Potsdam Institute for Climate Impact Research

PIK

The Risk of Cascading Failures in Electrical Grids Triggered by Extreme Weather Events

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Leibniz Association

Dr. Mehrnaz Anvari

- Mehrnaz Anvari received the M.Sc. degree in physics from Iran University of Science and Technology, Tehran, Iran, in 2010 and the Ph.D. degree from Carl von Ossietzky University Oldenburg, Germany, in 2016, where she was awarded the George Christoph Lichtenberg Fellowship for this period.
  She was awarded a two-year project fellowship from the Max-Planck Institute for Physics of Complex Systems, where she worked on the dynamics of grid frequency and load profile. Currently, she is a researcher at the Potsdam Institute for Climate Impact Research, working group Infrastructure and complex networks.

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Research Interests & Projects

› Stochastic Processes

› Data Analysis

› Network (Focus: Electrical Network)

Collective Nonlinear Dynamics of Complex Power Networks

CoNDyNet

STROMNETZE

Forschungsinitiative der Bundesregierung

Hybrid and multimodal energy systems

DFG SPP 1984

Motivation

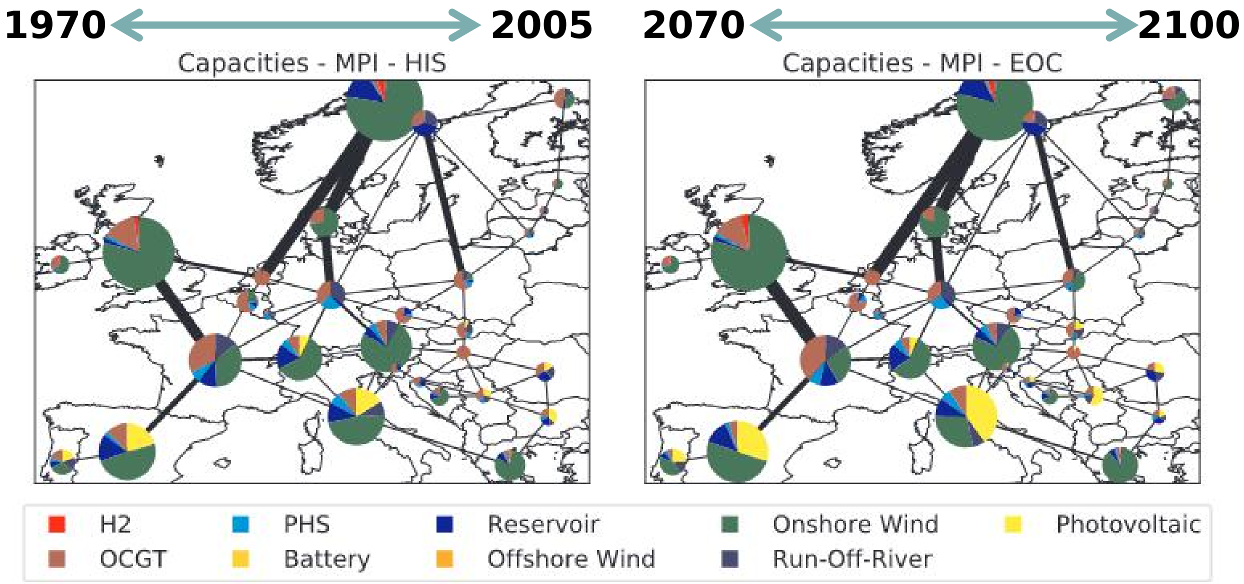
What is the effect of climate change on electrical grids?

Climate change and resource adequacy

Shortages of rain: Blackout in Kenya (2010), India (2008), Tanzania (2006), ...

An aerial view of Folsom Dam and Lake in Sacramento County shows low water levels in January 2014. (Image credit: Paul Hames / California Department of Water Resources)

The **impact of climate change** on a renewable European electricity network



Markus Schlott, et. al., Applied Energy, vol. 230, pp. 1645-1659 (2018)

Extreme weather events and damage in infrastructures

- Human-induced climate change leads frequent extreme weather events: floods, heavy rainfall, winter storms, icing, hurricanes, ...

Science,vol. 352, pp. 1517, 2016

Hurricane Laura 2020
https://dailyenergyinsider.com/

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- Reports show that electrical grid components are at greater risk of failure
  - Wind storm in Britain

    2014 International Conference on Probabilistic Methods Applied to Power Systems IEEE
  - Localized downburst in Australia

    Engineering structures, vol. 22, pp. 1173, 2000.
  - Intense hurricanes in coastal states of the U.S.

    Scientific reports, vol. 8, pp. 1, 2018

    U.S. Department of Energy, “Combined report: Hurricanes Sally &Laura,” September 2020

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Content

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Content

› Synthetic electrical grid of Texas
› Electrical grid model: AC & DC model
› Hurricane-induced failures: Hurricane Ike
› Cascading failures

Hurricane Laura 2020
https://dailyenergyinsider.com/

Synthetic Electrical Grid of Texas

Introduce the electrical test case

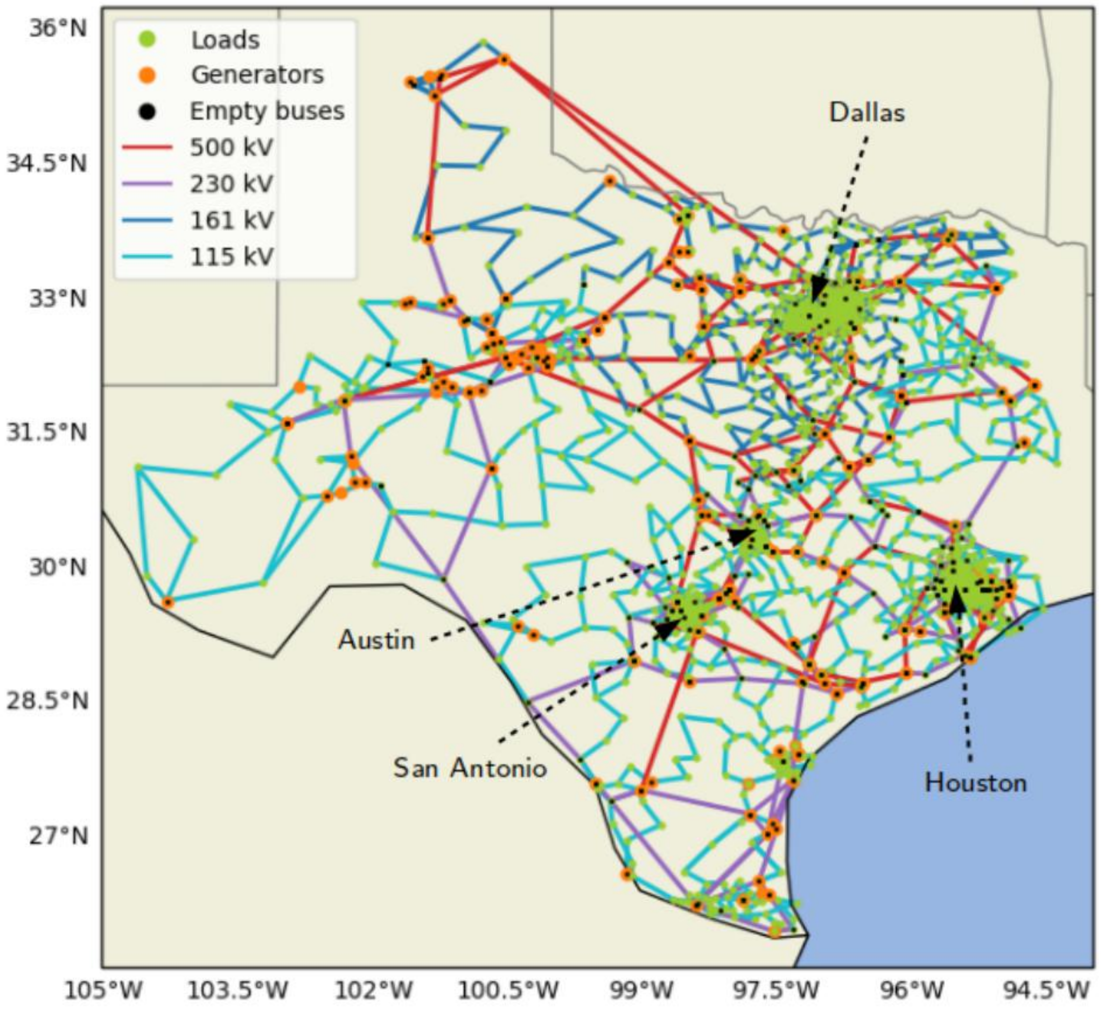
Texas electrical grid

Number	Name	SubLatitude	SubLongitude	BusCat	NomkV	Vpu	kV	Vangle	LoadMW	LoadMvar	GenMW	GenMvar	ShuntMvar
1001	ODESSA 2 0	31.907	-102.262	PQ	115.00	0.97944	11.263.510	-2.273.484	2.078.100	588.795			
1002	PRESIDIO 2 0	29.888	-104.519	PQ	115.00	101.274	11.646.468	-1.808.854	1.541.400	436.730			
1003	O DONNELL 1 0	32.926	-101.648	PQ	115.00	100.926	11.606.523	-1.708.670					
1004	O DONNELL 1 1	32.926	-101.648	PQ (Gens at Var Limit)	230.00	101.307	23.300.626	-1.893.400	15.825.000	-3.038.000			
1005	BIG SPRING 5 0	32.208	-101.388	PQ	115.00	100.558	11.564.125	-1.607.716					
1006	BIG SPRING 5 1	32.208	-101.388	PV	13.80	100.000	1.380.000	-1.390.559	2.573.000	-435.362			
1007	VAN HORN 0	31.093	-104.625	PV	115.00	102.000	11.730.000	-1.846.721	700.800	198.560	-0.84895		
1008	IRAAN 2 0	30.931	-102.201	PQ	115.00	101.929	11.721.778	-860.521					
1009	IRAAN 2 1	30.931	-102.201	PQ (Gens at Var Limit)	13.80	100.924	1.392.751	-530.960	6.187.000	-1.188.000			

