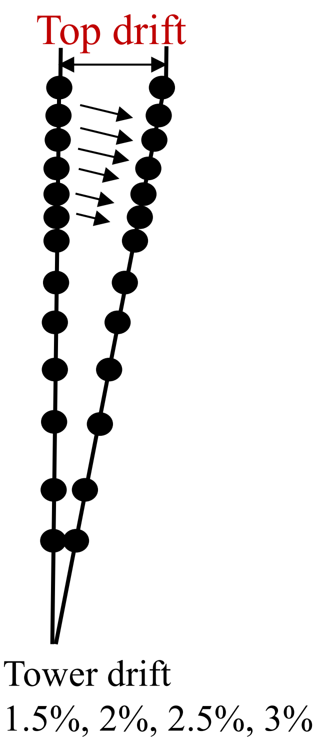
Structural Drawings



Finite Element Modeling

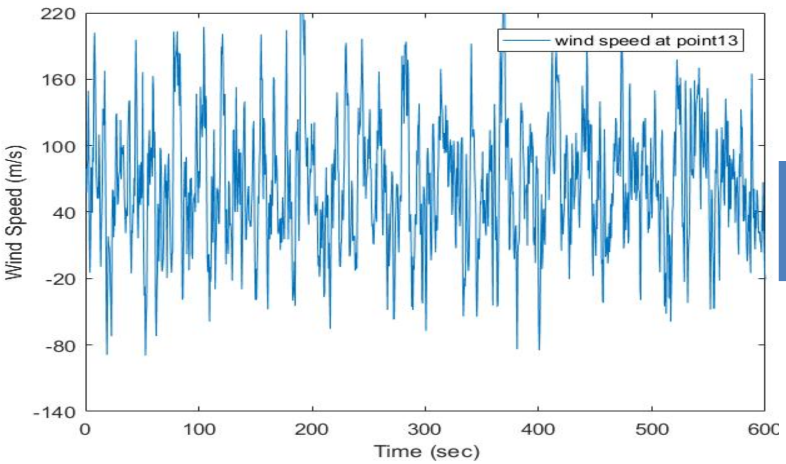


Stability under Dynamic Wind Loading

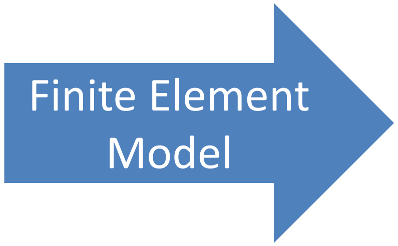


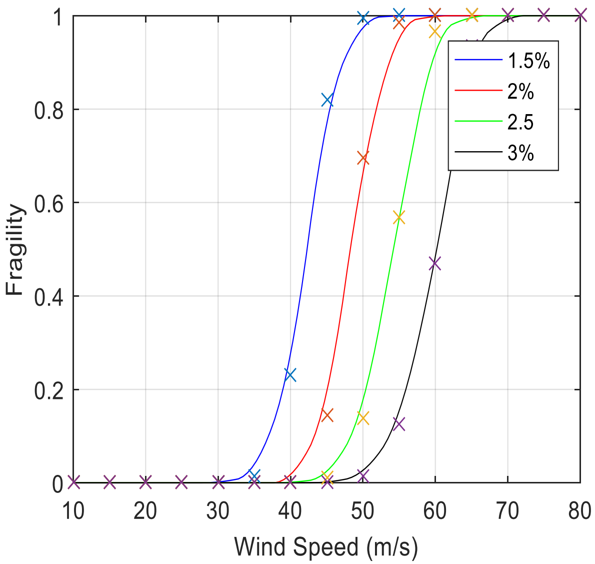
Transmission Failure Estimation II

- Finite element (FEM) models can be computationally demanding
- FEM will be used to develop fragility curves
  - Probabilistic description of failure likelihood, based on the wind speed



