Combat the Disaster: Communications in Smart Grid Alleviate Cascading Failures

Mingkui Wei and Wenye Wang
Department of Electrical and Computer Engineering
NC State University

Presented by Dr. Wenye Wang

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Outline

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Cascading Failures in Power Grids

Cascading Failures

- Large system outage caused by spread of small scale failures.
- Can result in huge cost to human societies.

Figure: 2003 US & Canada Blackout: more than 60 million people were impacted[1].

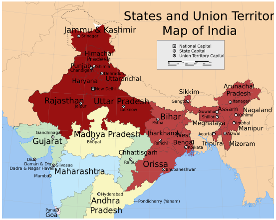

Figure: 2012 Indian Blackout: over 600 million people were without power[1].

[1]Wikipedia: Northeast blackout of 2003 & 2012 India blackouts.

Smart Grid vs. Cascading Failures

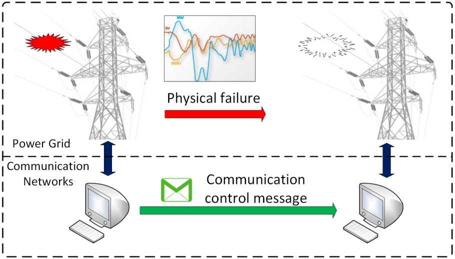

Figure: Cyber and physical domain of a typical smart grid

Smart grid helps on alleviating cascading failures

- Power devices are able to exchange status information via communication networks.
- Reactions can be taken right before a physical failure propagates and causes new damage.

Questions and Challenges

Research questions

How and to what extent can smart grid help in alleviating the aftermath of a cascading failure?

- Industry: Cost and benefit trade-off.
- Academia: Allocation of research resources and efforts, etc.

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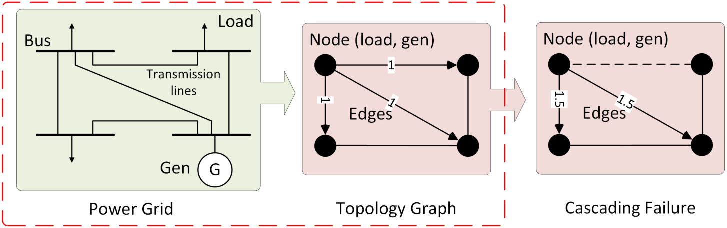
Challenges

1. A set of metrics which numerically and precisely profile a cascading failure;
    - Space, time, and scale.
2. A cascading failure model which reflects those metrics.
    - A cascading failure model built in real-time simulator.

Outline

Related Works



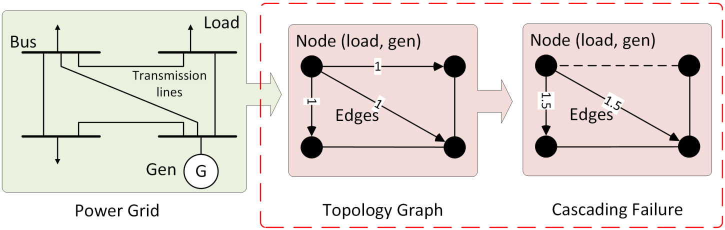
Topology based modeling

- Complex network: Node degree, Betweenness (P. Holme 02').
- AC and DC power flow model: actual load and power flow (I. Dobson 01', 02', 06').

Overload based assumption

- Failure initiation: removal of nodes or edges.
- Failure propagation: "load" redistribution.

Related Works



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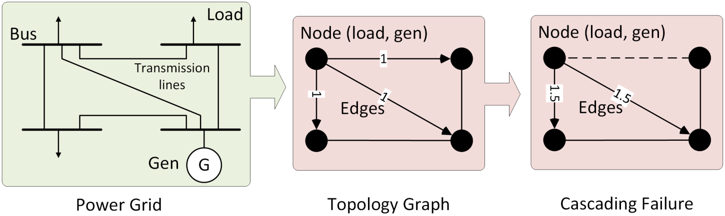


Shortages in existing models

1. Unable to depict time: graphs are timeless.
2. Does not cover other failure types, in particular, overcurrent.
   - Large blackouts are usually caused by significant current disturbance (S. Mei 11', NERC Steering Group 04').
   - Overload is a phenomenon which is caused by overcurrent.
3. Because of above, it is hard to know *exactly* when (temporal) and where (spacial) the failure propagates.

