Impact of Initial Stressor(s) on Cascading Failures in Power Grids

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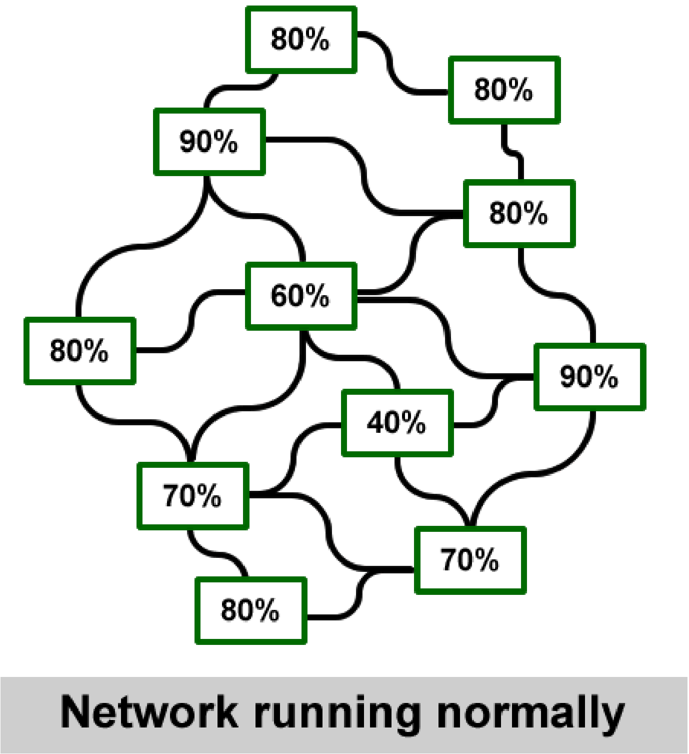
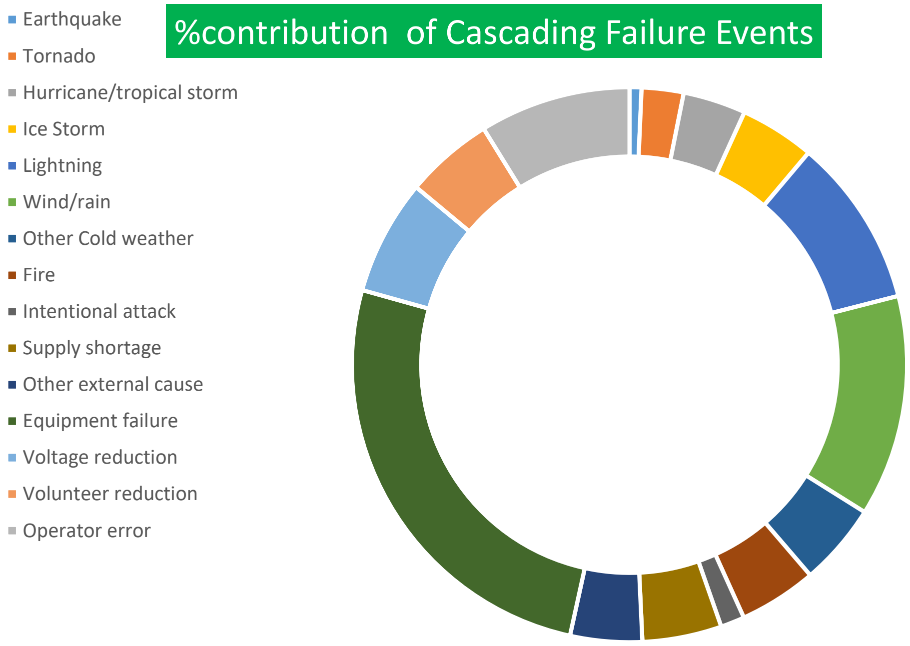
Cascading Failures in Power Grid : Overview