Substation data :
https://electricgrids.engr.tamu.edu/

Texas electrical grid

- 2000 buses
- 1125 load buses with
  ~ 70 MVA total load
- 432 generator buses
  ... in 1250 substations
- 861 transformers
- 2345 transmission lines
- 4 high voltage levels



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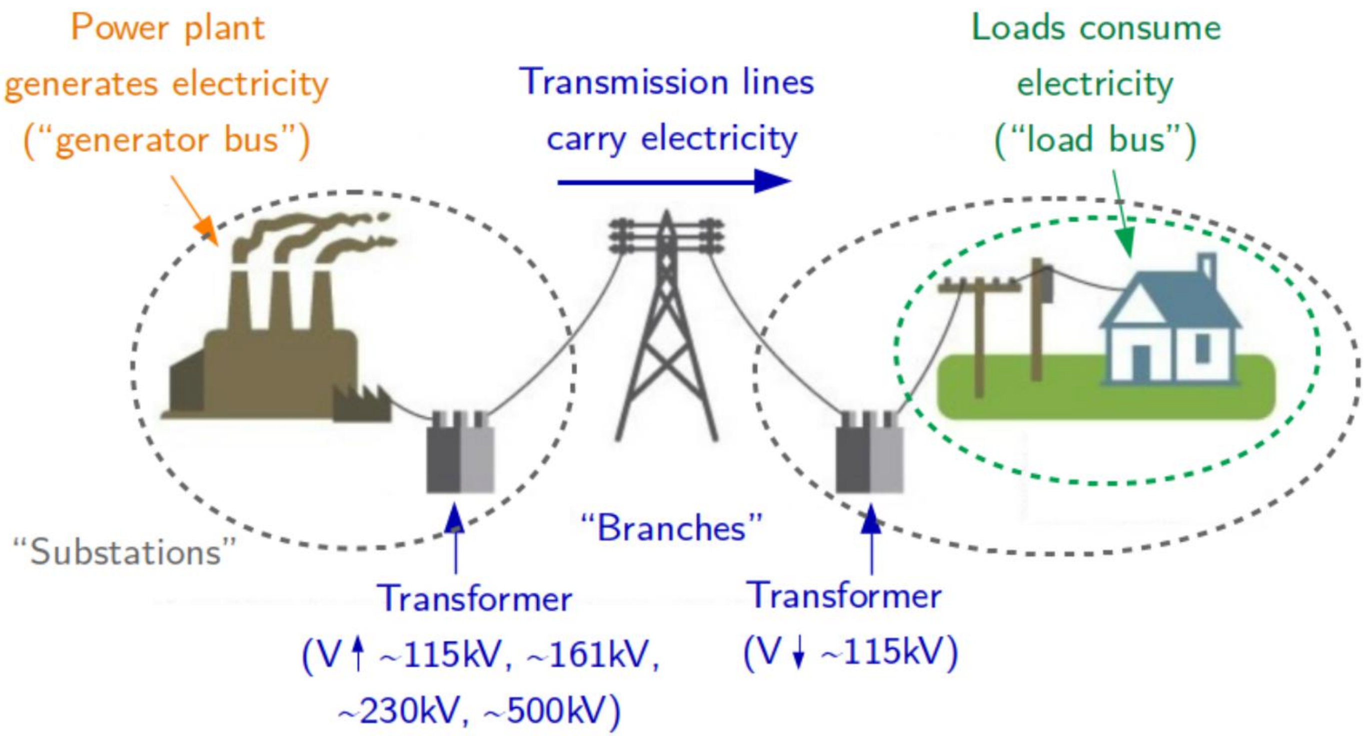

Source:
Natural Resources, vol. 10, pp. 96-114 (2019)

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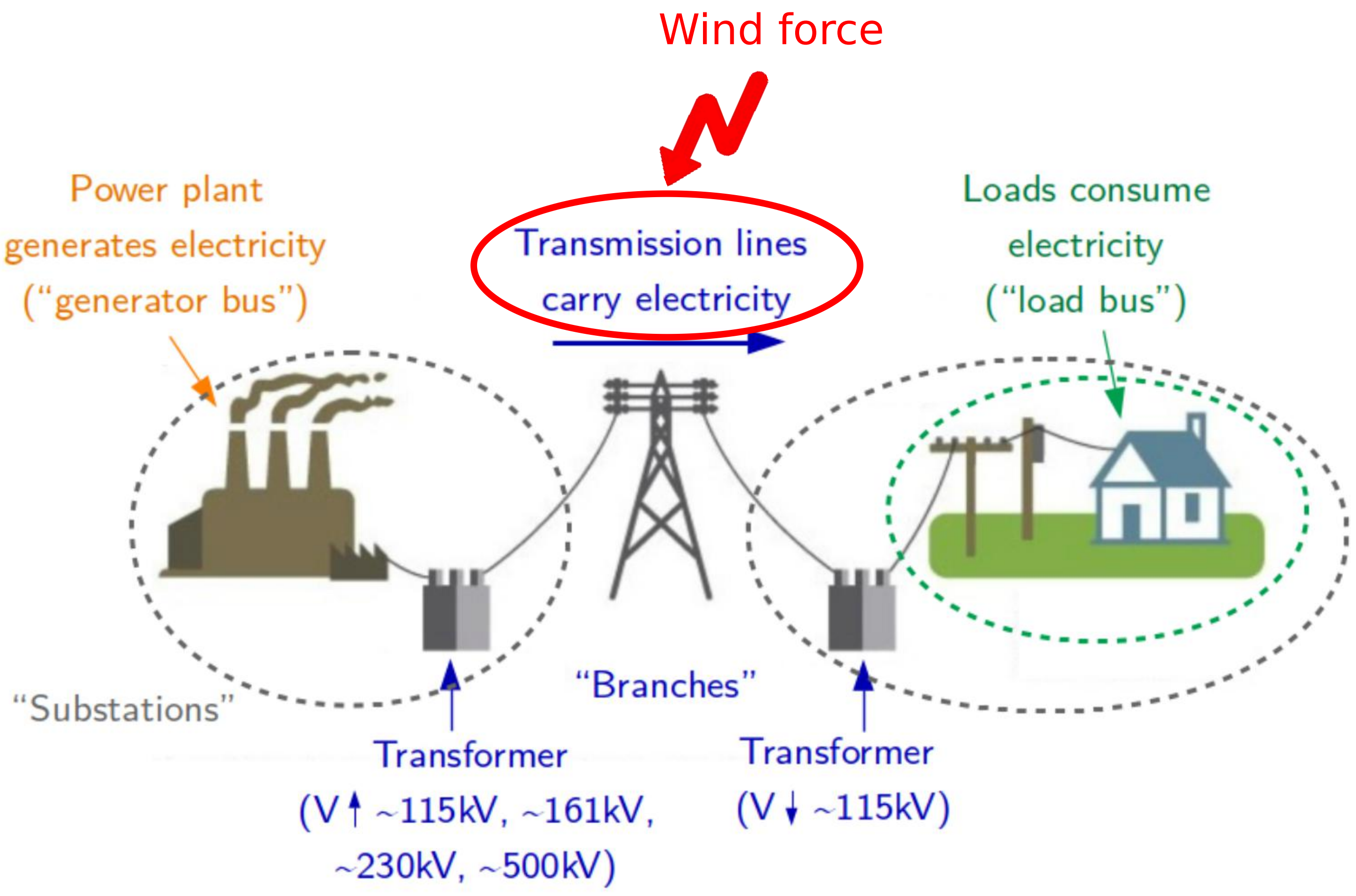

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Electrical Grid Modeling
AC & DC power flow model

Electrical grid: AC power flow model

› Apparent power:

$$S_i = P_i + iQ_i = V_i I_i^* \; ; \; V_i = |V_i| e^{i\theta_i}$$

$$current: \; I_i = \sum_{j=1}^{N} Y_{ij} V_j$$

$$admittance: \; Y_{ij} = G_{ij} + iB_{ij}$$

$$P_i = \sum_{j=1}^{N} |V_i||V_j|(G_{ij} cos(\theta_i - \theta_j) + B_{ij} sin(\theta_i - \theta_j))$$

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- Loads/PQ buses: (P, Q)<0, (|V|,θ)$\rightarrow$ $unknown$

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- Generators/PV buses: P>0, |V|=const, θ $\rightarrow$ *unknown*

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Electrical grid: DC power flow model

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1 Neglect ohmic losses: $G_{ij} \sim 0$

Electrical grid: DC power flow model

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2

$$current: \; I_i = \sum_{j=1}^{N} Y_{ij} V_j$$

1

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1

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2 Fix the voltage magnitude: $|V_i| = 1 \; p.u.$