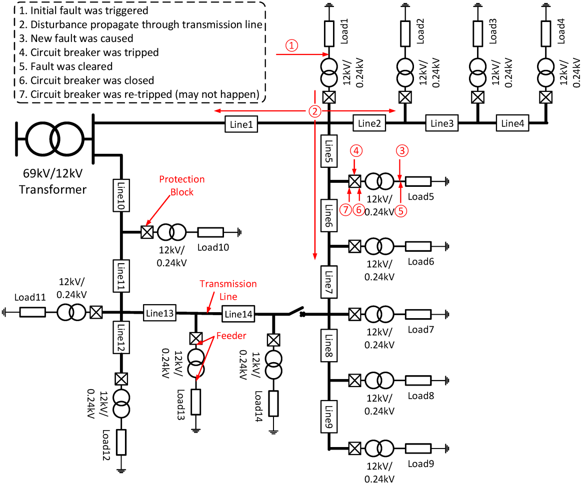
Outline

Cascading Failure Modeling

Highlights

1. Built in PSCAD, a real-time power system simulator, such that temporal feature can be captured.
2. Assume *overcurrent* is the cause of cascading failure, which covers failure causes more comprehensively.
3. Mimic the reactions of real relays and circuit breakers, which provides more practical suggestions.

Cascading Failure Model Example

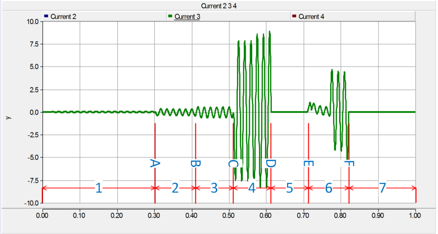


- *Green Hub*, developed in FREEDM Center, NCSU.
- Each step is modeled and detailed definition can be find in paper.

Outline

Simulation Setup

Example of fault propagation process



1: Normal operation.

2: Fault current arrives.

3: T_{flt}: Line will fault after this time.

4: T_{brk}: Circuit breaker reaction time.

5: T_{rc} + T_{clr}: Fault clear and circuit breaker re-close after this time.

6: T_{rt}: Circuit breaker re-trip after this time.

[2] *Dist System Feeder Overcurrent Protection*, www.geindustrial.com

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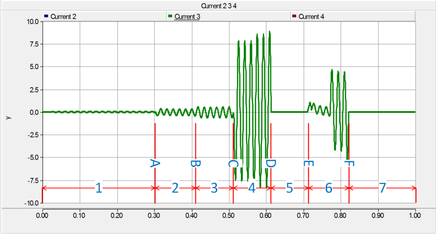

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Simulated parameters in this paper [2]

Par	Value	Range during simulation
C_t	250 A	na
T_{flt}	0.1 sec	0.05sec - 0.2sec, with 0.01sec step
T_{brk}	0.1 sec	0.03sec - 0.10sec, with 0.01sec step
T_{clr}	0.05 sec	na
T_{rc}	0.1 sec	na
T_{rt}	0.1 sec	na

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Simulation Results

Parameter Snapshot

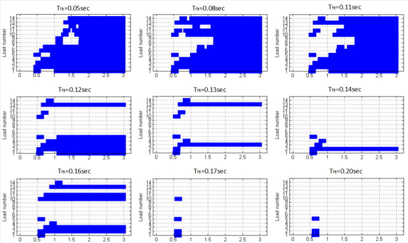


Figure: T_{flt}: 0.05 - 0.20 (sec) [3].

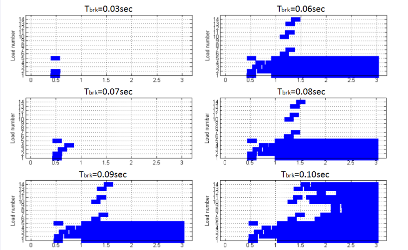


Figure: T_{brk}: 0.03 - 0.12 (sec) [3].

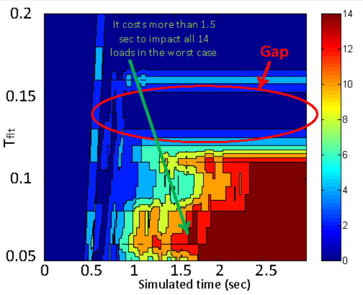
Insights:

- Minute parameter calibration causes significant system change.
- Long tail: some loads are always impacted (closet ones).
- Scale does not change monotonically with parameter.