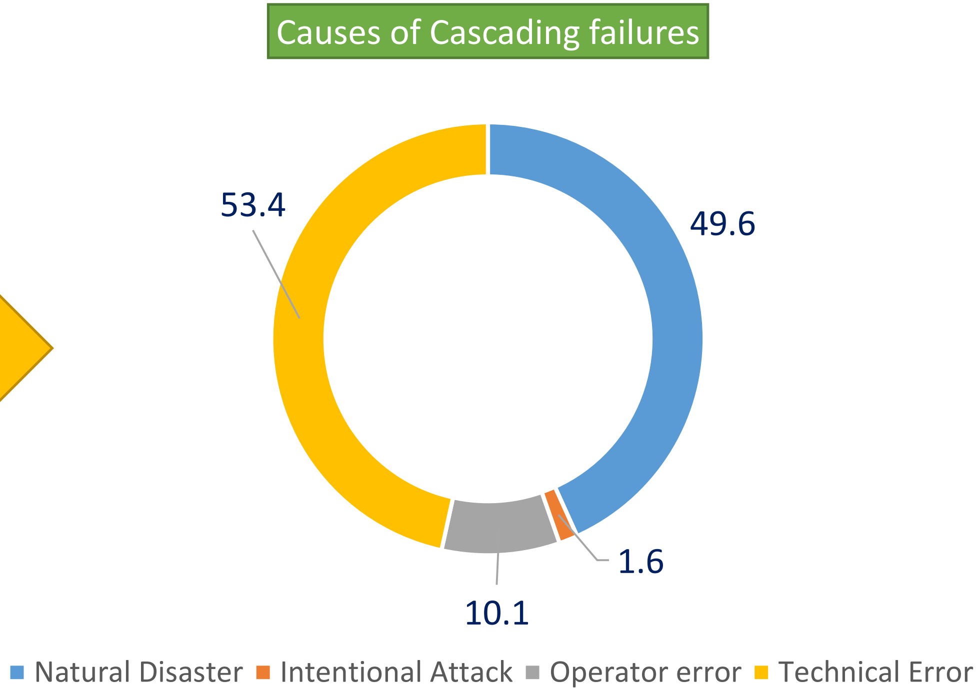


Source: Wikipedia

one of the elements fails (completely or partially) → shifts its load to nearby elements in the system → nearby elements are then pushed beyond their capacity → become overloaded and shift their load onto other elements → Cascading chain of event starts and can lead to system blackout