Electrical grid: DC power flow model

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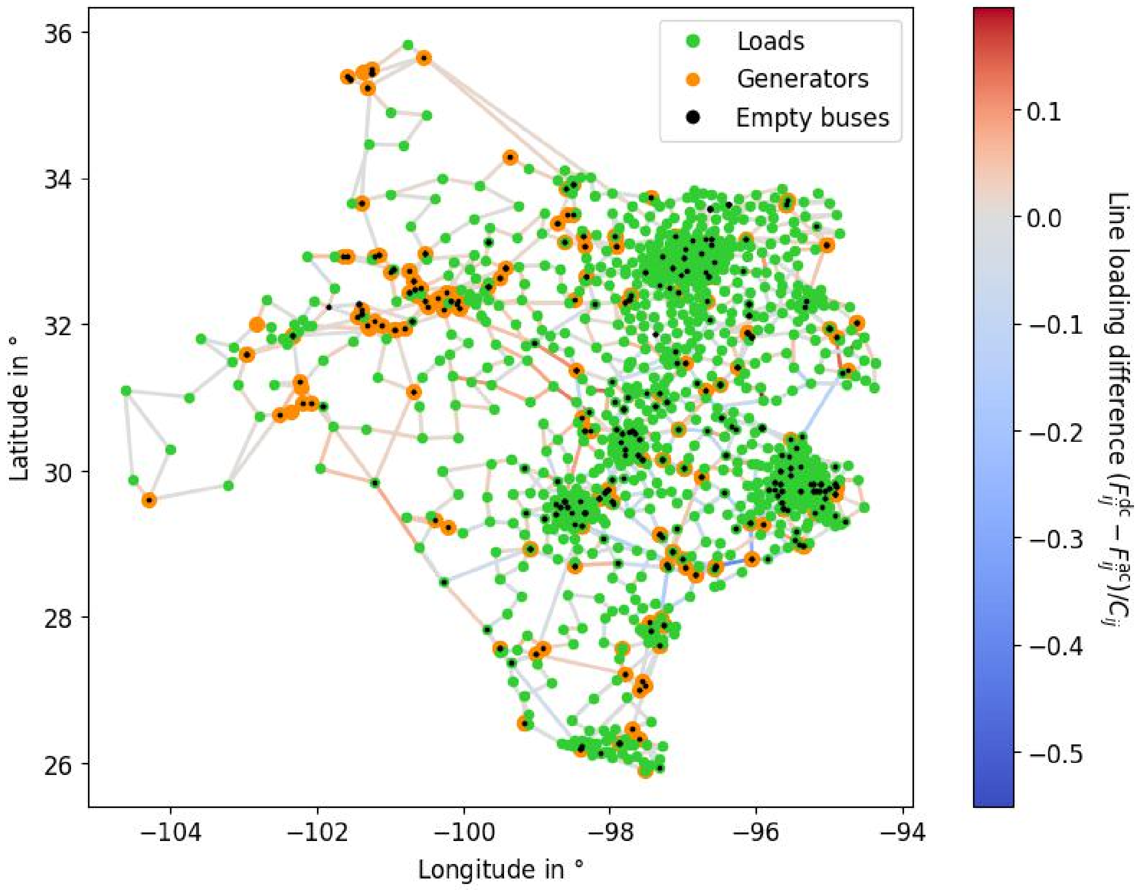
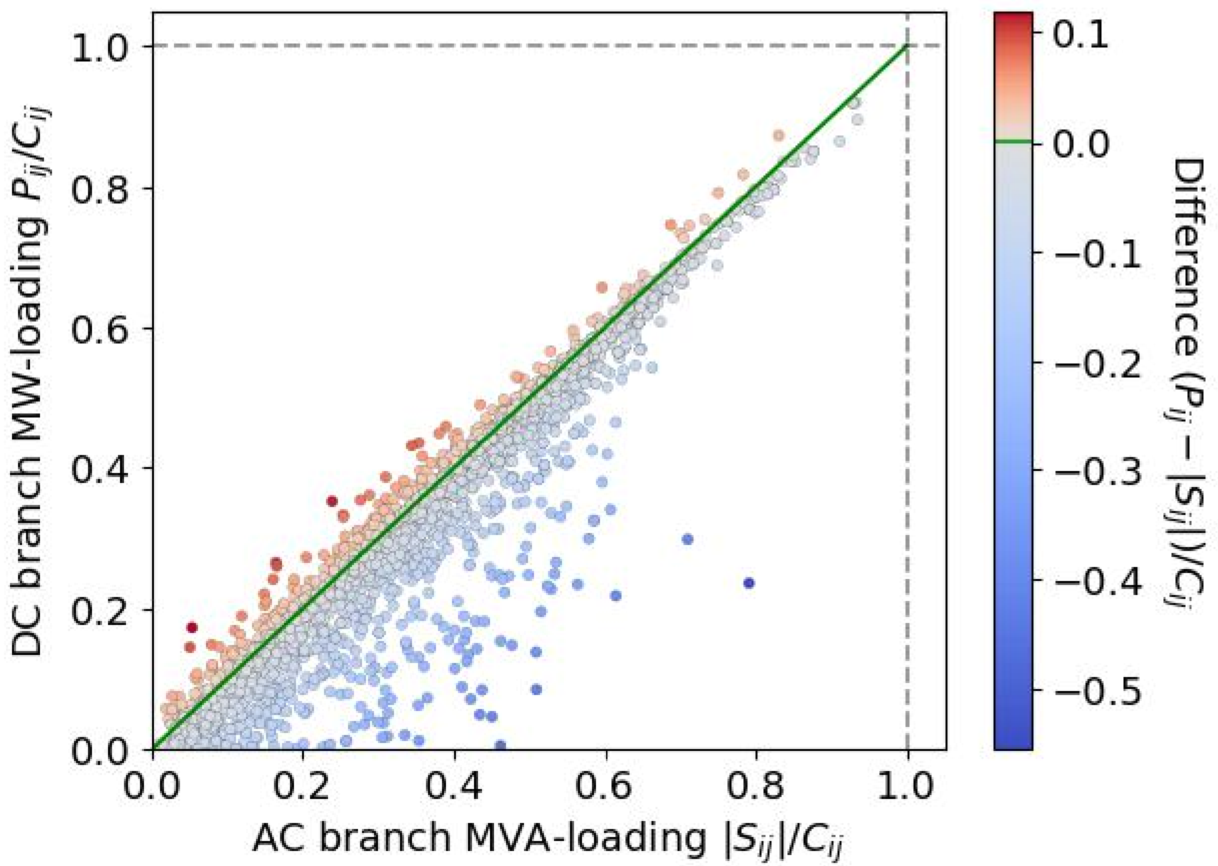
Comparison of AC & DC power flow

