Electric Power Network Blackout Issues

Causes and Possible System Improvements

Seminar at IEEE Section

09 December, 2014
Dhaka, Bangladesh

Prof. Saifur Rahman
srahman@vt.edu
Virginia Tech – Advanced Research Institute
www.saifurrahman.org

VirginiaTech
Invent the Future

Virginia Tech Research Center Arlington, Virginia, USA

U.S.-Canada Power System Outage Task Force

Final Report on the August 14, 2003 Blackout in the United States and Canada:

Causes and Recommendations

Canada

April 2004

REPORT OF THE ENQUIRY COMMITTEE

ON

GRID DISTURBANCE

IN NORTHERN REGION

ON 30th July 2012

AND

IN NORTHERN, EASTERN & NORTH-EASTERN REGION

ON 31st JULY 2012

16th AUGUST 2012
NEW DELHI

Joint U.S.-Canada Power System Outage Investigation

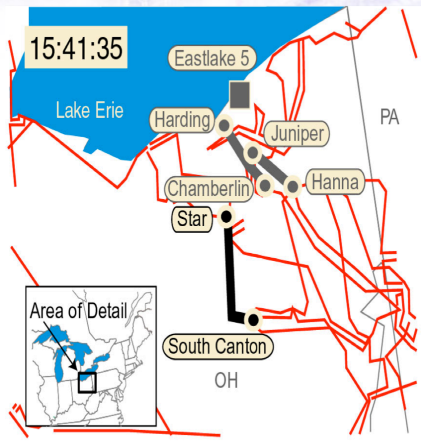
Causes of the
14 August 2003 Blackout in the
United States and Canada

Conclusions of the Interim Report

- What caused the blackout
  - **Inadequate situational awareness by FirstEnergy**
  - **Inadequate tree-trimming by FirstEnergy**
  - **Inadequate diagnostic support by reliability coordinators serving the Midwest**
- Explanation of the cascade and major events
- Nuclear plants performed well
- No malicious cyber attack caused blackout

What happened on August 14

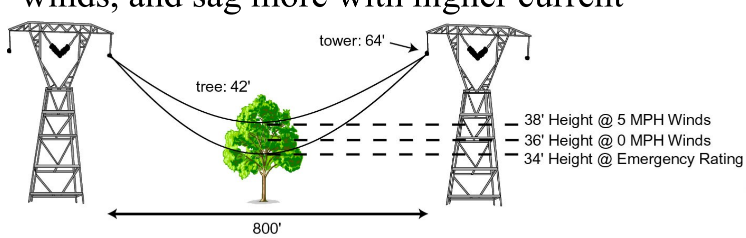
- At 1:31 pm, FirstEnergy lost the Eastlake 5 power plant, an important source of reactive power for the Cleveland-Akron area
- Starting at 3:05 pm EDT, three 345 kV lines in FE's system failed – within normal operating load limits -- due to contacts with overgrown trees



What happened (2) -- Ohio

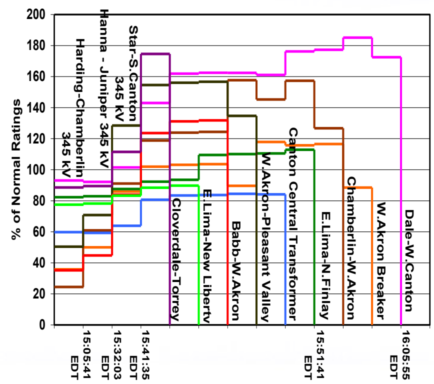
Why did so many trees contact power lines?