200 random wind speed samples





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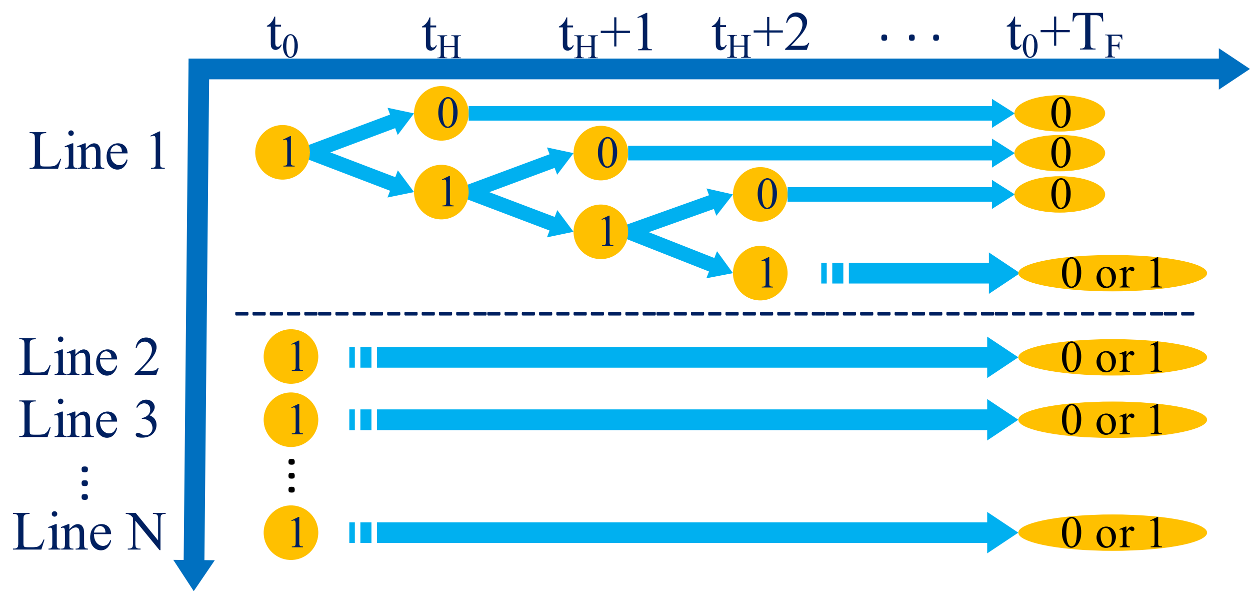
Line Outage Scenario Generation



The total number of scenarios can be calculated as

$$N_s = (T_F + 1)^{N_{br}}$$

the probability for each scenario can be calculated as

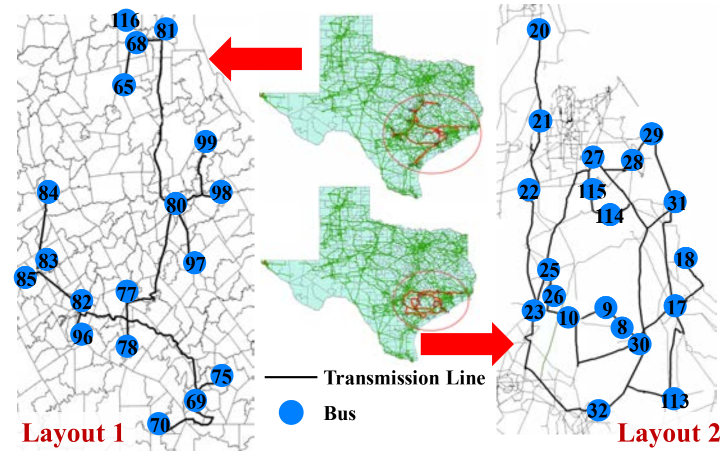
$$p_s = \prod_{k=1}^{N_{br}} \left(p_{k,t_k} \prod_{t=t_H}^{t_k-1} (1 - p_{k,t}) \right).$$

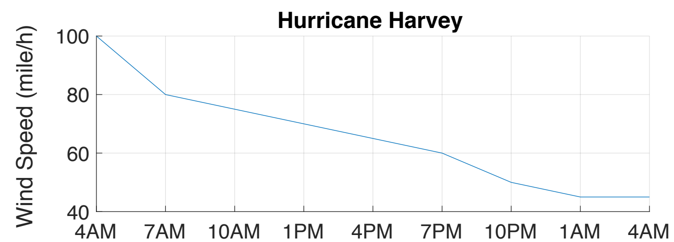
Preventive Power System Operation

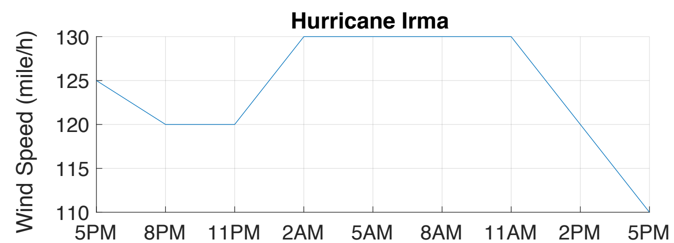
- Stochastic optimization
  - Scenarios: unplanned line outages
  - Load shedding is penalized by a large penalty factor
- Computational needs:
  - Stochastic optimization can be computationally demanding
  - Scenario reduction can help reduce the computational burden:
    - Elimination of unlikely scenarios, below a threshold
    - Elimination of inconsequential scenarios
- The solution will change the dispatch to minimize load shedding