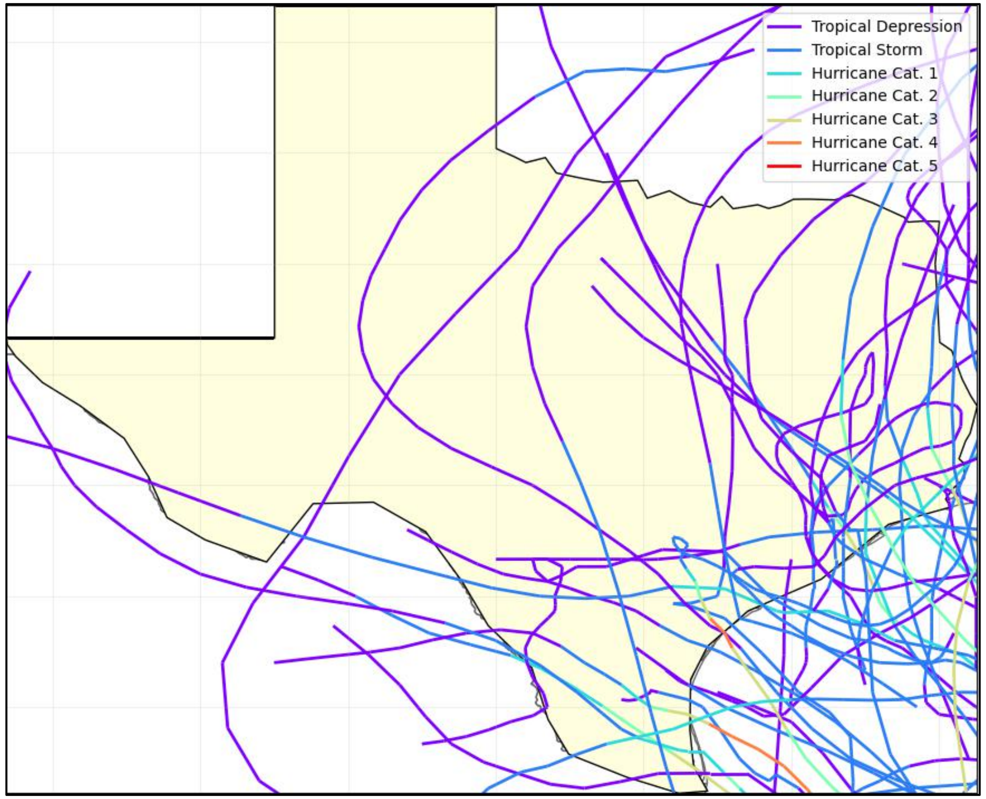




Wind-Induced Damages

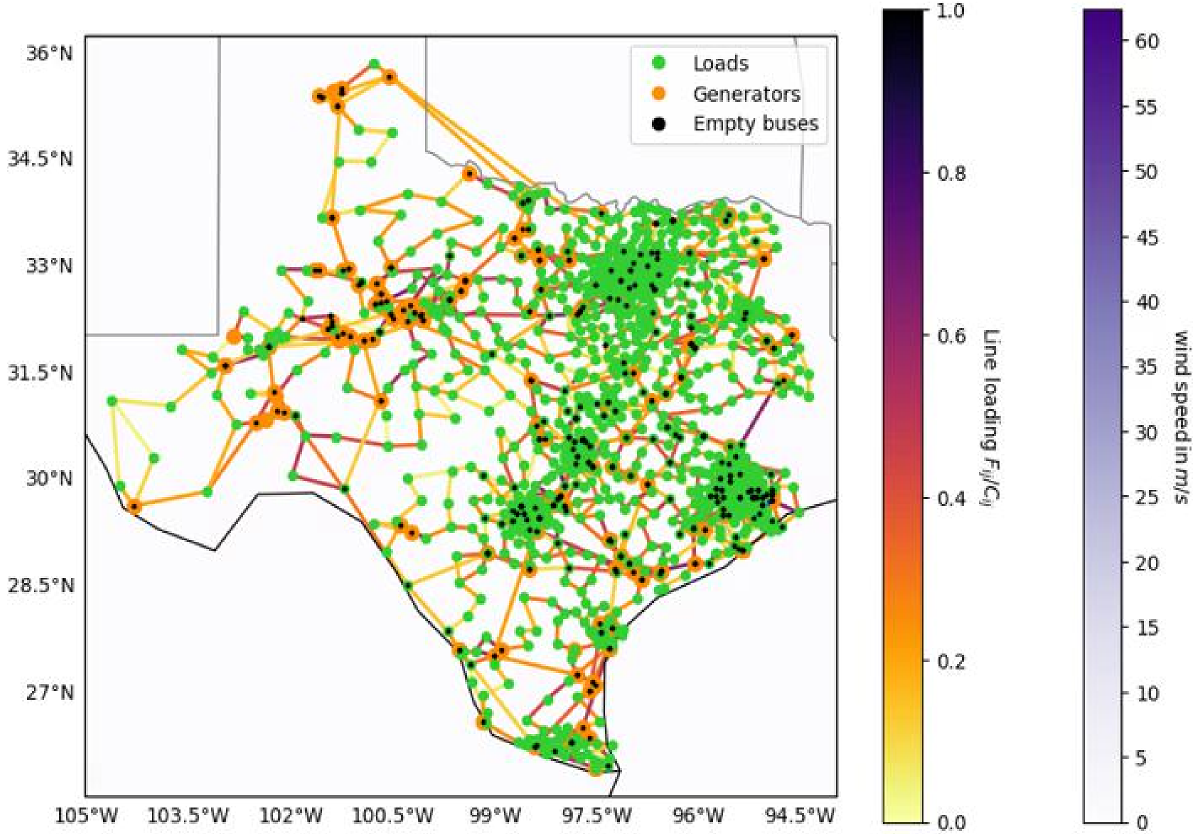
Ike hurricane

All tropical storms hitting Texas between 1980 & 2020



Source:
Dr. Thomas Vogt, Transformation Pathway Department, PIK

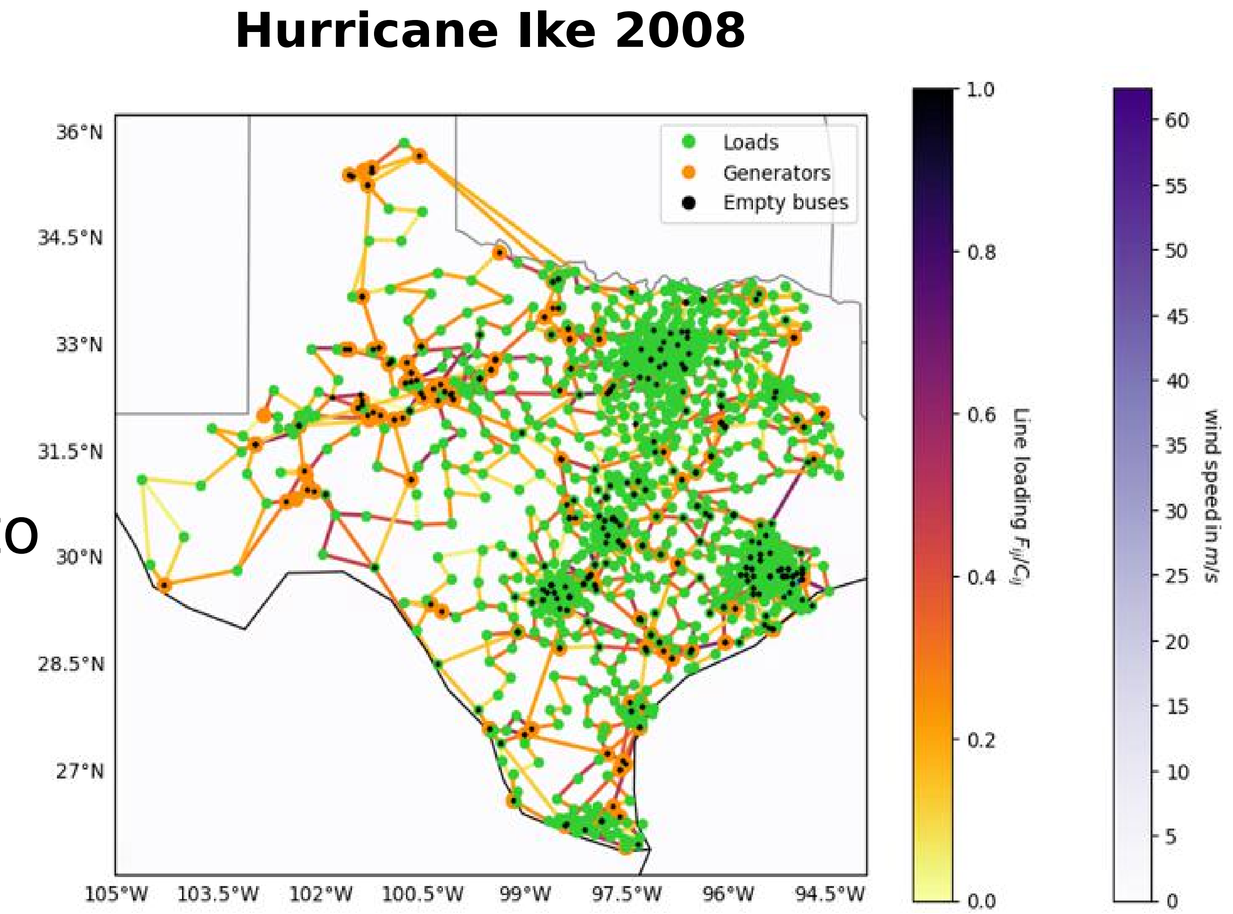
Hurricane Ike 2008



Source of Wind field data:
Dr. Thomas Vogt, Transformation Pathway Department, PIK
Using **CLIMADA** Python implementation & the **IBTrACS** archive

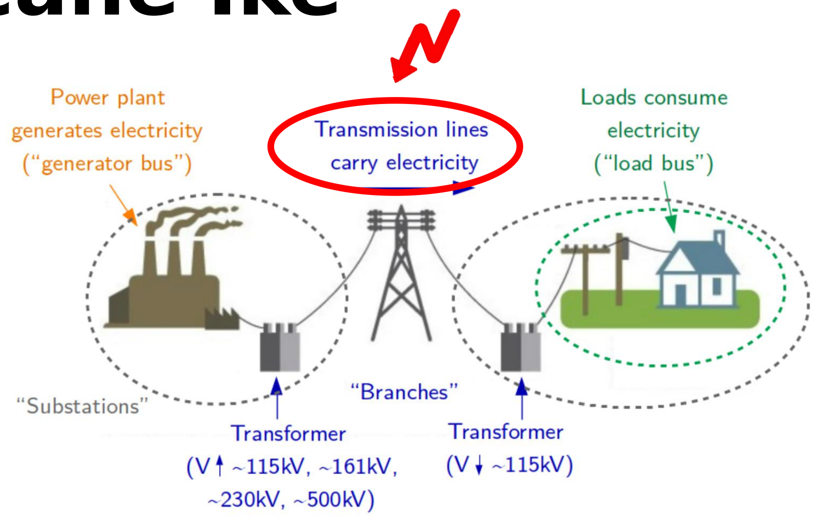
Hurricane Ike September 2008

- Category 4 hurricane
- Third major hurricane of the 2008 Atlantic hurricane season
- Made landfall on Texas on Sep. 14th
- Caused min. 195 death
- Damages in U.S. ~30$ billion
- Millions of people (ranging from 2.8 to 4.5 millions) without electricity in Texas for weeks



Transmission lines damages in hurricane Ike

› Wind force on transmission lines[1]



Source:
Natural Resources, vol. 10, pp. 96-114 (2019)

[1] American Society of Civil Engineers (ASCE)

Transmission lines damages in hurricane Ike

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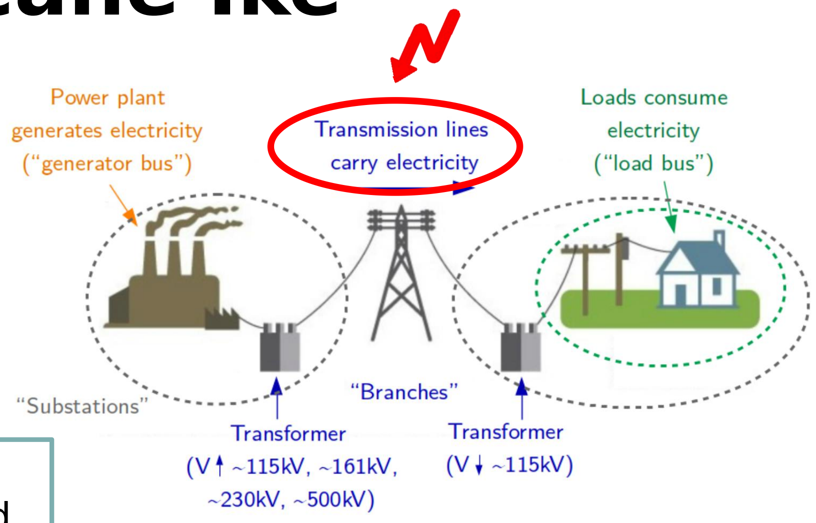
$$F_{wind}(v,l) = \overbrace{Q}^{\text{air density}}\underbrace{k_z}_{\text{terrain correction}}\overbrace{I_{FW}}^{\text{importance factor}}\underbrace{G_{WRF}(l)}_{\text{wire strain}}\overbrace{C_f}^{\text{force coefficient}}\underbrace{A_C}_{\text{cross-sectional area}}\underbrace{v^2}_{\text{wind speed}}$$



