“Energy Systems”
A Critical National Infrastructure
Slide Deck #1

James D. McCalley
Professor of Electrical and Computer Engineering
Iowa State University Ames, IA

WEBPAGE:
http://home.engineering.iastate.edu/~jdm/ee303/ee303schedule.htm

HELPFUL BOOK:

2  Automobile
9  Telephone
6  Radio/television
11 Interstate highways
1  Electrification
13 Internet
12 Spaceflight
19 Nuclear technologies
5  Electronics
8  Computer
3  Airplane
4  Water supply

See www.greatachievements.org
Content of these slides

- Evolution of electricity industry
- Integrated electric energy systems
- Power systems: how they work
- Power systems: what can go wrong?
- The 2003 NE Blackout
- The future of energy
Evolution of Electric Industry

1600: William Gilbert invents the compass.
1736: James Watt invents steam engine.
1732: Stephen Gray discovers conduction.
1745: Musschenbroek invents Leyden jar (capacitor)
1752: Ben Franklin proves lightning is electricity.
1745: Johann Gauss related magnetic flux & electric charge.
1785: Charles Coulomb discovers relation between force and charge.
1792: Alessandro Volta invented the battery.
1800: Friedrich Gauss invented magnetic compass.
1820: Hans Oersted discovered magnetic effects of a current on a compass needle.
1827: Joseph Henry discovered inductance.
1820: Marie Ampere discovered the relation between voltage, current, and resistance.
1827: George Ohm discovered the law of electrolysis.
1831: Michael Faraday discovered Faraday’s law and invented the generator.
1835: James Watt invented the steam engine.
1839: James Clerk Maxwell wrote equations describing electro-magnetic fields, and predicted the existence of electromagnetic waves.
1835: Johann Gauss related magnetic flux & electric charge.
1845: Gustav Kirchhoff developed laws enabling the efficient calculation of currents in complex circuits.
1855: Wilhelm Weber defined units for current and resistance.
1873: James Clerk Maxwell wrote equations describing electro-magnetic fields, and predicted the existence of electromagnetic waves.
1879: Thomas Edison invented the incandescent lamp and in 1882 supplied Pearl St (NY) with light from DC generator.
1886: William Stanley invented the transformer.
1888: Nikola Tesla patented the AC polyphase motor.
1888: H. Hertz experimentally verified Maxwell’s equations.
1895: George Westinghouse harnessed Niagara Falls and commercialized AC generation, transformation, and transmission.
Evolution of Electric Industry

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Evolution of Electric Industry

- 1903 Samuel Insull understanding **economies of scale** (generators when scaled up produce power at a lower $/kWhr – big is better!) installs 5 MW generator in Chicago and manages load to increase his **load factor** (avg load/max load) to increase profits.

- 1907 Insull realizes that profitability from managing economies of scale and load factor grows with corporate size, and so forms Commonwealth Edison, Chicago, by buying all of his competitors.

- 1907 States begin recognizing electric companies as **natural monopolies** similar to the railroads, with large economies of scale requiring huge capital investment so that it was not socially efficient to have multiple competitors.

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Steam turbo-generators, Long Island railways, c.1907

Fiske Street Station steam turbine Chicago, c.1907

Transmission switches on wooden towers, 1906
Evolution of Electric Industry

- 1914 About 43 states had established government oversight (state regulation) of electric utilities, requiring reliability and the obligation to serve from utilities, and giving right to recover reasonable return from the rate base on their investments, contributing to perspective that utility stocks were good for retirement.

- 1920, Congress established the Federal Power Commission (FPC) to coordinate hydroelectric projects under federal control.

- 1927 In US, 75,400 MWhr sold, from 5700 MWhr in 1907

- Equipment manufacturers (GE) started holding companies that would buy and manage many operating companies, offering them equipment and services that they could not afford themselves, & establishing interconnections between them.

Potomac Electric Power Co.
power station near Washington DC, 1939
1927 There were 4400 operating companies, 180 holding companies; top holding companies in pyramids often overcharged subsidiary (operating) companies.

1929 Stock market crash caused loss among holding companies; a few survived.

1932 Only 8 holding companies owned 75% of the operating companies, & they were exempt from state regulation since their business crossed state boundaries.