Case Study Setup

- Test system: IEEE 118-bus
- Two layouts:
  - Areas affected by the hurricane
- Two synthesized hurricanes:
  - Harvey
  - Irma







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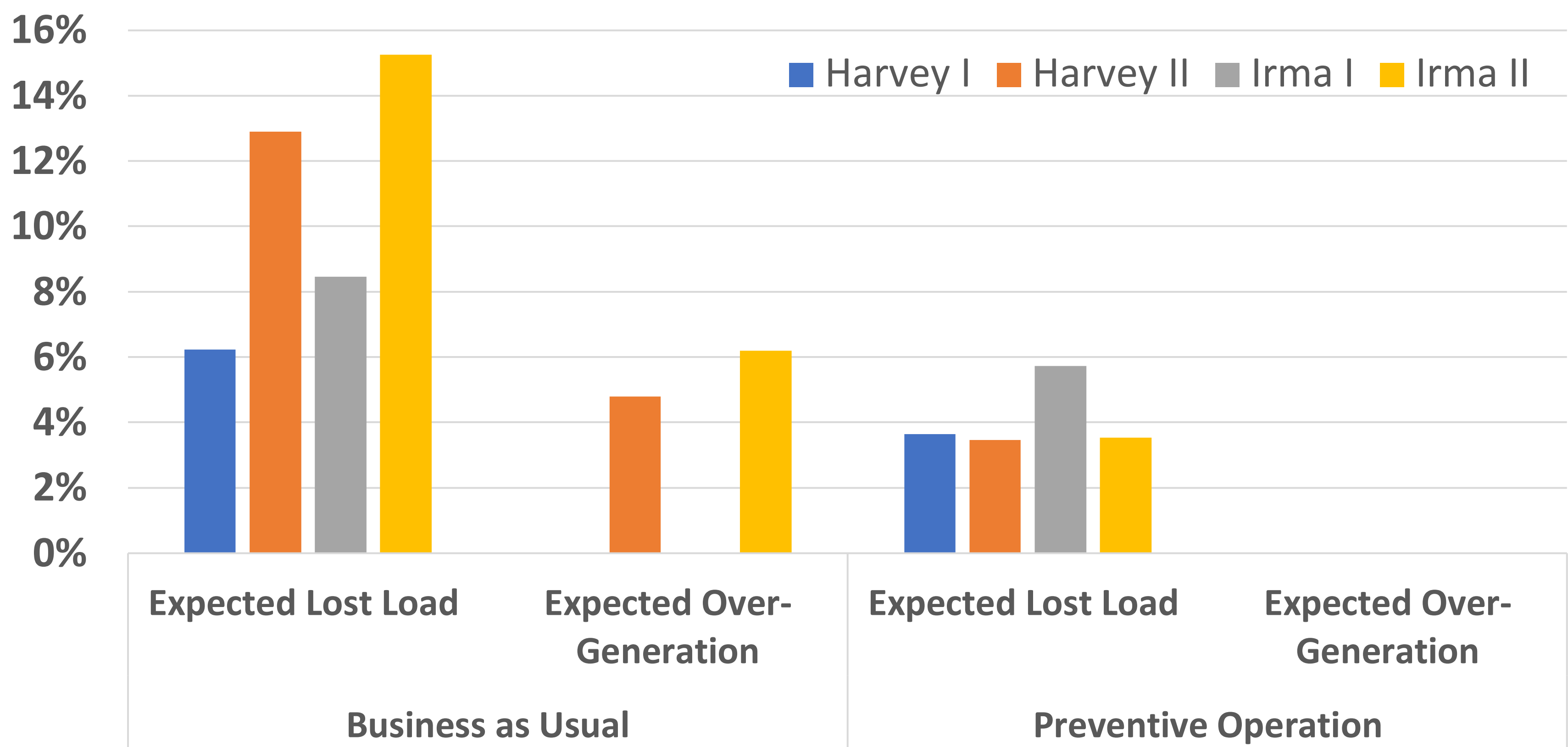
Results: Reliability Improvement