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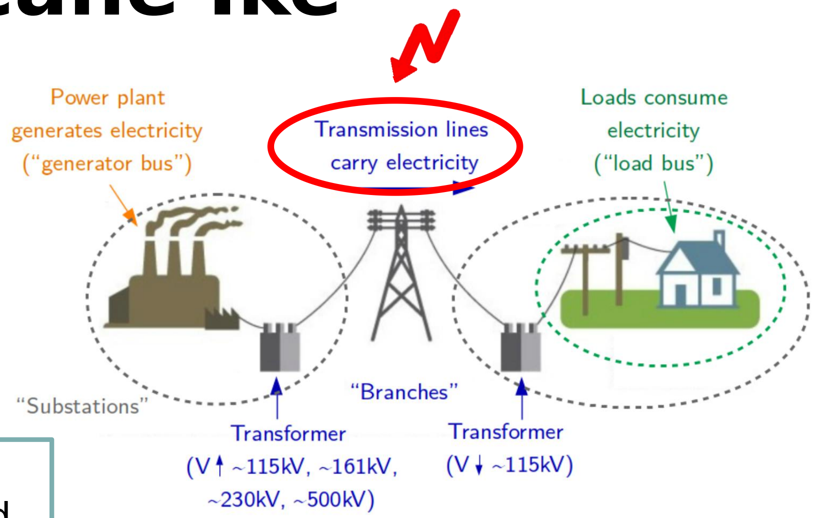

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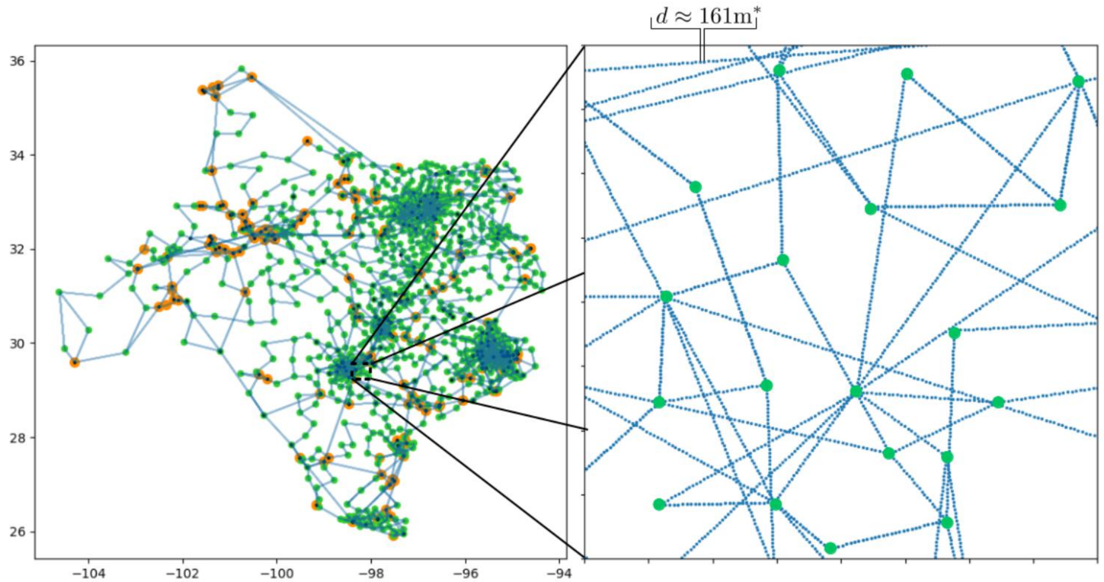

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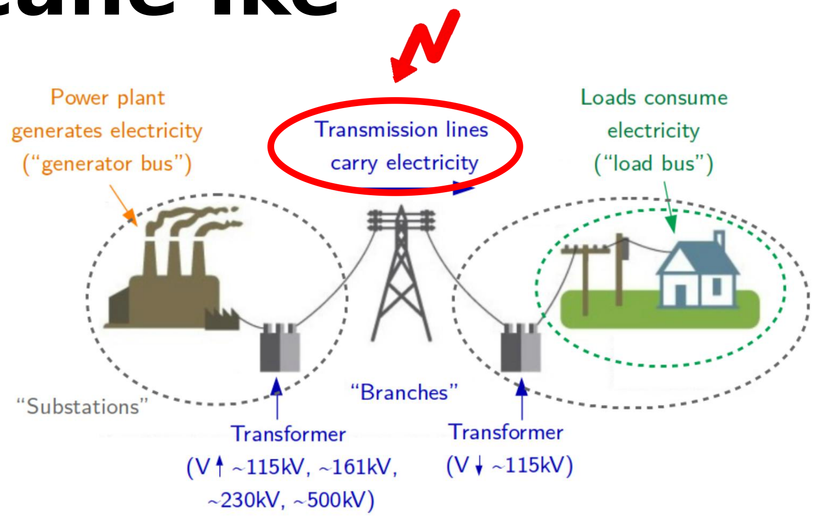
Transmission lines damages in hurricane Ike

› Wind force on transmission lines[1]

$$F_{wind}(v,l) = Qk_z I_{FW} G_{WRF}(l) C_f A_C v^2$$

› Calculate line damage probability[2]



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[2] Reliability Engineering and System Safety, vol. 95, pp. 323 (2010)

Transmission lines damages in hurricane Ike

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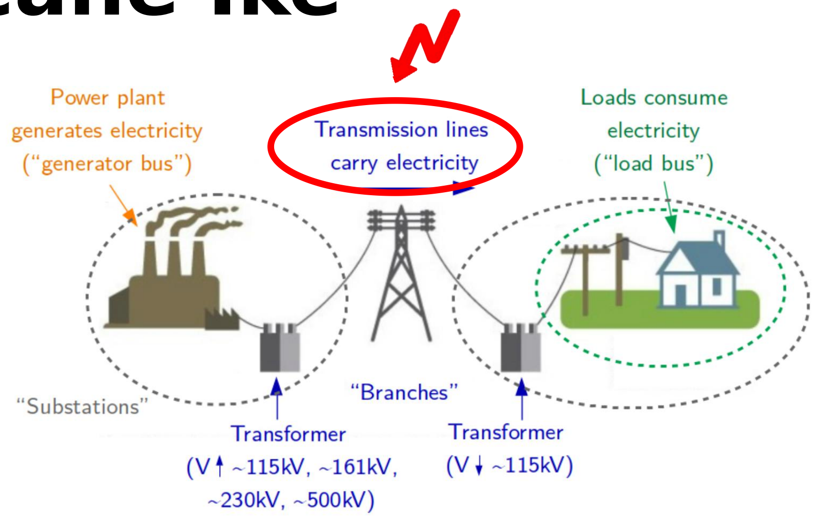
› Calculate line damage probability[2]

$$p_k(v,l) = min(\underbrace{\gamma}_{\text{scaling parameter}} \frac{F_{wind,k}(v,l)}{\underbrace{F_{brk,k}}_{\text{max. wind force}}}, 1)$$



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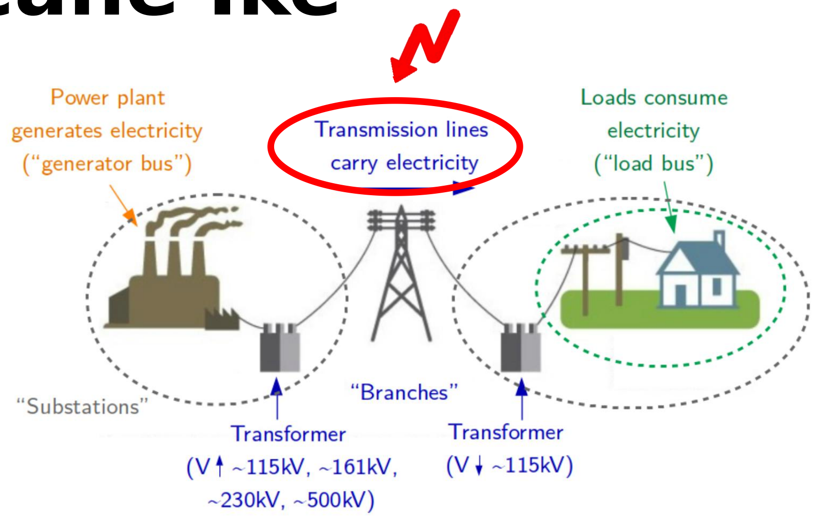
$$p_k(v,l) = min(\gamma \frac{F_{wind,k}(v,l)}{F_{brk,k}}, 1)$$

- To calibrate the value of γ



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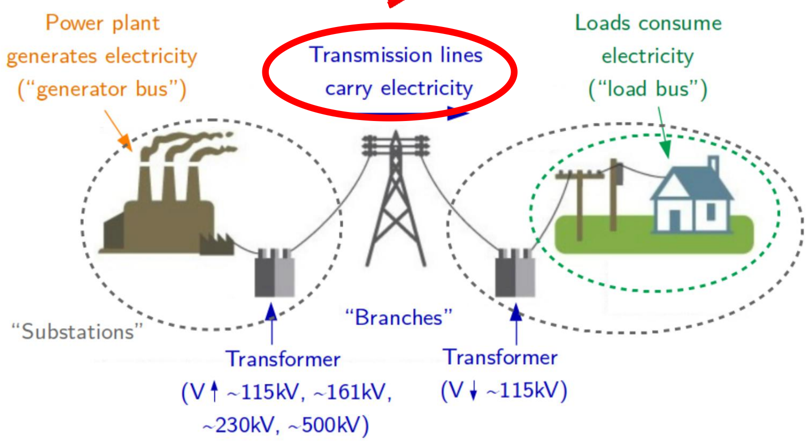