1932 FDR elected on promise to reform the industry of “the Ishmaels and the Insulls, whose hand is against everyman's.”

1935 Investor-owned utilities (IOUs) resisted supplying rural areas on grounds it would not be profitable. So US Rural Electrification Administration created to facilitate creation of municipals and co-operatives in rural areas.

1935 Public Utility Holdings Company Act (PUCHA)

- Broke up layered interstate holding companies; allowed 1 level above operating company; required them to divest holdings that were not within a single circumscribed geographical area; reduced existing monopoly power.
- Required companies to engage only in business essential for the operation of a single integrated utility, and eliminated non-utility generators (NUGs-didn’t want companies moving into other areas); reduced future monopoly power.
- Required companies to register with Security & Exchange Commission (SEC)
Evolution of Electric Industry

1938-1964: Golden years!
- Holding companies declined from 216 to 18.
- Generator max plant efficiencies increased from ~20% to ~40%.
- Generation max size increased from ~110 MW to ~1000 MW.
- Transmission typical voltage increased from mostly 60 kV to 230, 345, and 500 kV.
- Load grew at ~8%/year, doubling every 10 years.
- Price declined at 50 cents/kWhr to 10 cents/kWhr.
- Grow and build!

1964 About 77% electric energy from IOUs and 23% from municipals, co-ops, and government (e.g., WAPA, BPA, TVA).
Evolution of Electric Industry

- 1965, 5:27 pm, Nov 9: Northeast Blackout, 20000 MW lost, 80,000 people interrupted in northeast US, including NYC.

- 1968 North American Electric Reliability Corporation (NERC) created.
Evolution of Electric Industry

◆ 1970 Technical limits to economies of scale and to plant efficiencies, aversion to coal due to cheap petroleum and nuclear, & OPEC.

◆ 1973 Energy Crisis

◆ 1977 Department of Energy (DOE) created to address US policies regarding energy and safety in handling nuclear material

◆ 1977, FPC changed to FERC (regulates transmission and wholesale markets for interstate commerce).

◆ 1978, Airline industry deregulated

◆ 1978 Public Utility Regulatory Policies Act (PURPA): utilities had to interconnect, buy, at avoided cost from qualifying facilities (small power producers using 75% renewables or cogeneration).

◆ 1978: Fred Schweppe at MIT proposed “spot pricing” of electricity

◆ 1979 Three-mile island accident.

◆ 1987 Non-utility generation grows ➔

“the moral equivalent of war.”

Schweppe initially called it “homeostatic control.” The word homeostasis combines forms of homeo, "similar," and stasis, "standing still," yielding "staying the same."

MAJOR QUESTION: Are electric utilities natural monopolies?
Evolution of Electric Industry

- 1992 Electric Policy Act
  - Exempt Wholesale Generators: class of unregulated generators of any technology, utilities did not have to buy their energy.
  - But utilities did have to provide transportation (wheeling) for wholesale transactions; no rules were specified regarding transmission service price.

The 1992 EPA motivated by price disparity throughout the US. Large industrials were hungry for lower prices.
1996 FERC Orders 888, 889, required IOUs to
- file nondiscriminatory transmission tariffs
- pay tariffs for transmission service for their own wholesale transactions
- maintain an information system that gives equal access to transmission information (OASIS)
- functionally **unbundle** their generation from “wires”
- FERC order did not specify how; can be done via divestiture or “in-house”

- Major outages: WSCC (‘96, ’97), Bay area (‘98), NY (‘99), Chicago (‘00)
- 1997: Startup of 21 OASIS nodes across US
- 1998 (April) California legislation gave consumers right to choose supplier
  - 1999 (June) 1% residential, 3% small commercial, 6% commercial, 21% large industrial, 3% agricultural have switched providers in California
  - 2000 (Jan) 13.8% of total load switched in Cal

- 1996-2002: Independent System Operators begin: PJM, ISO-NE, ERCOT, CALISO, NYISO, MISO, SPP. ISOs own no transmission but are responsible for operating and planning the grid, and operating electricity markets. Most ISOs also obtained RTO status (see next slide).
Transmission and System Operator

Vertically Integrated Utility

1900-199?

Transmission Operator

Independent System Operator

Today
Evolution of Electric Industry

- 2000 FERC Order 2000 formalized operating, planning, market functions and also required significant regional size to become a regional transmission organizations (RTO). US ISOs subject to FERC jurisdiction (not ERCOT) that satisfy a list of requirements become RTOs.