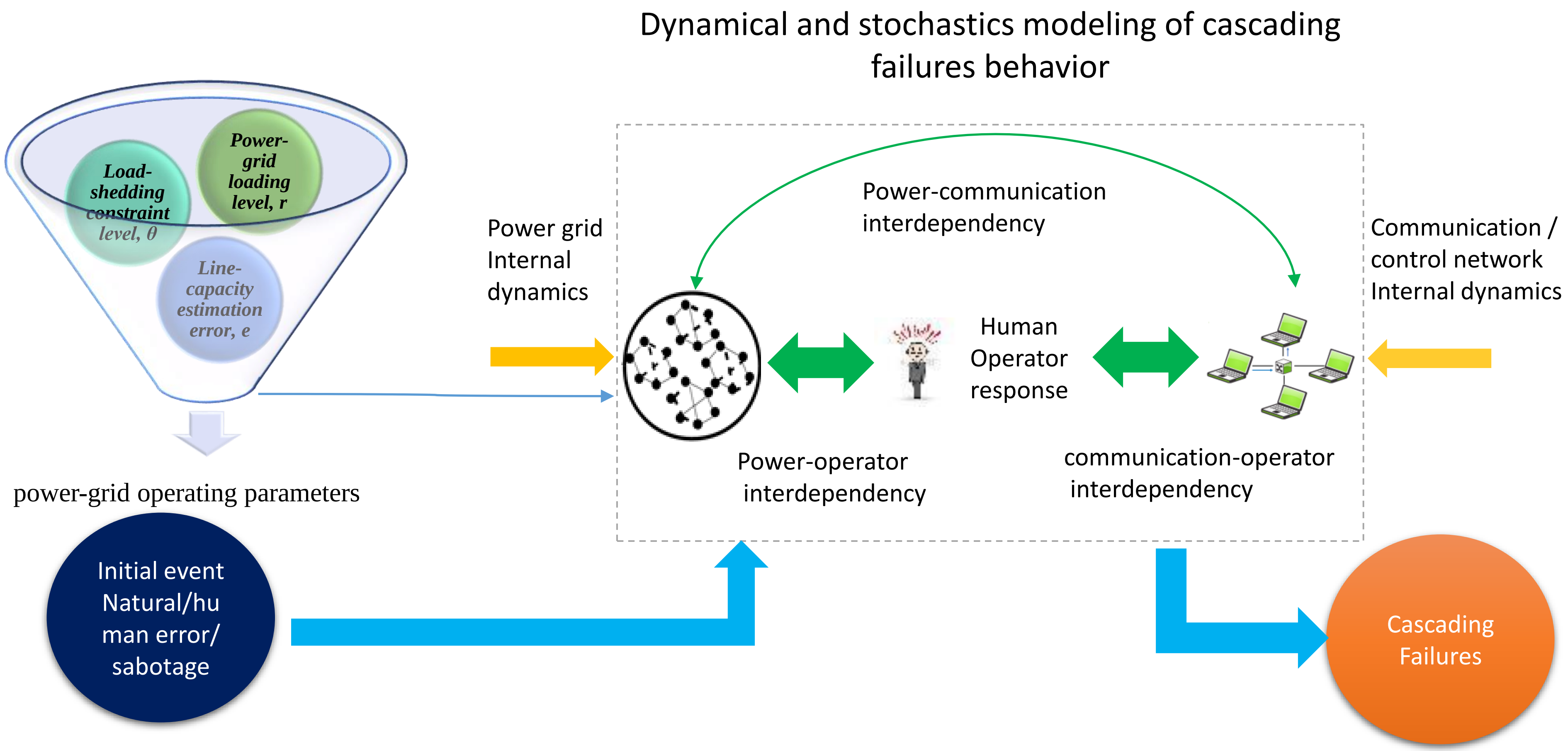
Cascading Failures in Power Grid : Causes





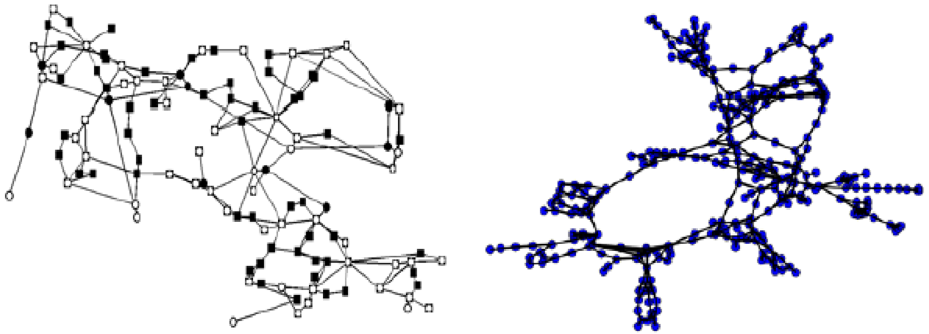
Hines, Paul, Jay Apt, and Sarosh Talukdar. "Trends in the history of large blackouts in the United States." *Power and Energy Society General Meeting-Conversion and Delivery of Electrical Energy in the 21st Century, 2008 IEEE*. IEEE, 2008.