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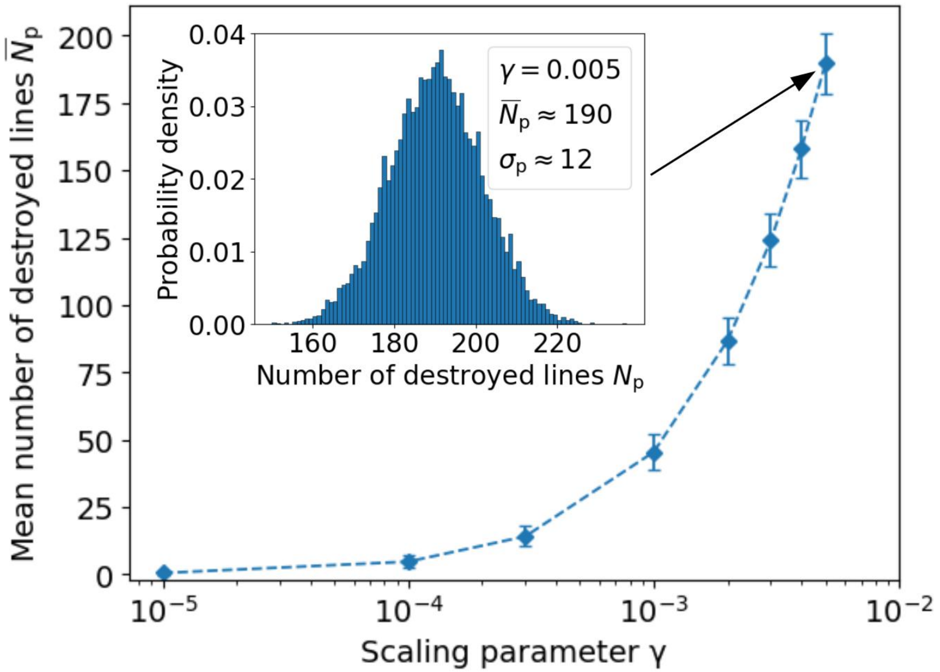

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Cascading Failures

Hurricane-induced cascading failures

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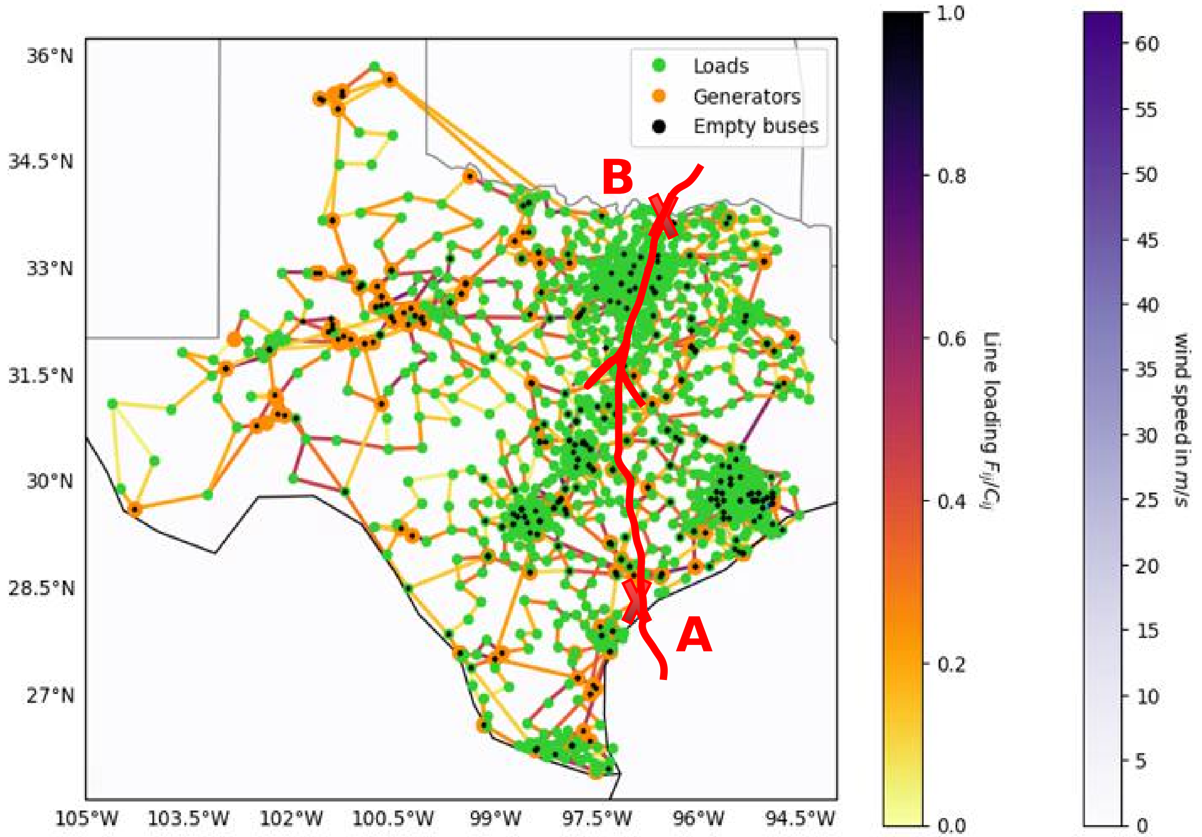
- Wind field data --> **one-hour time resolution**, ~60 hours



Hurricane-induced cascading failures

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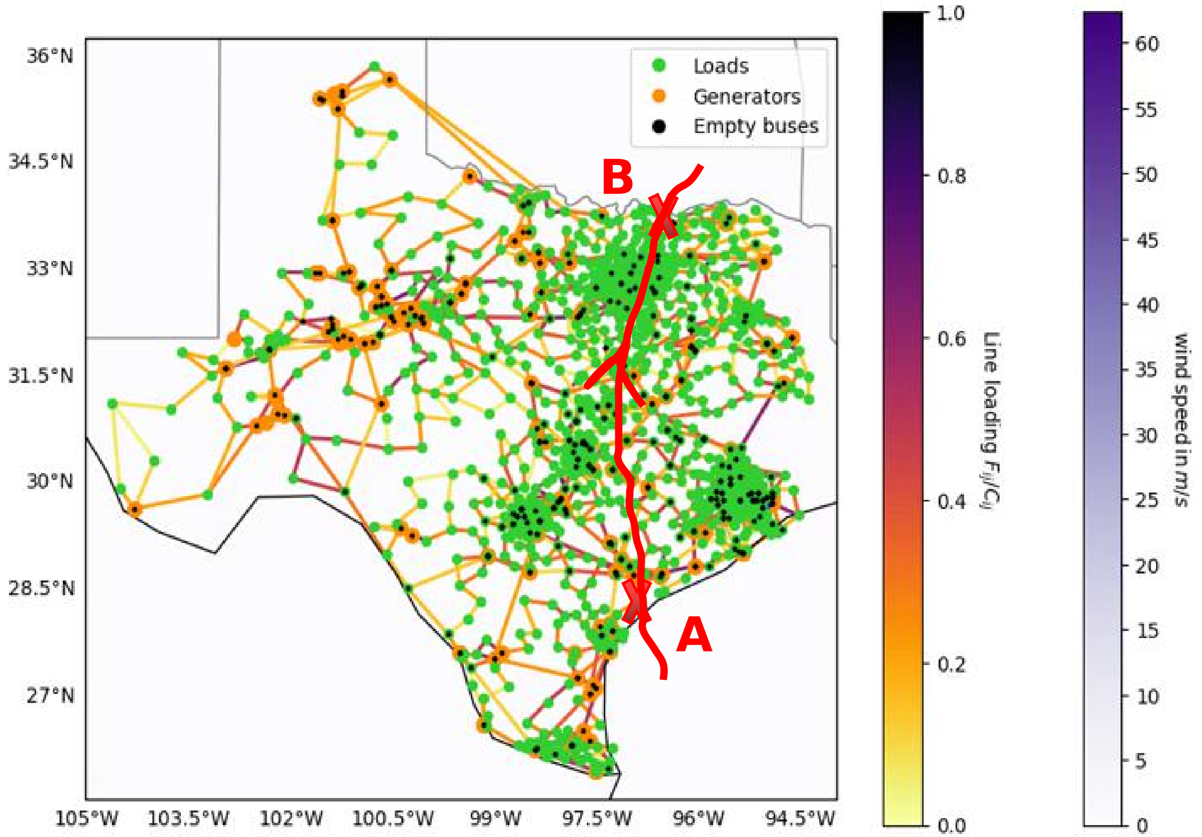
(1) Calculate wind-induced line failures in **each hour**