- 2000-2001 California energy crisis
  - Drought, hot weather, outaged generation, natural gas shortage, transmission bottlenecks, flawed market design allowing price manipulation by some companies, problematic political forces

- 2001, April PG&E went bankrupt

- 2001, November Enron collapse

- 2002 FERC standard market design issued.

- 2003 Major blackout in the northeast US
Evolution of Electric Industry

- 2004, First large wind farm in Iowa (160.5MW Intrepid plant in NW Iowa)
- 2006, “An inconvenient truth” (Al Gore) about global warming

“The effects of global warming on temperature, precipitation levels, and soil moisture are turning many of our forests into kindling during wildfire season.”
Evolution of Electric Industry

2008, Economic depression, Obama elected
2009, In response to depression Obama initiated the American Recovery and Reinvestment Act of 2009, which included $80B “energy money” as follows:
- $3.4B for smart grid investment
- Launched the Advanced Research Projects Agency (ARPA-E) to fund innovative energy concepts
- Imposed new efficiency standards for home appliances
- Imposed fuel efficiency policies for cars
- Increase production of biofuels
- Required reporting of greenhouse emissions by power plants
2010, Obama proposed an energy security plan to reduce offshore energy need
2011, Obama state of union: 80% of US electricity from clean sources by 2035
2015, Obama’s EPA: Clean Power Plan to lower power plant CO₂ emissions
2016, 2/3 electric utilities support CPP, but congressional & legal pushback abounds
2016, Trump elected
2017, US withdraws from Paris Agreement
2018, Trump proposes Affordable Clean Energy Rule, giving CO₂ authority to states
Integrated Electric Energy Systems

ELECTRIC TRANSMISSION

GAS TRANSMISSION

RAILWAY FOR COAL

SHALE GAS PLAYS
## US Generation mix

<table>
<thead>
<tr>
<th></th>
<th>2000</th>
<th>2008</th>
<th>2010</th>
<th>2015</th>
<th>2016</th>
<th>2018</th>
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<td></td>
<td></td>
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<tr>
<td>OIL</td>
<td>1.9%</td>
<td>1.6%</td>
<td>1.0%</td>
<td>0.8%</td>
<td>0.7%</td>
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<td>COAL</td>
<td>57%</td>
<td>49%</td>
<td>45%</td>
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<td>27%</td>
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<tr>
<td>NAT GAS</td>
<td>10%</td>
<td>20%</td>
<td>23%</td>
<td>33%</td>
<td>34%</td>
<td>34%</td>
</tr>
<tr>
<td>OTHER GAS</td>
<td>0.4%</td>
<td></td>
<td></td>
<td>0.5%</td>
<td>0.5%</td>
<td>0.5</td>
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<tr>
<td><strong>NUCLEAR</strong></td>
<td>23%</td>
<td>19.4%</td>
<td>20%</td>
<td>20%</td>
<td>20%</td>
<td>19%</td>
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<td><strong>RNWBLIES</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>HYDRO</td>
<td>7.5%</td>
<td>7%</td>
<td>7%</td>
<td>6%</td>
<td>6%</td>
<td>6.8%</td>
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<tr>
<td>WIND</td>
<td>0%</td>
<td>0.6%</td>
<td>1.8%</td>
<td>4.7%</td>
<td>5.6%</td>
<td>8.3%</td>
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<tr>
<td>SOLAR</td>
<td>0%</td>
<td>0.1%</td>
<td>0.1%</td>
<td>0.6%</td>
<td>0.9%</td>
<td>1.5%</td>
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<tr>
<td>BIOMASS</td>
<td>0.2%</td>
<td>1.3%</td>
<td>1.5%</td>
<td>1.6%</td>
<td>1.6%</td>
<td>1.7%</td>
</tr>
<tr>
<td>GEOTRML</td>
<td>0.4%</td>
<td>0.4%</td>
<td>0.4%</td>
<td>0.4%</td>
<td>0.4%</td>
<td>0.4%</td>
</tr>
<tr>
<td>Coal+gas+wind</td>
<td>67%</td>
<td>69.4%</td>
<td>69.8%</td>
<td>70.7%</td>
<td>69.6%</td>
<td>69.3%</td>
</tr>
</tbody>
</table>
Power System Basics

- Current (amperes), is like water flow
- Voltage (volts), is like water pressure
- Resistance (ohms), is like $1/$pipe diameter: $I=V/R$
- Electricity is either DC or AC

- Real power (watts), is ability to do work, light a bulb
  $P=3VI\cos\theta$
- Reactive power (vars), does no work, but anything with a winding (motor) must have them.
  $Q=3VI\sin\theta$
Power System Basics

AC voltages can be easily changed from one level to another using power transformers.