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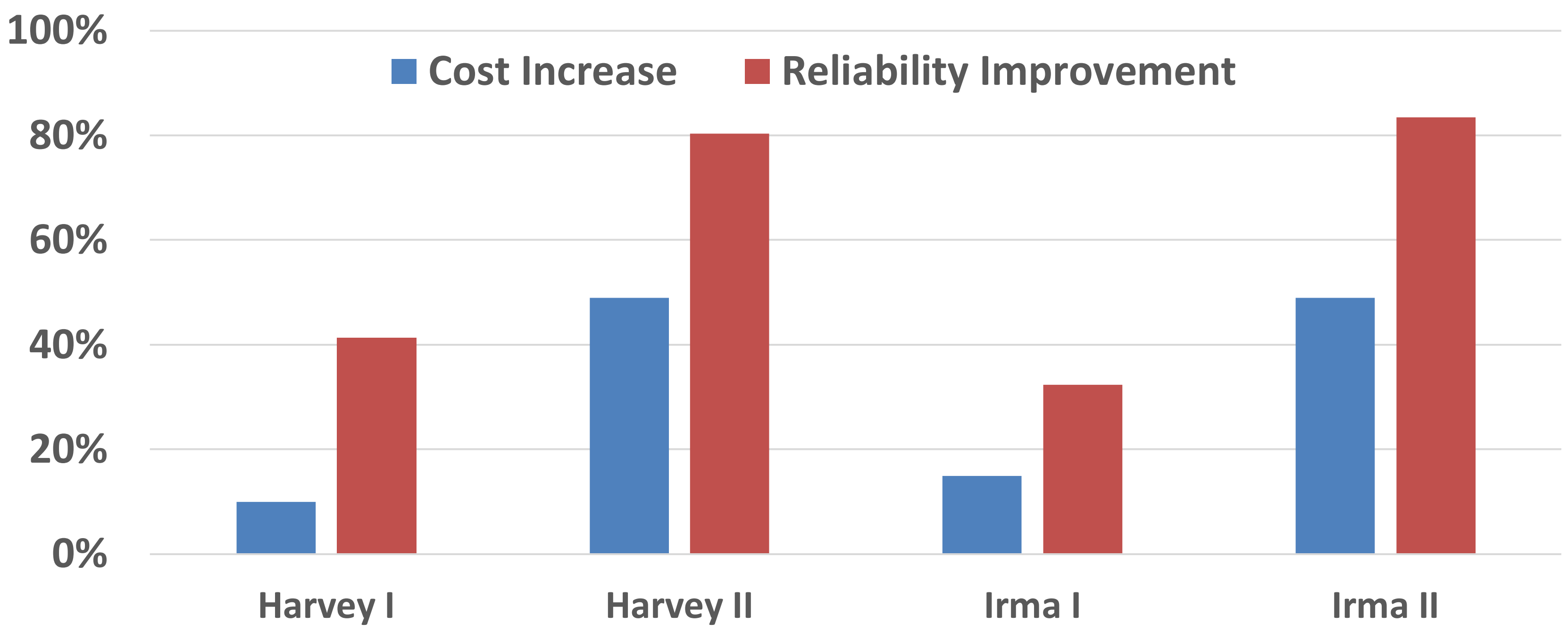
Results: Reliability versus Cost



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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.

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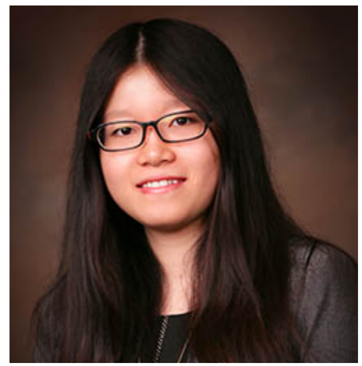
Acknowledgement

Our Research Team

Principal Investigators

Atmospheric Sciences	Civil Engineering	Electrical Engineering
		
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References and Further Reading

- Y. Sang, J. Xue, M. Sahraei-Ardakani, and G. Ou, "Effective Scenario Selection for Preventive Stochastic Unit Commitment during Hurricanes," *2018 IEEE International Conference on Probabilistic Methods Applied to Power Systems (PMAPS),* Boise, ID, USA.
- M. Sahraei-Ardakani and Ge Ou, "Day-Ahead Preventive Scheduling of Power Systems During Natural Hazards via Stochastic Optimization," *IEEE PES General Meeting 2017*, Chicago, IL, USA.
- Y. Sang, J. Xue, M. Sahraei-Ardakani, and G. Ou, "Reducing Hurricane-induced Power Outages through Preventive Operation," *working paper, available at:* *https://ardakani.ece.utah.edu/wp-content/uploads/sites/75/2018/05/HurricanePaper.pdf*

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Thank You!