Simulating Impacts of Extreme Events on Grids with High Penetrations of Wind Power Resources

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Introduction

As extreme weather events become more frequent and intense, the demand for connecting grid operation and infrastructure planning with extreme event models will increase as well. We present a methodology for creating damage contingencies and scenarios for electric transmission grids during a hurricane strike. Using WIND Toolkit meteorological data in conjunction with fragility curves for various electric grid elements, we generate stochastic damage scenarios that can be used for short- and long-term planning problems, e.g., emergency asset management. Included is an example case study: Hurricane Dolly damaging a synthetic 2000-bus test system during its landing in Southern Texas.

Scenario: Hurricane Dolly

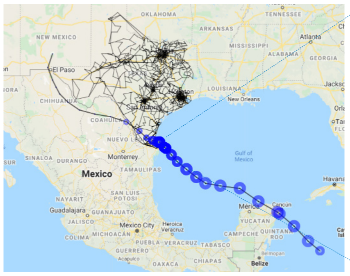


Figure 1: Path of the Hurricane Dolly (July 20 -27) and synthetic TAMU 2000 bus transmission grid. Size of the blue circles corresponds to hurricane's radii and their color intensity correspond to maximum wind speed.

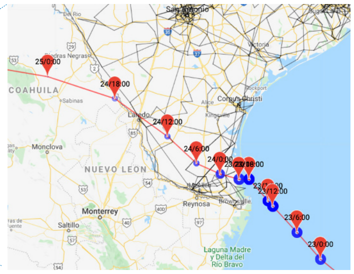


Figure 2: Landing and overland period: July 23, 00:00 – July 25, 00:00 Most damage occurs during 8-hour period: July 23, 18:00 – July 24, 02:00

Our working example includes the path of the Hurricane Dolly over a week in July of 2008 and synthetic TAMU 2000-bus grid (Figure 1 & 2). NREL's WIND Toolkit data (Figure 3) is mostly over continental Unites States, and it contains only the last 2 days of Hurricane Dolly. However, that is what we are interested in most: landing and overland period. Most of the damages occur within the first 8 hours of landing.

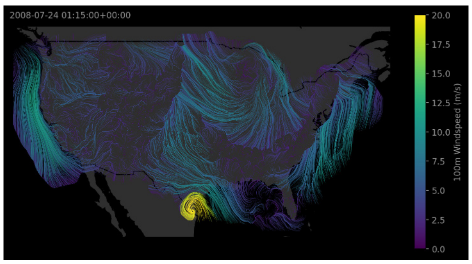
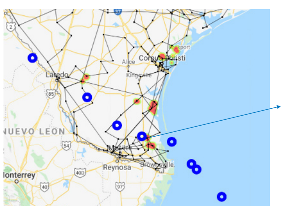


Figure 3: NREL WIND Toolkit wind field at 100m during Dolly's landing.

Fragility curves: idea via wind plant example

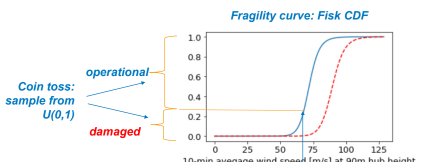


Wind plant

```
GenID                          1
GenMWMax                     200
GenMWMin                      60
GenWindPowerFactor             1
GenFuelType                 Wind
GenUID                4050_Wind_1
BusName              SEBASTIAN21
Latitude                 26.3307
Longitude               -97.5857
Zone                          19
Point      POINT(-97.5857 26.33072)
```

100 2MW turbines; toss a biased coin 100 times

Use WTK windspeed data to define biased coin



Obtain 10-min wind speed maximum

$$F(u;\alpha,\beta)=\frac{\left(\frac{u}{\alpha}\right)^{\beta}}{1+\left(\frac{u}{\alpha}\right)^{\beta}}$$

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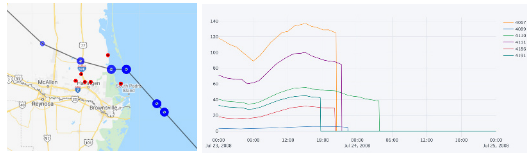
Results

Substation



1000 MC run statistics: damaged substations

Mean	Std	Max	Min
2.35	1.02	6.0	0.0

Figure 3: (left) A realization when max number of substations (6) were damaged and (right) resulting load time series at damaged substations.

Fragility curve for substations is given by $P(D > d_j|w) = \phi\left(\frac{\ln(w)-\mu_{j,k}}{\sigma_{j,k}}\right)$, where ϕ is standard normal CDF, and d_j is damage level, $\mu_{j,k}$ and $\sigma_{j,k}$ depend on terrain type and damage level.

1000 MC run statistics

Branch

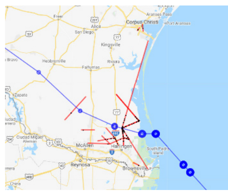


Figure 4: Realization when max number of branches were damaged. Damaged lines (red lines) and damaged poles (black dots)

1000 MC run statistics: damaged transmission

	Mean	Std	Max	Min
Poles	69.5	8.1	95	47
Branches	20.9	2.3	28	14

Fragility curve is given for transmission structures (poles) within 50 miles of Texas coast. About 2600 lines have total of ~300K poles (average distance of 0.16 km). We assume that a line is damaged if at least one pole is damaged.

Wind turbine

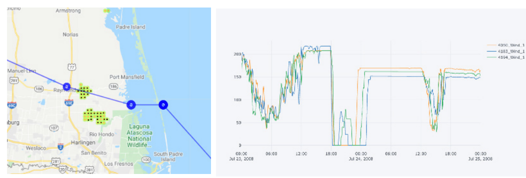


Figure 5: (left) 3 wind plants (heat map) composed of individual wind sites (eight 2-MW turbines per site). Most wind sites had at least one damaged turbine (black dots). (right) Power production at 3 damaged wind plants.

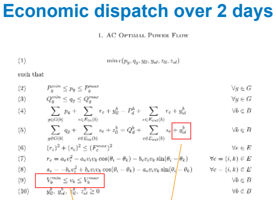
1000 MC run statistics: damaged wind turbines

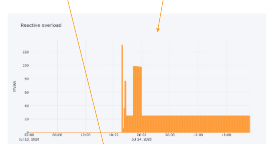
Mean	Std	Max	Min
53.4	6.5	75	34

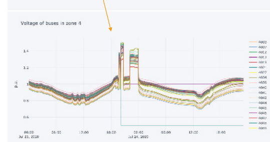
GenUID	Turbines damaged	Capacity	Capacity lost
4050_Wind_1	19	208.0	38
4183_Wind_1	33	218.0	66
4194_Wind_1	23	208.0	46

Applications

Economic dispatch over 2 days

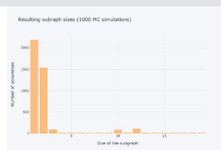




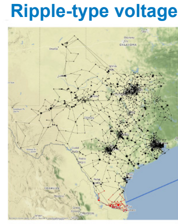


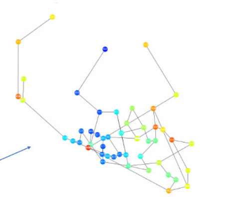
Resulting topology

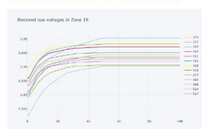
	Mean	Std
1st largest	1992.3	4.8
2nd largest	3.8	3.6
3rd largest	1.6	0.5

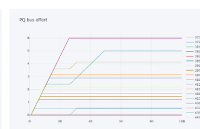


Ripple-type voltage control









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