- The trees were overgrown because rights-of-way had not been properly maintained
- Lines sag lower in summer with heat and low winds, and sag more with higher current



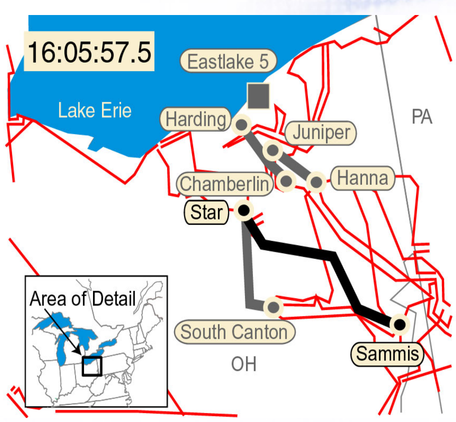
What happened (3) -- Ohio

After the 345 kV lines were lost, at 3:39 pm FE's 138 kV lines around Akron began to overload and fail; 16 overloaded and tripped out of service



What happened (4) -- Ohio

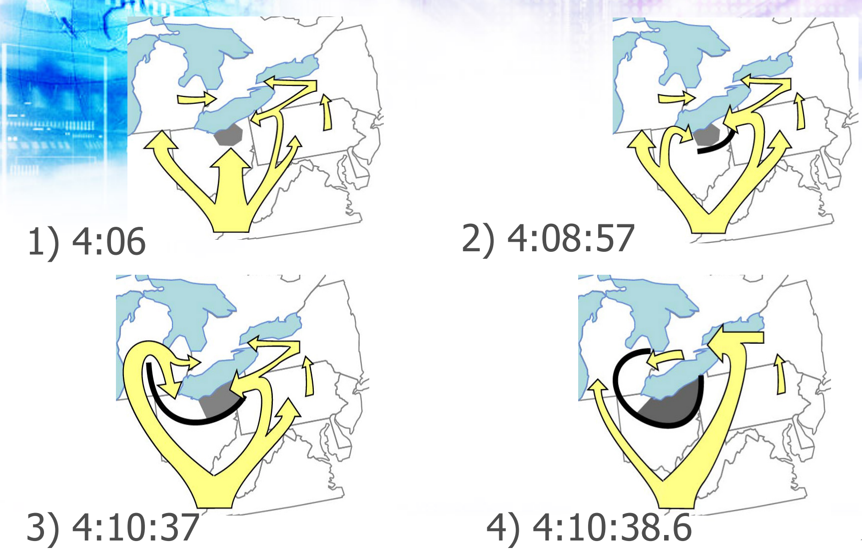
At 4:05 pm, after FirstEnergy's Sammis-Star 345 kV line failed due to severe overload.



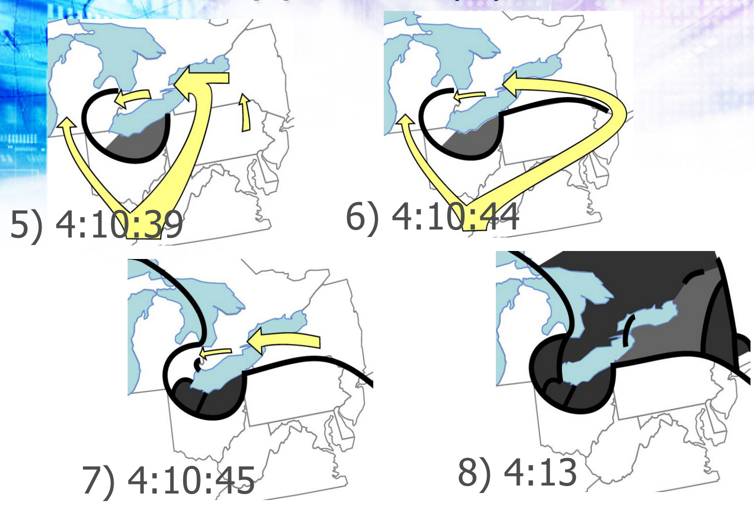
What happened (5) -- cascade

- Before the loss of Sammis-Star, the blackout was only a local problem in Ohio
- The local problem became a regional problem because FE did not act to contain it nor to inform its neighbors and MISO about the problem
- After Sammis-Star fell at 4:05:57, northern Ohio's load was shut off from its usual supply sources to the south and east, and the resulting overloads on the broader grid began an unstoppable cascade that flashed a surge of power across the northeast, with many lines overloading and tripping out of service.