Overview of the cascading failure dynamics



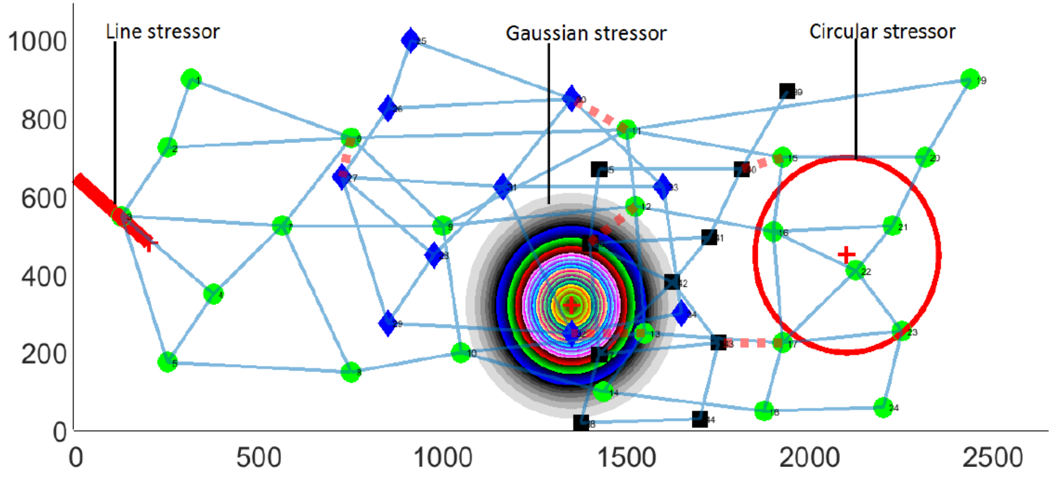
Contribution of Our Work

- In this Work, we modeled and then analyzed the impact of Initial Stressor(s) i.e., disaster events on Cascading Failures in Power Grid



(a) IEEE 118-bus topology (b) IEEE 300-bus topology

Stressor(s)



- Multiple stressor events can occur in one geographical location, or they can spread over different geographical areas and initiate initial failures in power grid.
- These initial failures can range from natural disasters (e.g., tornado, cyclone, earthquake) to intentional human-made attacks (e.g., use of weapons of mass destruction(WMD), High altitude electromagnetic pulse (HEMP), cyber-attack in the communication layer of the power grid).
- We consider 3 major types of stressor which covers most of the physical initial events:

Gaussian stressor	Circular Stressor	Line stressor
Intensity degrades with Ae^{-x^2}	Intensity degrades with A/r^2	Intensity remains same

Modeling Stressor(s) Events

- Transmission-line failure probability for a single stressor event:

Where,

- Stressor(s) event, W
- Stressor intensity, $I_w(x_i,y_i)$
- Transmission-line failure probability, $p((B_i,B_j)|W)$
- (B_i,B_j) is a transmission line
- B_i is a bus
- We assume the attack intensity is a discrete-time short pulse not continuous in time.

- And transmission-line failure probability for multiple stressor events occurring at the same time is

$$p(((B_i,B_j)|W) = min(\max_{k\in 1,\ldots,N(B_i,B_j)} I_w(x_k,y_k),1)$$

$$p((B_i,B_j)|W=(w_1,\ldots,w_L)) = min((\sum_{i=1}^{L}\max_{k\in 1,\ldots,N(B_i,B_j)} I_{w_i}(x_k,y_k)),1)$$

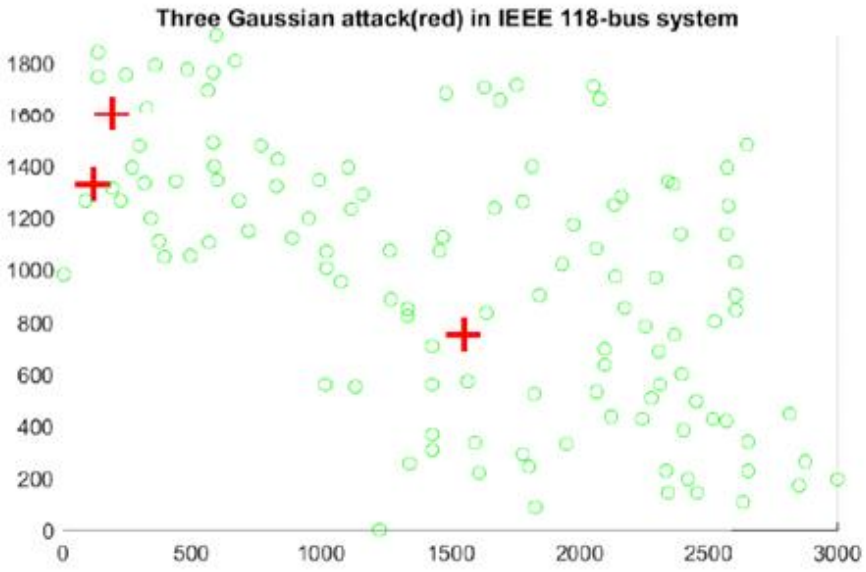
Modeling Stressor(s) Events

- Similarly Node/Bus failure probability, $p((B_i)|W)$:

$$p((B_i)|W = (w_1, ..., w_L)) = min((\sum_{i=1}^{L} I_{w_i}(x_k, y_k)), 1)$$

- We consider that initial failures of a network component does not depend on other components. Then, the joint failure probability of power grid transmission line due to stressor(s) event can be represented using the product of their individual failure probabilities.

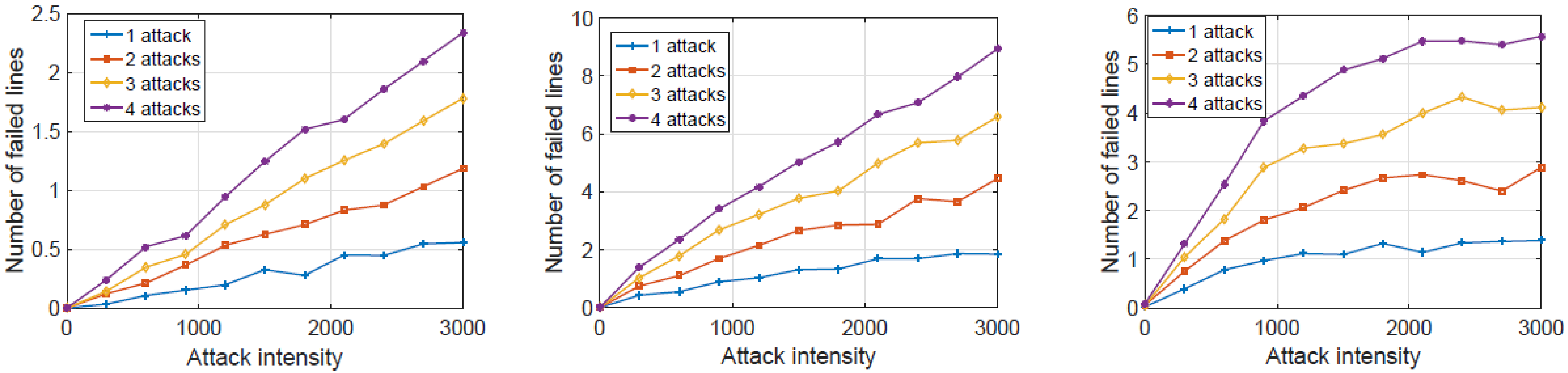
$$p(((B_1, B_2), ..., (B_{N-1}, B_N))|W) = \prod_{(B_i,B_j)\in V} p((B_i, B_j)|W),$$



Gaussian stressor(s) were simulated for 100 times in IEEE 118-bus topology.Single or multiple stressors contributing three intitial transmission lin failures were considered. Stressor points were chosen randomly over the topology.

Simulation Set-Up

- Used the model for transmission-line failure probability due to a stressor event
- we did Monte-Carlo simulation over the IEEE 118-Bus and IEE-300Bus topology for stressor(s) event (gaussian, circular and line) with certain intensity and measure individual line failure probability.
- We consider a line is failed if the probability exceeds certain threshold