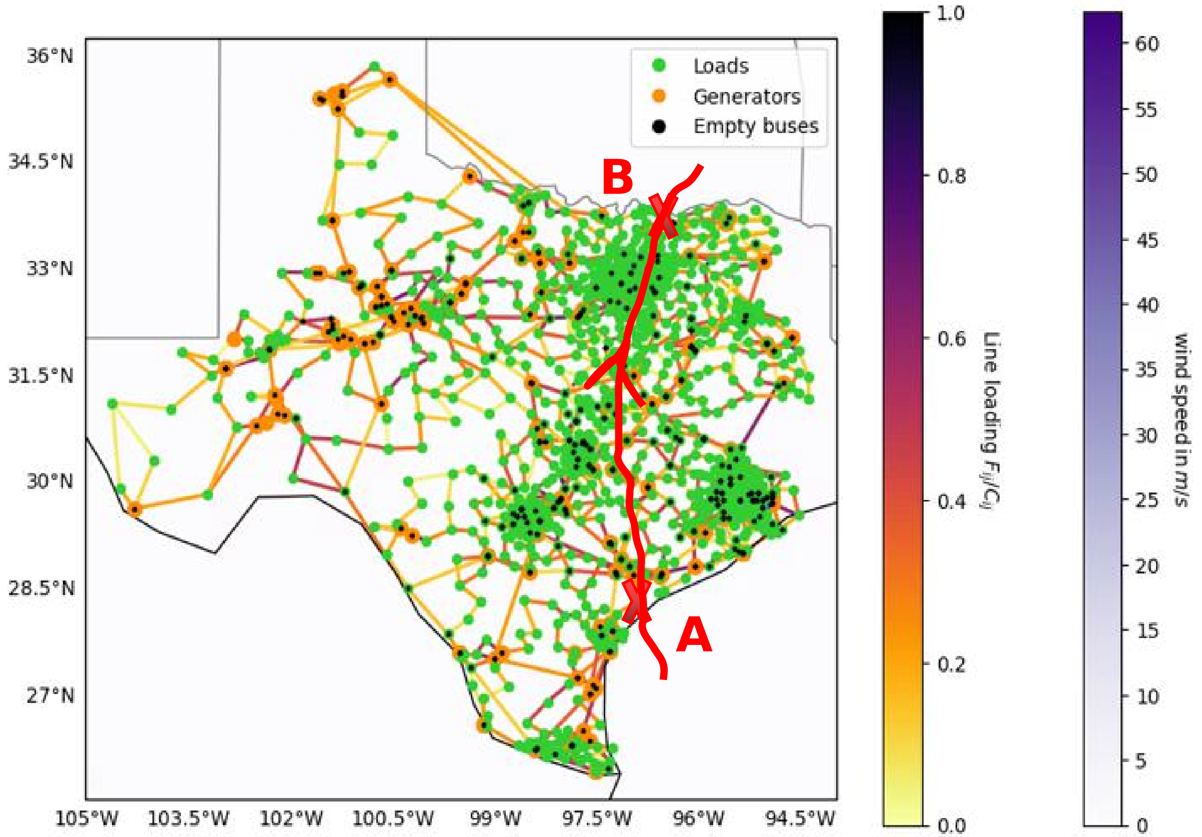
Hurricane-induced cascading failures

- Wind field data --> **one-hour time resolution**, ~60 hours

(1) Calculate wind-induced line failures in **each hour**

(2) Recalculate DC power flow & deactivate overloaded lines

(3) Repeat step (2) till there is no overloaded lines



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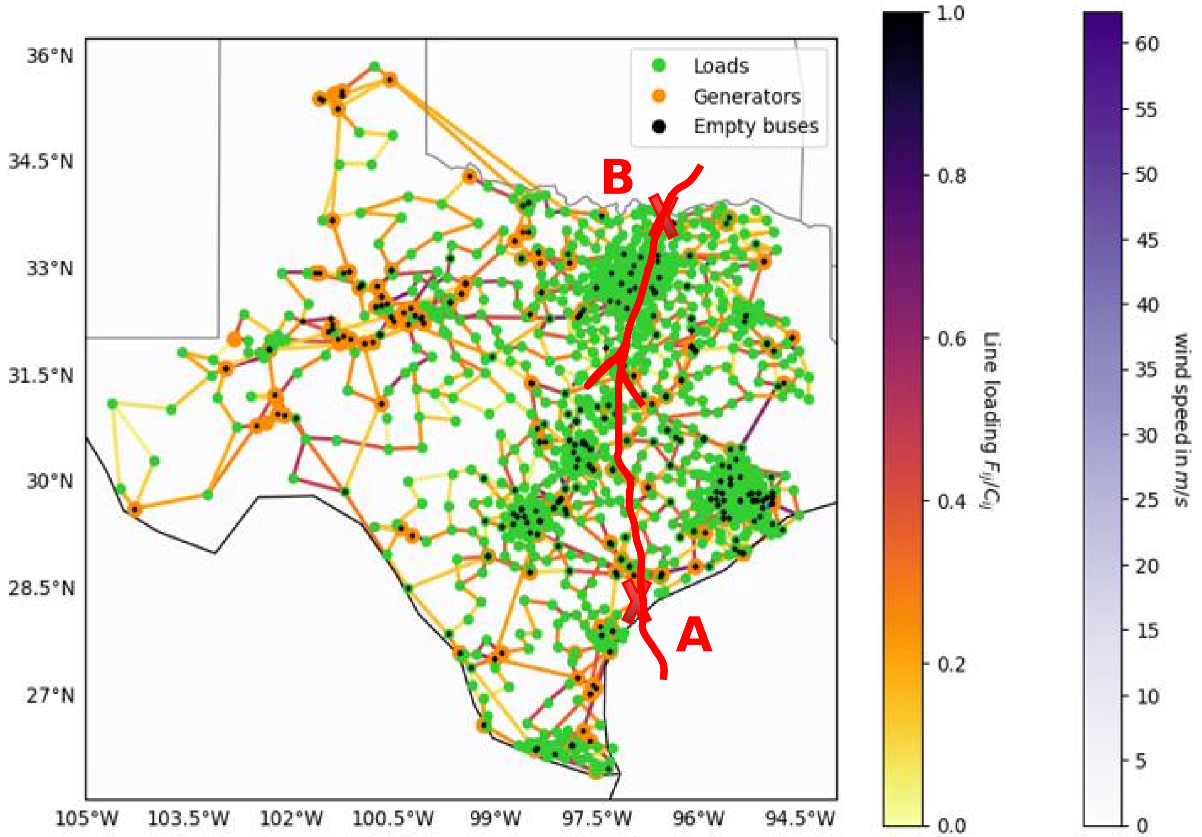
Time-scale~seconds

+ Control loop



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- Wind field data --> **one-hour time resolution**, ~60 hours

(1) Calculate wind-induced line failures in **each hour**

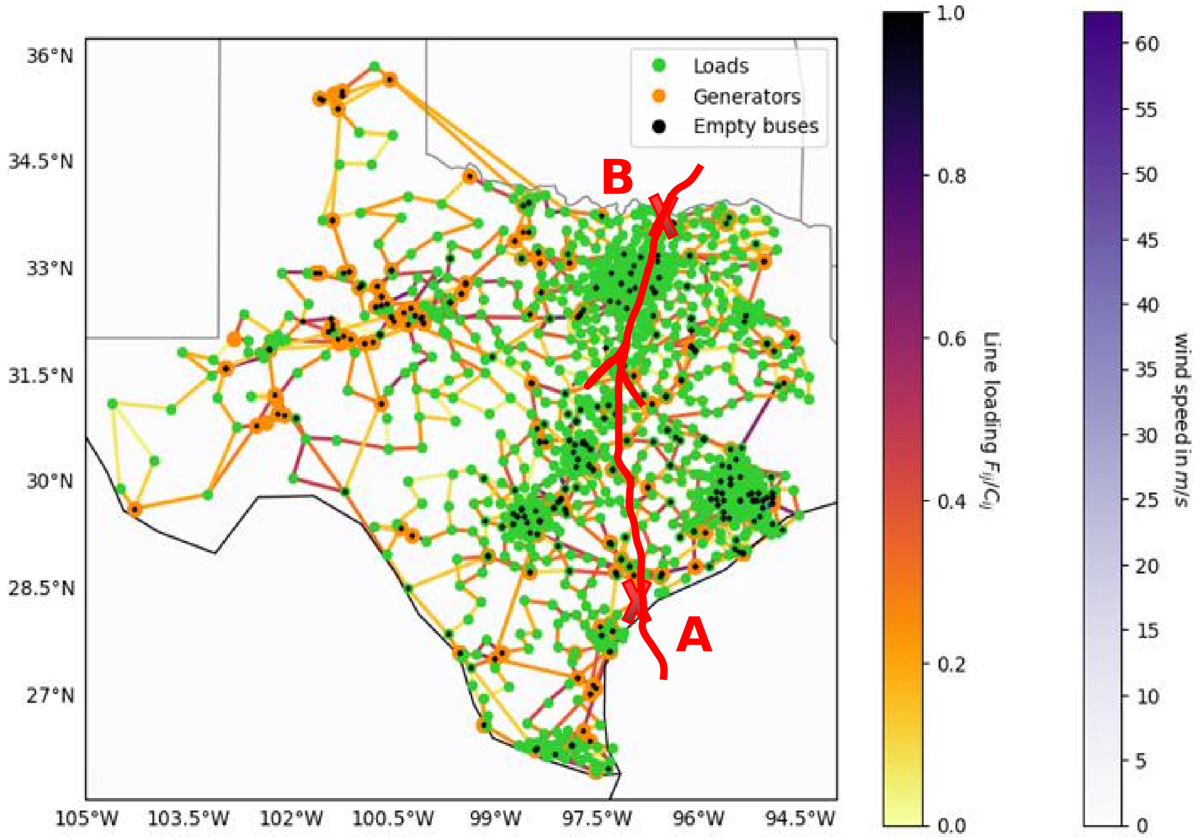
(2) Recalculate DC power flow & deactivate overloaded lines