Power generation occurs at low voltages (<30,000 volts) because of insulation requirements.

Power transmission occurs at high voltages (69,000 to 765,000 volts) to minimize current for given power transfer capability and thus minimize losses in wires.

Power distribution occurs at low voltages (≤34,500 volts) for safety reasons.

So power systems are mainly AC because of ability to easily transform AC voltages from low levels in the generators to high levels for transmission and back to low levels for distribution and usage.
Power System Generation & Transmission

- Power circuits can be single-phase or 3-phase

- Generation & transmission is always 3-phase because
  - Gives the same power but requires 3 wires instead of 6
  - Power is constant and large motors run smoother
Balancing authorities (the circles): They all perform power balancing. And they all have energy control centers. CAISO, ERCOT, SPP, MISO, PJM, NYISO, and ISONE also operate markets.

Substation

Remote terminal unit

SCADA Master Station

Communication link

Energy control center with EMS

EMS 1-line diagram

EMS alarm display
Energy control centers
Energy Control Centers

Energy Control Center (ECC):

- SCADA, EMS, operational personnel
- Eyes & hands of the power system

Supervisory control & data acquisition (SCADA):

- Supervisory control: remote control of field devices, including gen
- Data acquisition: monitoring of field conditions
- SCADA components:
  - Master Station: System “Nerve Center” located in ECC
  - Remote terminal units: Gathers data at substations; sends to Master Station
  - Communications: Links Master Station with Field Devices, telemetry is done by either leased wire, PLC, microwave, or fiber optics.

Energy management system (EMS)

- Topology processor & network configurator
- State estimator and power flow model development
- Automatic generation control (AGC), Optimal power flow (OPF)
- Security assessment and alarm processing
Balancing Systems

Day-Ahead Market
- 1 sol/day gives 24 operating conditions

Real-Time Market
- 1 sol/5min gives 1 operating condition

Energy & Reserve
- Sell Offers

Automatic Generation Control System

Frequency Deviation from 60 Hz

Network
Power systems: What can go wrong?

- Lightning
lightning induced flashover!
Power systems: What can go wrong?

- Lightning
- Natural events (wind & snow, earthquakes, wildfires...)

the weather man said light snow showers!

hurry up, I can’t hold it much longer
Mon 3 Feb 2003: no electricity for 70% of Indian state of Bihar

It was the wrong sort of snow!
Power systems: What can go wrong?

- Lightning
- Natural events (wind and snow, earthquakes, wildfires...)
- Deterioration (insulation failure)

Golf will never be the same again
arc across 400kV insulator
Power systems: What can go wrong?

- Lightning
- Natural events (wind and snow, earthquakes, wildfires...)
- Deterioration (insulation failure)
- Animals (mainly squirrels & snakes, but sometimes....)

Time for a nap?
Power systems: What can go wrong?

- Lightning
- Natural events (wind and snow, earthquakes, wildfires...)
- Deterioration (insulation failure)
- Animals (mainly squirrels & snakes, but sometimes....)
- Vehicles and construction (accidents)

Crane contacts overhead power line during freeway construction.

46,000 volts travel through the crane and beneath the concrete road.
Power systems: What can go wrong?

- Lightning
- Natural events (wind and snow, earthquakes, wildfires...)
- Deterioration (insulation failure)
- Animals (mainly squirrels & snakes, but sometimes....)
- Vehicles and construction (accidents)
- Mistakes during maintenance

I hope you switched it off!
Power systems: What can go wrong?

- All of the previous situations cause faults.
- Faults are dangerous situations that can hurt people and destroy equipment.
- Protection equipment removes faults:
  - Fuses detect faults and melt a wire. Must be replaced.
  - Relays detect faults and signal circuit breaker to trip.
  - Circuit breakers open lines. Can be re-used.
Staged Faults on 400kV line
The New York Times

POWER SURGE BLACKS OUT NORTHEAST HITTING CITIES IN 8 STATES AND CANADA MIDDAY SHUTDOWN'S DISRUPT MILLION.