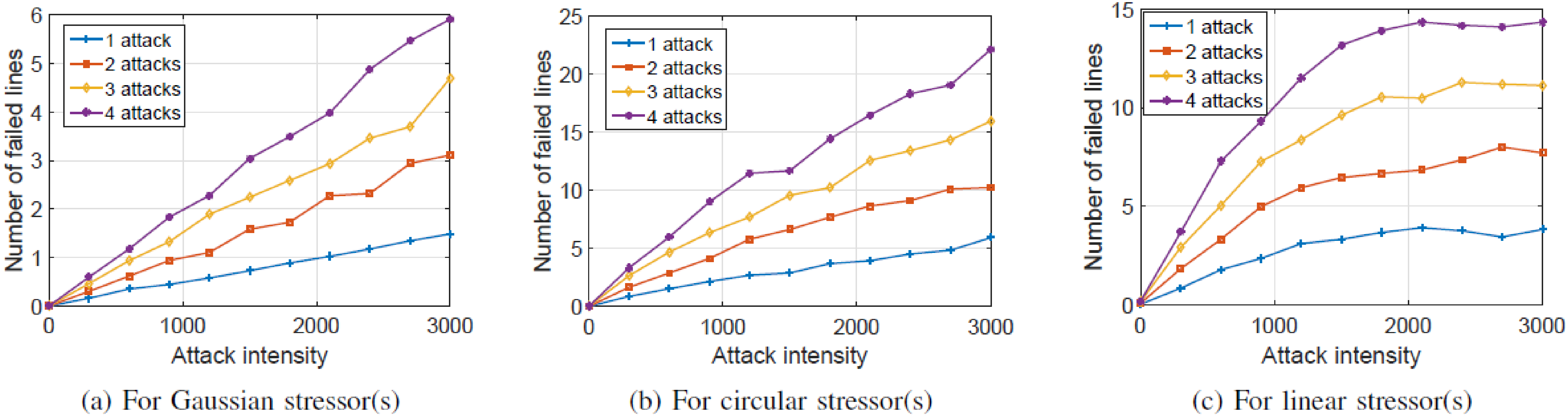


(a) For Gaussian stressor(s) (b) For circular stressor(s) (c) For linear stressor(s)

Average number of failed transmission lines in IEEE 118-bus topology due to to Gaussian, circular and linear stressor(s) with various intensities.

Impact of Stressor events (IEEE 118-Bus)

- Number of line failure increases with number of attack and attack intensity
- Circular attack is the most devastating among the three types

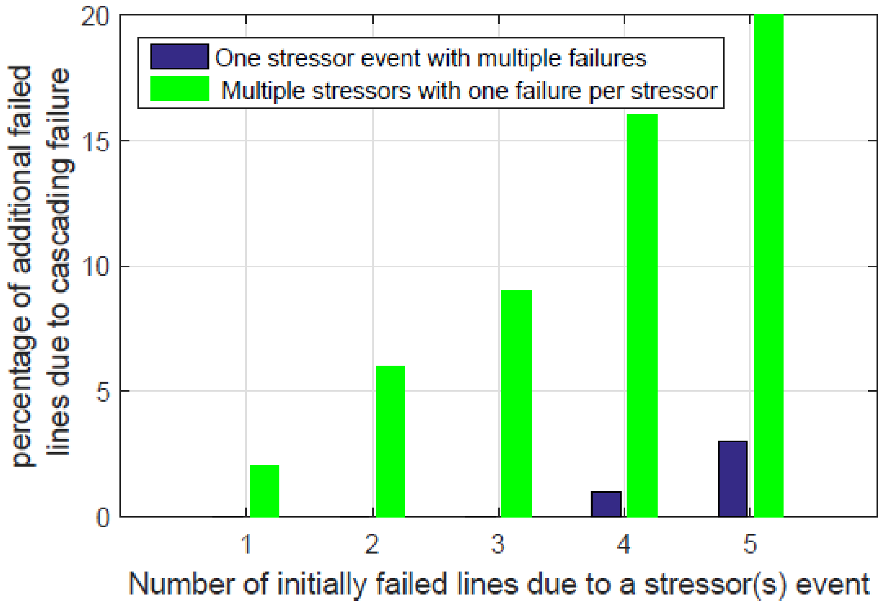


Average number of failed transmission lines in IEEE 300-bus topology due to to Gaussian, circular and linear stressor(s) with various intensities.