[3] Note: it is assumed load 1 is the initial failure in all simulations.

Simulation Results

Parameter Contour



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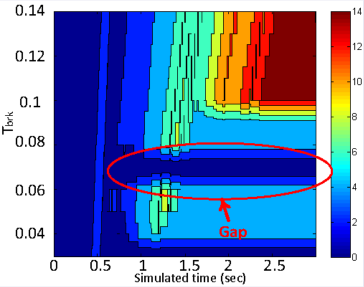

Figure: T_{brk}: 0.03 - 0.12 (sec).

Suggestions:

- A robust system scheduling and calibration is imperative.
- A sub-optimal solution is much easier to achieve.

Simulation Results in Smart Grid

Smart grid assumptions

- Loads are able to send event messages to their neighbors.
- Neighbors change from "delayed trip" to "instant trip" ($T_{brk} = 0$).

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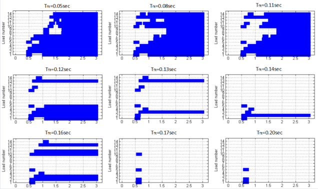

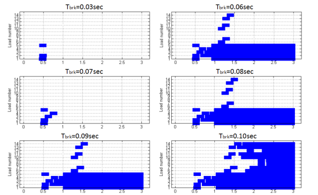

- Load 2 and load 5 are always impacted by load 1.

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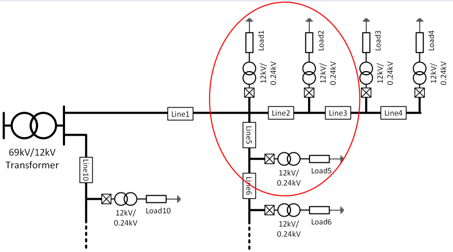
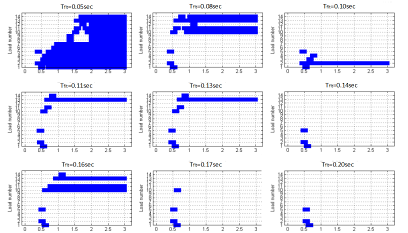
Simulation setup



- They are direct neighbors of load 1, and will be informed by load 1 of it's fault.

Simulation Results

Parameter Snapshot



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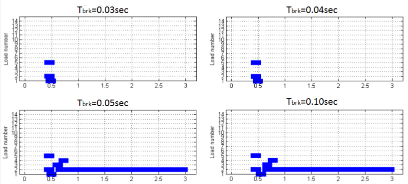

Figure: T_{brk}: 0.03 - 0.12 (sec).

Insights:

- Communication is able to greatly reduce the consequences of a cascading failure.

Simulation Results

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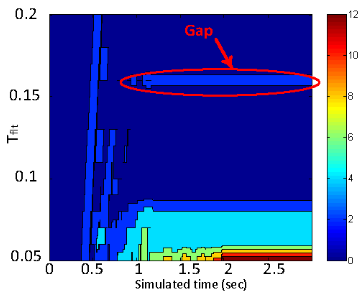

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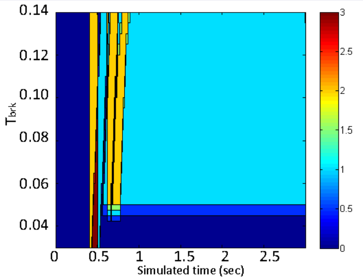

Figure: T_{brk}: 0.03 - 0.12 (sec).

Suggestions:

- Simple communications between limited devices could significantly enhance system stability.

Outline

Conclusion

A new cascading failure model

- Built in real-time power system simulator such that temporal and spacial features of cascading failure can be depicted.
- Assume *overcurrent* as the cause of failure, which covers more comprehensive types of failures.
- Model fault management reactions following real power devices which provides more practical suggestions.

Conclusion

A new cascading failure model

- Built in real-time power system simulator such that temporal and spacial features of cascading failure can be depicted.
- Assume *overcurrent* as the cause of failure, which covers more comprehensive types of failures.
- Model fault management reactions following real power devices which provides more practical suggestions.

Simulations in communication enabled smart grid

- Endorse smart grid's benefit by showing that even a simple communication between limited power devices can significantly enhance power system stability.

Questions?