The Boston Globe

Great blackout of '03

Outage hits millions in US, Canada

New York takes chaos in stride

Officials find few answers but grief's fragility

Traffic running smoothly; pedestrians calmly drift

Chicago Tribune

50 million lose power

Largest blackout in history hits U.S., Canada cities

Local politicians play on broad area in獾ant

Liberia's wait ends: U.S. troops land

The Philadelphia Inquirer

POWERLESS

Blackout hits 50 million in U.S., Canada

Powerless and frustrated, Americans cope

Key Al Qaeda figure captured

Daily News

BREAKING NEWS

VOICE OF DARYN KAGAN

5:45p ET

NEW YORK CITY

NY’sers stranded by huge blackout

Blackout

50 million lose power

City swelters to a halt

Rush-hour chaos today

NEW YORK POST

SPECIAL EDITION

VOICE OF DARYN KAGAN

5:45p ET

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NY’sers stranded by huge blackout
# Blackouts

## Summary of well-known blackouts

<table>
<thead>
<tr>
<th>Location</th>
<th>Date</th>
<th>Scale in term of MW or Population</th>
<th>Collapse time</th>
</tr>
</thead>
<tbody>
<tr>
<td>New York[2]</td>
<td>7/13/77</td>
<td>6,000 MW, 9M people</td>
<td>1 hour</td>
</tr>
<tr>
<td>France[3]</td>
<td>1978</td>
<td>29,000 MW</td>
<td>26 mins</td>
</tr>
<tr>
<td>US-West[5]</td>
<td>12/14/94</td>
<td>9,300 MW</td>
<td></td>
</tr>
<tr>
<td>US-West[5]</td>
<td>7/3/96</td>
<td>1,200 MW</td>
<td>&gt; 1 min</td>
</tr>
<tr>
<td>US-NE[7]</td>
<td>8/14/03</td>
<td>62,000 MW, 50M people</td>
<td>&gt; 1 hour</td>
</tr>
<tr>
<td>London[8]</td>
<td>8/28/03</td>
<td>724 MW, 476K people</td>
<td>8 secs</td>
</tr>
<tr>
<td>Denmark &amp; Sweden [9][10]</td>
<td>9/23/03</td>
<td>4.85M people</td>
<td>7mins</td>
</tr>
</tbody>
</table>
WHAT HAPPENED ON AUGUST 14, 2003???

1. 12:05 Conesville Unit 5 (rating 375 MW)
2. 1:14 Greenwood Unit 1 (rating 785 MW)
3. 1:31 Eastlake Unit 5 (rating: 597 MW)
4. 2:02 Stuart – Atlanta 345 kV
5. 3:05 Harding-Chamberlain 345 kV
6. 3:32 Hanna-Juniper 345 kV
7. 3:41 Star-South Canton 345 kV
8. 3:45 Canton Central-Tidd 345 kV
9. 4:05 Sammis-Star 345 kV
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INITIATING EVENT

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SLOW PROGRESSION

10. 4:08:58 Galion-Ohio Central-Muskingum 345 kV
11. 4:09:06 East Lima-Fostoria Central 345 kV
12. 4:09:23-4:10:27 Kinder Morgan (rating: 500 MW; loaded to 200 MW)
13. 4:10 Harding-Fox 345 kV
14. 4:10:04 – 4:10:45 20 generators along Lake Erie in north Ohio, 2174 MW
15. 4:10:37 West-East Michigan 345 kV
16. 4:10:38 Midland Cogeneration Venture, 1265 MW
17. 4:10:38 Transmission system separates northwest of Detroit
18. 4:10:38 Perry-Ashtabula-Erie West 345 kV
19. 4:10:40 – 4:10:44 4 lines disconnect between Pennsylvania & New York
20. 4:10:41 2 lines disconnect and 2 gens trip in north Ohio, 1868 MW
21. 4:10:42 – 4:10:45 3 lines disconnect in north Ontario, New Jersey, isolates NE part of Eastern Interconnection, 1 unit trips, 820 mw
23. 4:10:50 – 4:11:57 Ontario separates from NY w. of Niagara Falls & w. of St. Law. SW Connecticut separates from New York, blacks out.
Immediate causes of the 8/14/03 blackout

1:30  Loss of East Lake generator (over-excitation)
2:02  Loss of Stuart-Atlanta (tree contact)
2:02  MISO system model becomes inaccurate
2:14-3:08  Loss of software in FE control center
3:05  Loss of Harding-Chamberlain (tree contact)
3:32  Loss of Hanna-Juniper (tree contact)
3:41  Loss of Star-S.Canton (tree contact)
4:06  Loss of Sammis-Star (high overload looked like fault to “zone 3” of the protection system)
Why so much tree-contact?