(3) Repeat step (2) till there is no overloaded lines

Time-scale~seconds

+

Control loop



(4) Repeat steps (1) to (3) for each hour

Hurricane-induced cascading failures

- Wind field data --> **one-hour time resolution**, ~60 hours

(1) Calculate wind-induced line failures in **each hour**

(2) Recalculate DC power flow & deactivate overloaded lines

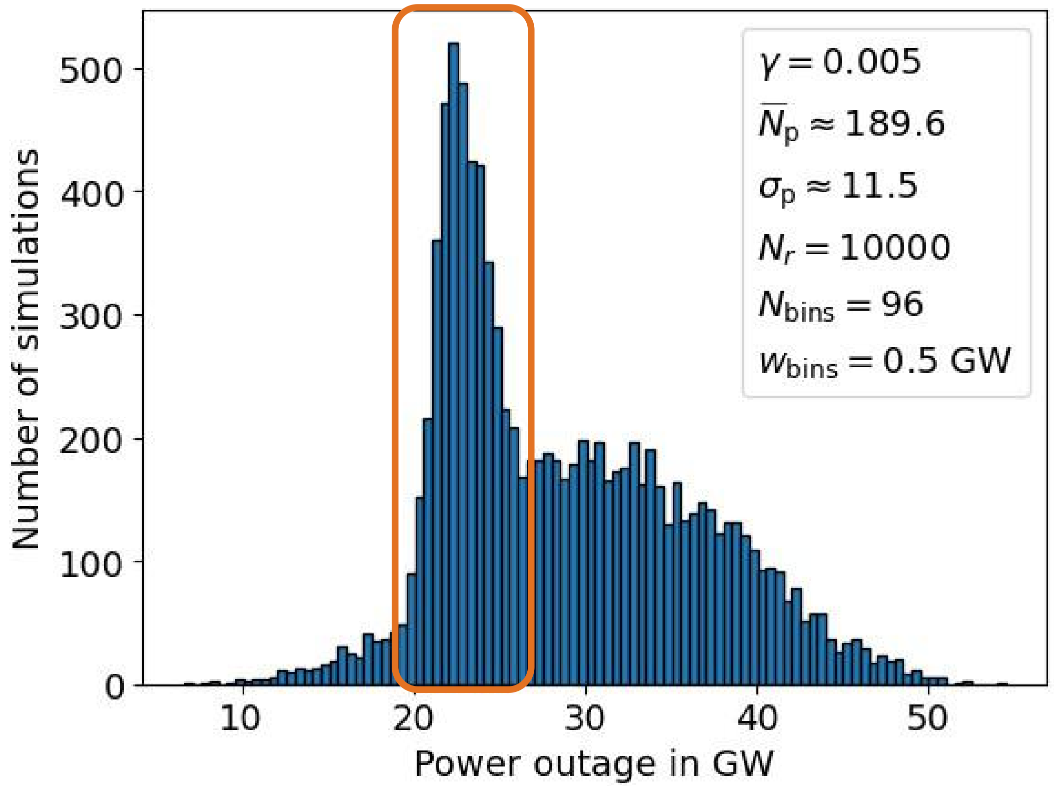
(3) Repeat step (2) till there is no overloaded lines

Control loop

(4) Repeat steps (1) to (3) for each hour

10,000 simulations

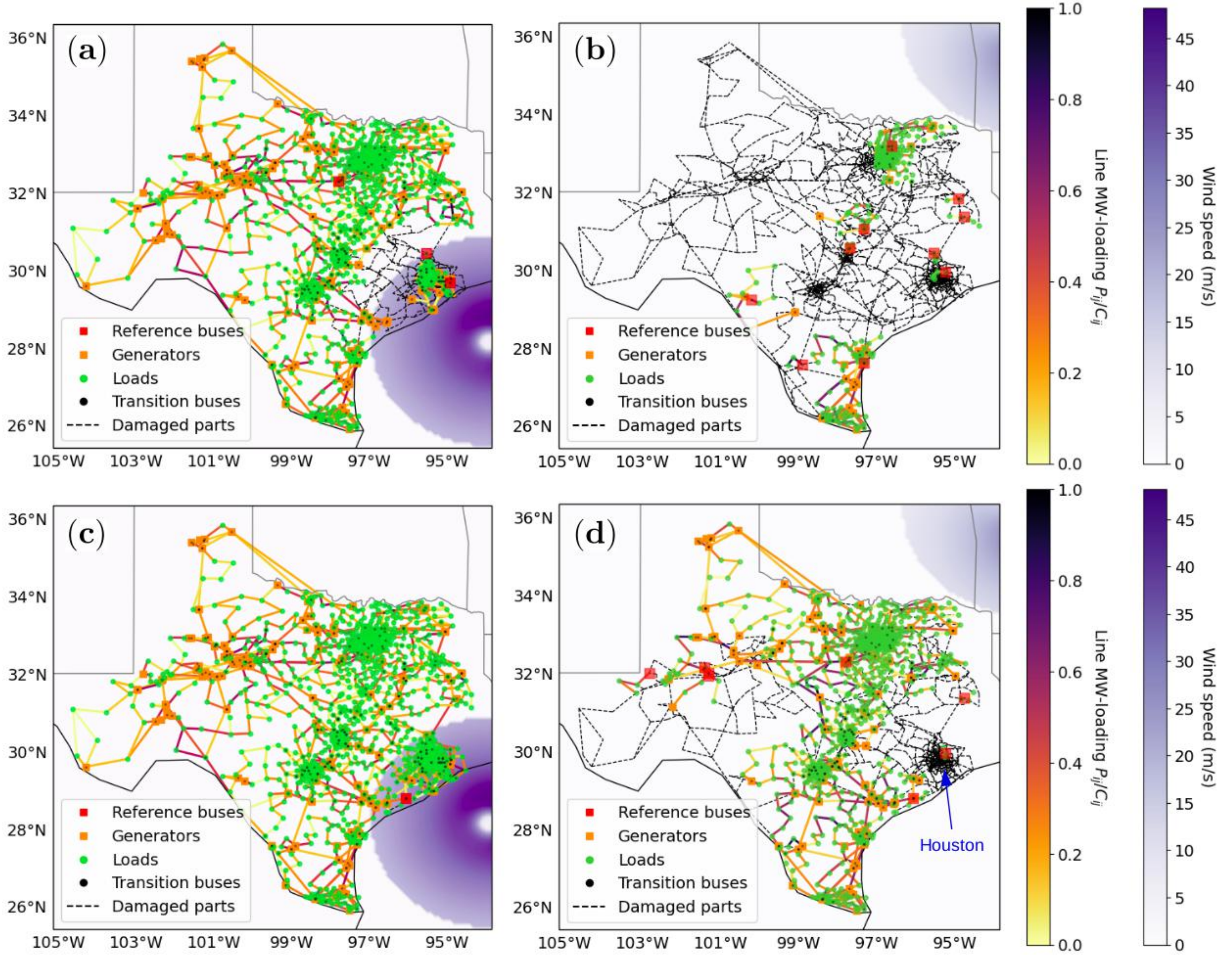
Typical scenario



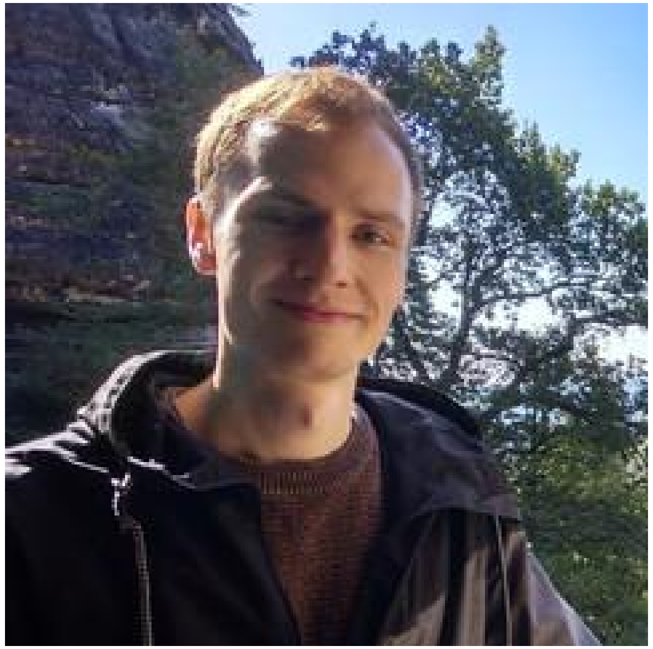
Typical and worst case scenario

Worst scenario
final loss~80%

Typical scenario
final loss~30%



Collaborators



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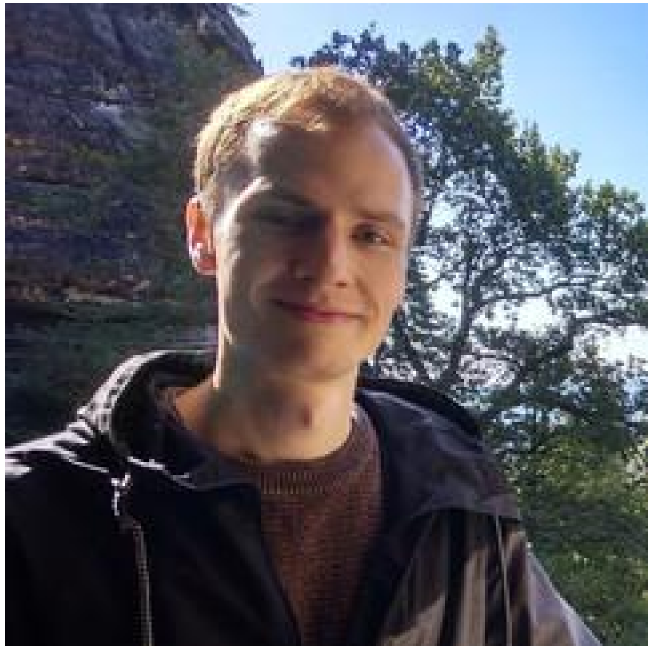
Thank you!



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