Comments on cost, reliability, and data-driven resilience to cascading

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Cost and reliability drive the grid and its redesign in the USA

- Generation cost (includes capital cost) over lifetime as in LCOE = Levelized Cost Of Energy ($ per kWh)
- Reliability is adequacy + transmission reliability
  - Adequacy is sufficient total generation for peak load under N-1
  - Transmission/distribution reliability (N-1 for higher voltages)
Cost scaling with max power

WIND: \[ \text{LCOE} \sim (P_{\text{max}})^{-0.17} \ $/\text{kWh} \]

SOLAR: \[ \text{LCOE} \sim (P_{\text{max}})^{-0.06} \ $/\text{kWh} \]

Thanks to my student Shikha Sharma for working this out from NREL sample data in their System Advisor Model
Influences of more connectivity
(bigger microgrid or connect to grid)

More connectivity affects cost and reliability:

• Access to larger generators (scale affects costs) and better generation locations

• Access to more generators and loads
  - less local overprovision of generation (reduced cost)
  - smooth some variations
  - perturbations are relatively smaller with larger grid
  - improved reliability!

• Unreliability propagating
  - worse reliability!
  - significant power interchange couples unreliability
  - so need to monitor and mitigate cascading risk
Cascading failure is a complicated sequence of dependent outages of individual components that successively weakens the power system.

Larger cascades cause blackouts

Cascading = initiating outages + propagating outages
Traditional bottom-up approach to risk-based grid reliability for dependent events

• make model of one type of interaction mechanism (usually steady state Markov Chain for up/down of components)
• seek data for model parameters

Advantage: understanding mechanism enables mitigation
Disadvantage: data sought but not found
Complementary top-down approach to grid reliability for cascading events

- Cascading is a complicated series of dependent events; many mechanisms
- Start from existing utility data; ignore detailed mechanisms
- Develop high-level probability models that can be estimated from the data such as branching processes
- Model parameters such as average propagation that are metrics of cascading and grid resilience
- Monitor average propagation and relate to risk
- Work out how to limit average propagation to improve resilience and mitigate risk
Quantifying typical cascading from TADS data

- TADS = Transmission Availability Data System; Standard outage data that is reported to NERC
- Automatic line outages can be grouped into initial outages and generations of propagating outages
- Can estimate average propagation, which is the average number of “children outages” per “parent outage”. For example, each line outage produces on average 0.25 line outages in next generation.
- Average propagation is a metric of resilience
- Uses a validated branching process model

Dobson, IEEE Trans power systems Nov 2012
Probability distribution of total number of line outages assuming 5 initial line outages

Predicting cascading failure extent from average propagation in utility data,
Real data on cascading line outages spreading in power grids

• Also uses the standard utility TADS data
• Solved the problem of locating the outages on a grid consistent with the outages
• Now we can see cascades spreading and learn about their spatial statistical properties
  - get typical statistics, not just the worst cases!
• Of course, cascading line outages do not mainly spread along the physical transmission network
  Actual grid is not the graph describing interactions
Utility network that is consistent with TADS data
For this cascade, red lines outage in order shown by the generation numbers
Example of real cascade statistics: distribution of number of “hops”
Some directions opened up by data-driven cascading analysis

• Validate cascading models and simulations
• Start disentangling how cascades spread top-down from the data – can we discriminate classes of mechanisms?
• Identify critical interactions from data? Formulate “causes” of cascading to aid effective mitigation?
• Verify grid performance from observed outages (any new technology fairly or unfairly associated with large blackouts will be curtailed)
Worst case cascading: for example, 
Sequence of outages in Western blackout, July 2 1996

from NERC 1996 blackout report