◆ Trees were overgrown because right-of-ways had not been properly maintained.

◆ Lines expand and sag due to heat; more prone in summer with high temperature & low winds; more prone with high current.

◆ Each successive line trip requires that the power it was carrying be transferred to flow elsewhere, resulting in increased power on remaining lines.
Another influence: insufficient reactive power

Another contribution to the blackout was insufficient reactive power in the Cleveland area, i.e., the reactive power (vars) in the Cleveland area generation was insufficient to meet the reactive power demand of its motors. Conditions that make a system prone to this include:

- High load, especially induction motors (air conditioners)
- Loss of generation in load-intensive area and/or loss of transmission into that load-intensive area

This results in voltage decline in the load-intensive area, and because $P \sim VI$, when voltage $V$ declines, current $I$ must increase in order to maintain the same power $P$.

When $I$ goes up, lines load up more heavily.
Another influence: insufficient reactive power
Another influence: Backup protection

- Relays sense V/I and trip if it is too low; good approach because fault conditions are low voltage, high current.
- Relays are directional; trip only for faults “looking” in one direction.
- Zone 1 trips instantly; trip zone for primary protection
- Zone 2 has small delay. Zone 3 has large delay; these are trip zones for “backup” protection
Why did the cascade happen (events 10-23)

- Oscillations in voltages and currents, and/or very high currents caused many transmission line zone 2,3 protection systems to see what appeared to be faults & trip the line.

- As a few generators tripped, load>gen imbalance caused underfrequency and lower voltages.

- Generators tripped for 1 of following reasons:
  - Underfrequency
  - Under-voltage
  - Overexcitation
  - Out-of-step
  - Over-voltage
The blackout shut down 263 power plants (531 units)

Total cost: ~10 billion $.

Half of DOE annual budget

Twice NSF annual budget
Final List of Main Causes

° There was inadequate situational awareness at First Energy (FE). FE did not recognize/understand the deteriorating condition of its system.

° FE failed to adequately manage tree growth in its transmission rights-of-way.

° Failure of the interconnected grid’s reliability organizations (mainly MISO) to provide effective real-time diagnostic support.

° FE and ECAR failed to assess and understand the inadequacies of FE’s system, particularly with respect to voltage instability and the vulnerability of the Cleveland-Akron area, and FE did not operate its system with appropriate voltage criteria.

• No long-term planning studies w/ multiple contingencies or extreme conditions
• No voltage analyses for Ohio area and inappropriate operational voltage criteria
• No independent review or analysis of FE’s voltage criteria and operating needs
• Some of NERC’s planning & operational requirements were ambiguous
A few of the 46 Recommendations

1. Make reliability standards mandatory and enforceable, with penalties for noncompliance.
2. Develop a regulator-approved funding mechanism for NERC and the regional reliability councils, to ensure their independence from the parties they oversee.
4. Clarify that prudent expenditures and investments for bulk system reliability (including investments in new technologies) will be recoverable through transmission rates.
8. Shield operators who initiate load shedding pursuant to approved guidelines from liability or retaliation.
11. Establish requirements for collection and reporting of data needed for post-blackout analyses.
12. Commission an independent study of the relationships among industry restructuring, competition, and reliability.
13. DOE should expand its research programs on reliability-related tools and technologies.
16. Establish enforceable standards for maintenance of electrical clearances in right-of-way areas.
19. Improve near-term and long-term training and certification requirements for operators, reliability coordinators, and operator support staff.
21. Make more effective and wider use of system protection measures.
23. Strengthen reactive power and voltage control practices in all NERC regions.
24. Improve quality of system modeling data and data exchange practices.
26. Tighten communications protocols, especially for communications during alerts and emergencies. Upgrade communication system hardware where appropriate.
33. Develop and deploy IT management procedures.