BLACKOUT PHENOMENA
LECTURE FOR MARCH 12 2008

Physics-Geology 30
Chaos, Complexity and Fractals
UC-DAVIS

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North American power transmission system

- Bulk power transfers across the nation
- High Voltage transmission network; >30,000 V
- Large Network; 10,000-100,000 nodes or branches
- A complex and complicated system
- Underpins our society and a key infrastructure
small test network with 118 nodes
Three networks for North America

Figure 2.2. North American Interconnections
How power flows in networks

- Power is energy per time (rate of energy flow) and is measured in Megawatts (MW).
  (1 MW powers roughly 1000 homes)
- For equilibrium,
  Power in (generators) = Power out (loads)
- What happens when you turn a light on and this increases the load?
- Power flows from generators to loads by multiple network paths according to circuit laws
Protecting equipment when there is a short circuit or other overload

- Large currents heat up and damage transmission lines, transformers, generators
- So engineers protect equipment with devices that senses large currents and switches the equipment out; eg “trip the line” (same function as circuit breakers or fuses in your house)
- Summary: there are limits to power flows and overloaded lines trip out.
What if power flow limit on lines is 250 and one line trips?

What power flow limit makes it safe for one line trip?
example of transmission line trip

- too much power flow heats transmission line
- line expands and sags, flashes over into untrimmed tree
- protection device disconnects line
- transient followed by a steady state redistribution of power flow to parallel paths.
- operators may readjust flows later by changing pattern of generation
- line trips can cascade by successively overloading parallel paths
Northeast blackout August 2003

- 50 million people in USA and Canada
- cost estimates average about $8 billion
- included cascading line overloads and many other types of interactions
DMSP F15
15 August 2003
0114Z
~7 hrs after Blackout

- Detroit
- Columbus
- Cleveland
- Buffalo
- Toronto
- Is dark
- Ottawa
- Montreal
- Albany
- Brightness in
  - Boston is unchanged
  - Long Island is MUCH reduced
Lines in Ohio area Aug 2003 blackout

Figure 6.3. Sammis-Star 345-kV Line Trip, 16:05:57 EDT

Remaining Paths

5A
Cascading line failures at start of August 13 2003 blackout
Figure 6.30. Cascade Sequence

1. 16:05:57
2. 16:05:58
3. 16:09:25
4. 16:10:37
5. 16:10:39
6. 16:10:40
7. 16:10:41
8. 16:10:44
9. 16:10:45
10. 16:13:00
discussion of
ISLANDING
and
VOLTAGE COLLAPSE
(saddle node bifurcation)

lectured on the whiteboard
Western blackout July 1996

- 2 million customers lost power
- included voltage collapse, islanding and other phenomena
Sequence of System Separations

Islands Formed -- July 2, 1996
Part of network; July 1996 blackout

source: Venkatasubramanian and Li IREP 2004
Plot of Malin voltage changing with time. 1996 western blackout
Two ways to lose a stable operating equilibrium

• Equilibrium disappears by coalescing with another equilibrium (eg voltage collapse; voltages drop). Called a saddle-node bifurcation.

• Equilibrium becomes unstable and oscillations start. Called a Hopf bifurcation.
Transients and oscillations in August 2003 blackout

Figure 6.17. Measured Power Flows and Frequency Across Regional Interfaces, 16:10:30 to 16:11:00 EDT, with Key Events in the Cascade
Large blackouts are complicated cascades of various types of failures and phenomena such as:

- Cascading line overloads and islanding
- Instabilities such as losing equilibrium or oscillations (bifurcations).
- Transient phenomena.
- Equipment or software malfunction and operator or design error.

For questions arising after the lecture, email dobson@engr.wisc.edu