Introduction to Electric Power Systems
Lecture 14
Contingencies and Blackouts

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Disclaimer

This lecture is a work in progress. The purpose of this lecture is to apply the intuitions we have developed in this class to real-world scenarios. Inevitably, this will result in oversimplifications of the scenarios. The purpose of these simplifications is not to cast doubt on past grid operation decisions for specific events which were made in real time based on imperfect information. Rather, the purpose is to develop intuition for the phenomena that underly automated grid actions and human operator decisions. Perhaps the best way to learn about grid operation is to study circumstances in which things went wrong.

1 Background

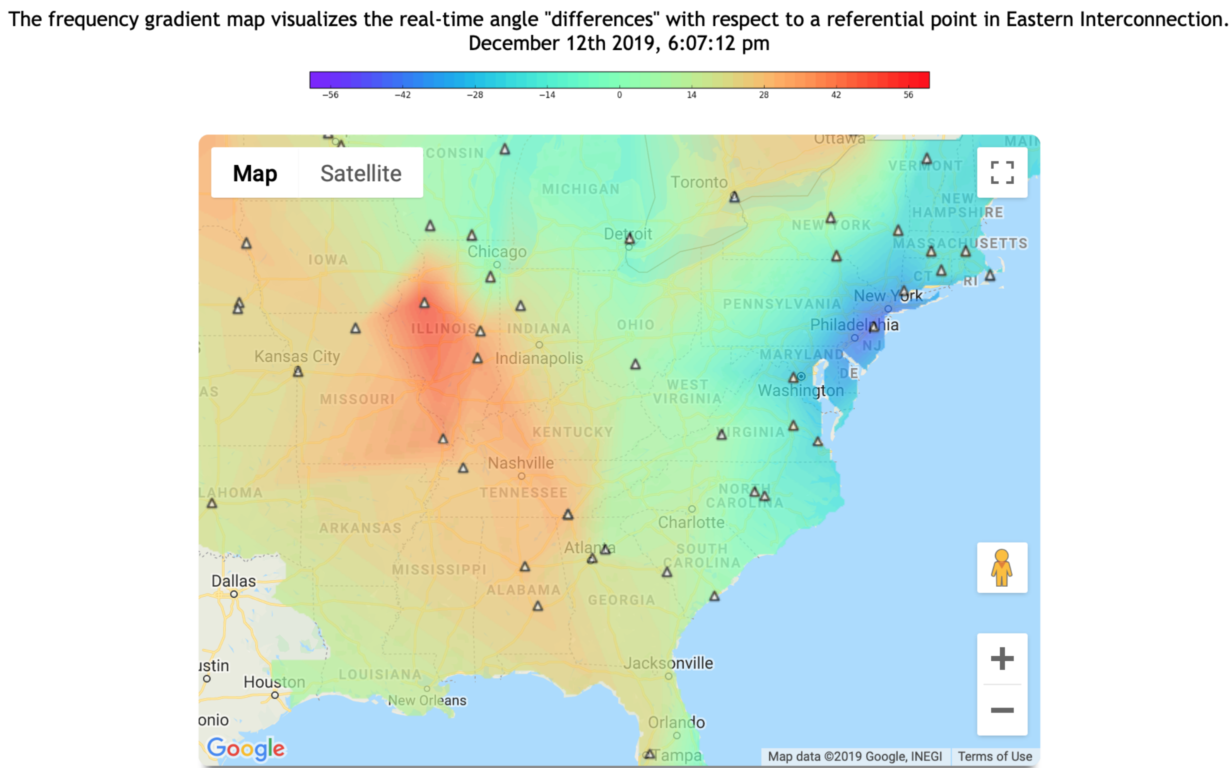

Figure 1: Heat map of the grid angles on Dec. 12 2019 on the Eastern Interconnection from http://fnetpublic.utk.edu/anglecontour.html

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Q. *How is it possible that there can be greater than 90 degrees separation on a connected electric grid?*

Q. *At a high level what controls are used to control power flows on the electric grid?*

for generators?

for transmission lines?

other resources?

Q. *What is a "fault?"*

Is voltage stability a fault?

Is angle stability a fault?

Is frequency stability a fault?

1.1 Transmission vs Distribution

The electric grid is divided between transmission and distribution networks. Typically, the transmission network is the system that connects the substations with the generation units, and can be as large as the Western/Eastern United States. Distribution networks are the networks that connect customers with their respective substations. Historically, power has flowed from transmission networks to distribution networks.

Q. *Fill in the table below, distinguishing each general feature difference between transmission and distribution.*

Property	**Transmission**	**Distribution**
Radial/Mesh Network		
Critical/Noncritical Infrastructure		
N-1 Standard/No N-1 Standard		
Reclosers and Fuses/Relays and Circuit Breakers		

2 Black Outs

Electrical networks consist of generators, transmission lines, and loads. Each portion of a transmission systems are overseen by a team of grid operators which are able to broadcast commands such as Automatic Generation Control signals. In addition to these commands, each of the generators and lines on the network are equipped with equipment that responds automatically to certain grid conditions in order to protect the expensive grid equipment. This "response" is almost always disconnecting from the grid, or opening a transmission line switch. The disconnect decision can be made by the grid operator (usually in the form of "load shedding"), or automatically, by the control logic in a given device. The control logic is designed to protect the grid machinery and infrastructure (loss of power is better than catastrophic failure), and usually disconnects the equipment when the line current/power flows are too large, the voltage deviation is too great, or the frequency deviates outside of permissible bounds. If an area of load is disconnected from the energized power system (generators), then the area will lose power and be "blacked out."