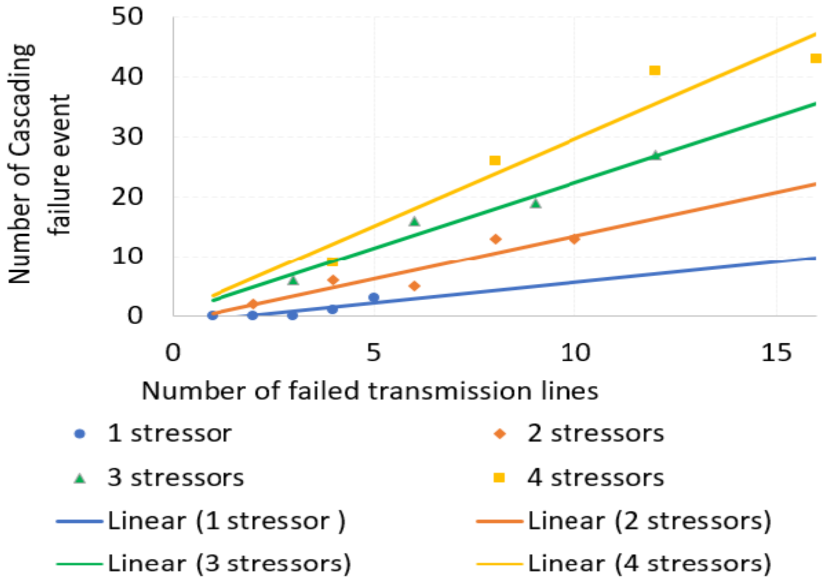
Impact of Stressor events (IEEE 300-Bus)

- Number of line failure increases with number of attack and attack intensity
- Circular attack is the most devastating among the three types

Impact of stressor(s) event on cascading failures

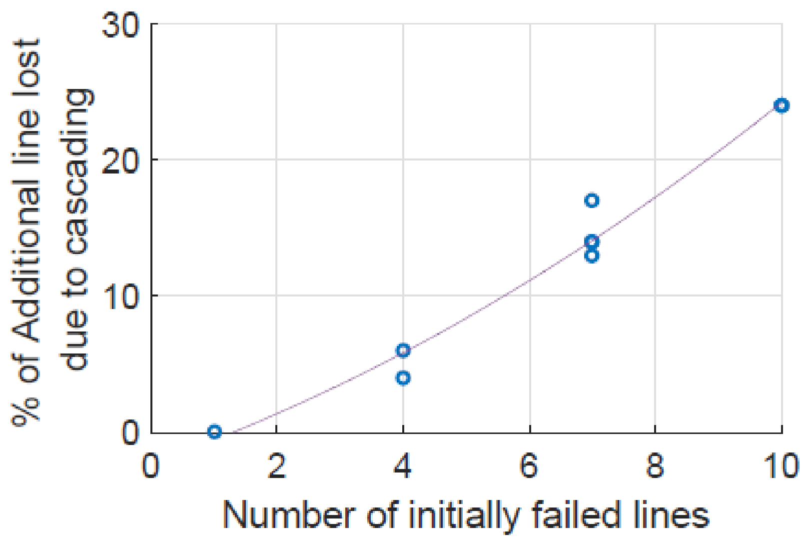


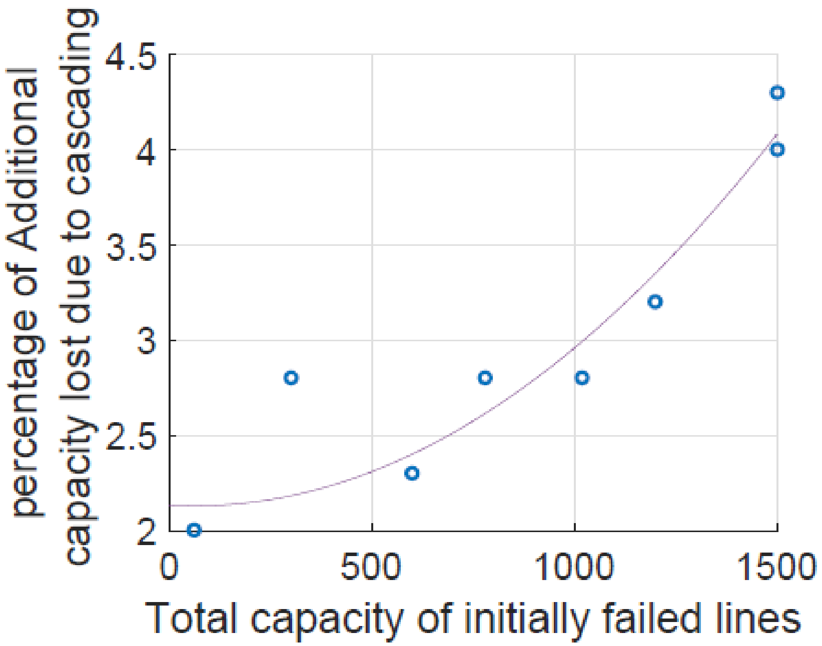
Number of failed transmission lines when one stressor location with multiple failures (blue) and considering randomly distributed failed transmission lines (green) where a stressor event contribute one transmission- line failure (we pick the line with maximum intensity to fail).