2.1 Issues for lines/Issues for generators

Lines have to disconnect when two things occur:

- line thermal limits
- line faults

Generators have to/choose to disconnect under a number of conditions. These conditions include:

- under/over frequency
- under/over voltage
- angle separation

In practice, it may be hard to diagnose angle separation and impending angle instability. To address this challenge, generators may choose to just disconnect above a certain current/power generation level.

2.2 Load Shedding

"Load shedding" is the action taken by a system operator that shuts off power for a portion of the grid. Load shedding is done by strategically opening switches. While not desirable, load shedding is an important strategic option available to grid operators which may be necessary to maintain the stability of the larger network.

Q. *Why would shedding load in a given area decrease the current into the area?*

Q. *Why would shedding load in a given area increase the voltage in the area?*

Q. *Whats the difference between a load shedding command and a line tripping off line because it is over capacity?*

2.3 Islanding

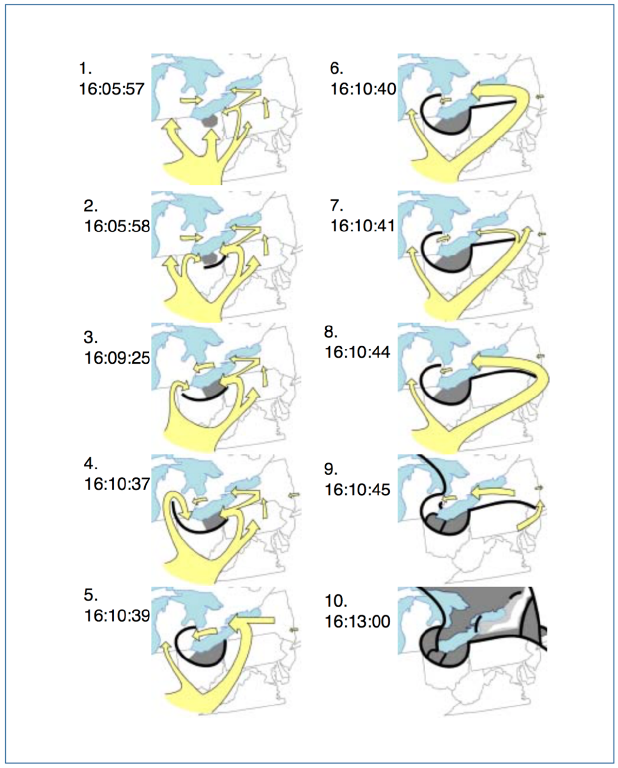
In power systems, “islands” are portions of the network that are energized, but are not connected electrically to the bulk power grid. Because the islands are not connected, they can operate at a different voltage magnitude, angle and frequency than the bulk power grid. While islanded operation is a viable and useful contingency protocol, islanded operation is more precarious than non-islanded operation.
Q. *Why is islanded operation more precarious than non-islanded operation?*

Q. *What must happen for two islands to connect?*

3 2003 Blackout Events

1. First Energy (FE) State estimator malfunctioned because the network information from MISO was incorrect
2. A generator in the FE region tripped off line
3. The FE alarm system failed and was turned off, presumably due to the malfunctioning state estimator.
4. Transmission lines supplying the Cleveland area tripped off because of overgrown trees. This was presumably unrelated to the generator trip and state estimator malfunction.
5. The Cleveland system began showing “signs of weakness,” i.e. dropping voltage and large power inflows.
6. FE grid operators did not shed load
7. Additional transmission lines supplying Cleveland area gradually tripped because of overloading
8. Sammis-Star line tripped because of overloading, created transient swings throughout the network
9. Cascade of automatic line tripping to avoid (perceived) physical damage (pictures on page 57 of report) from the transient swings (look at the time stamps on fig 6.30 on p 101, many of the line and generator tripping occurred within 5 seconds of Sammi-Star switching offline).

Figure 6.30. Cascade Sequence



Legend: Yellow arrows represent the overall pattern of electricity flows. Black lines represent approximate points of separation between areas within the Eastern Interconnect. Gray shading represents areas affected by the blackout.

Of note, the initial low voltage in the Cleveland region was due to lack of reactive power support in the Cleveland regions, and faulted transmission lines that supplied the Cleveland region. These low voltages (and high currents) led to additional line trips. This sequential line tripping is *not* traditional voltage collapse. Traditional voltage collapse is a sudden catastrophic phenomenon in which voltage drops to zero because the real/reactive load has exceeded the power transmission capability of the network.

Q. *In the 2003 blackout, Long Island and portions of NYC continued to provide power to certain regions via local generators. Why did NYC want to reconnect to the main grid as quickly as possible?*

Q. *In 2011, why did San Diego not have to exercise any black start capabilities after the blackout?*

Q. *Why did New England not lose power in the 2003 blackout, but San Diego did in the 2011 blackout?*

Q. *Why did the 2003 blackout not expand south indefinitely?*

Q. *Why is it beneficial to place generation near demand, if possible?*