Number of cascading failure event in power grid with different number of attack points and number of transmission line failures.

Analysis on Cascading Failures



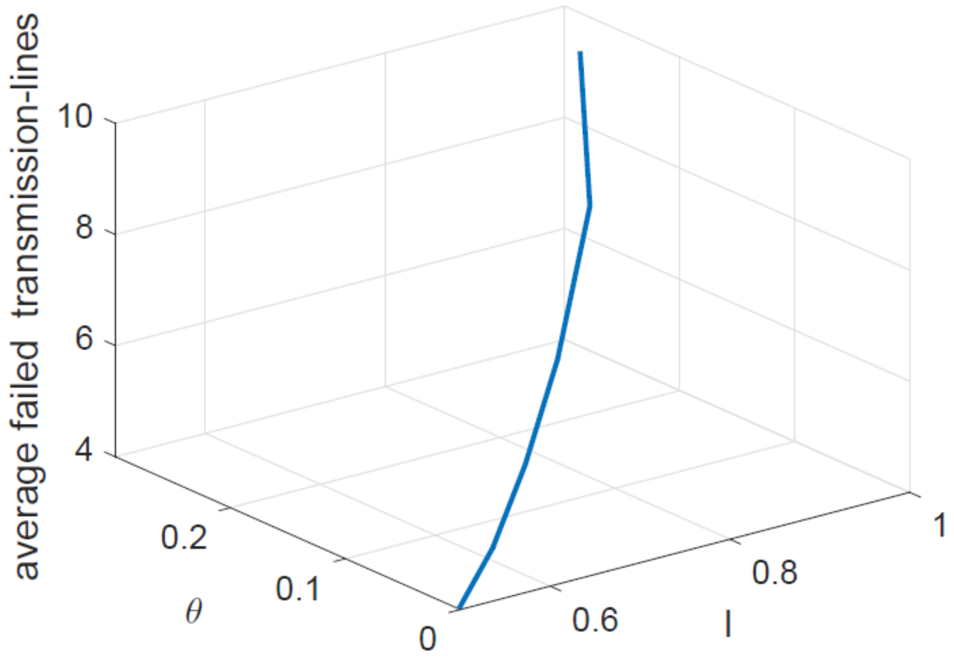


- Relationship between number of initially failed transmission line due to a stressor event with percentage of additionally failed lines due to cascading when the total capacity of the failed transmission lines are fixed, and the total capacity of the initially failed transmission lines with additional capacity lost due to cascading when the number of the failed transmission lines are fixed.

Impact of power grid parameters

- Dependence of the average number of failed transmission
lines on power grid operating parameters (l and theta).

- Clearly, increasing power grid loading and constraint on load shedding increases the average number of failed transmission lines



Conclusion

We have shown:

- The impact of stressor(s) events on cascading failure in power grid.
- impact of attack intensity (mapped to initial line failure) on percentage of additional transmission-line and capacity lost due to cascading failure
- The impact of r, theta on cascading failure in power grid.
- All these initial conditions eventually determine the blackout size during a cascading event.

- Future works may include:
- Analyzing the time continuous attack in a geographical location.
- An analytical cascading failure model that captures attack intensity into state transitions of a Markov Chain along with operating parameters

Thank you for your Attention

Questions?