What happened (6) -- cascade

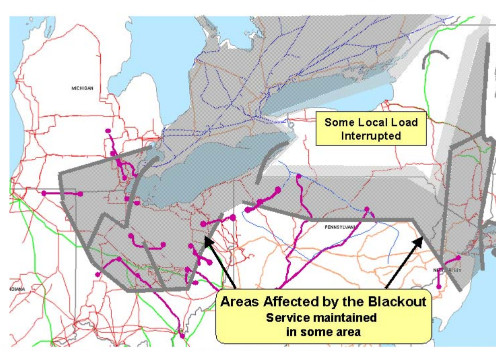


What happened (7) -- cascade



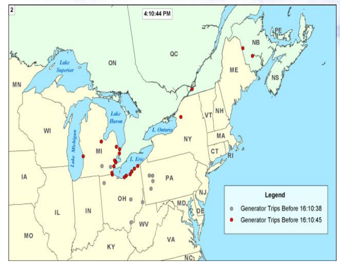
Affected areas

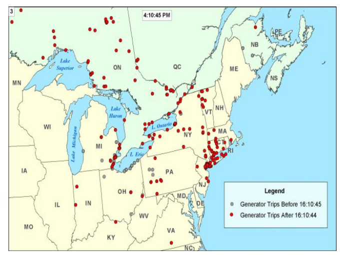
When the cascade was over at 4:13pm, over 50 million people in the northeast US and the province of Ontario were out of power.



Power plants affected

The blackout shut down 263 power plants (531 units) in the US and Canada, most from the cascade after 4:10:44 pm – but none suffered significant damage





Why the cascade spread

- Sequential tripping of transmission lines and generators in a widening geographic area, driven by power swings and voltage fluctuations.
- The result of automatic equipment operations (primarily relays and circuit breakers) and system design

Why the cascade stopped

- Early line trips separated and protected areas from the cascade (southern Ohio).
- Higher voltage lines are better able to absorb voltage and current swings, so helped to buffer against the cascade (AEP, Pennsylvania).
- Areas with high voltage profiles and good reactive power margins weren't swamped by the sudden voltage and power drain (PJM and New England).
- Areas with good internal balances of generation to load could reach internal equilibrium and island without collapsing (upstate New York and parts of Ontario's Niagara and Cornwall areas).

What did not cause the blackout (1)

1) High power flow patterns across Ohio
   - **Flows were high but normal**
   - **FE could limit imports if they became excessive**

2) System frequency variations
   - **Frequency was acceptable**

3) Low voltages on 8/14 and earlier
   - **FE voltages were above 98% through 8/13**
   - **FE voltages held above 95% before 15:05 on 8/14**

What did not cause the blackout (2)

4) Independent power producers and reactive power
   - **IPPs produced reactive power as required in their contracts**
   - **Control area operators and reliability coordinators can order higher reactive power production from IPPs but didn't on 8/14**
   - **Reactive power must be locally generated and there are few IPPs that are electrically significant to the FE area in Ohio**

What did not cause the blackout (3)

5) Unanticipated availability or absence of new or out of service generation and transmission
   - **All of the plants and lines known to be in and out of service on 8/14 were in the MISO day-ahead and morning-of schedule analyses, which indicated the system could be securely operated**

6) Peak temperatures or loads in the Midwest and Canada
   - **Conditions were normal for August**

7) Master Blaster computer virus or malicious cyber attack

Technical Reasons Behind the Blackout

What caused the blackout (1)

- FirstEnergy lost its system condition alarm system around 2:14pm, so its operators could not tell later on that system conditions were degrading.
- FE lost many capabilities of its Energy Management System from the problems that caused its alarm failure – but operators did not realize it had failed
- After 3:05pm, FE lost three 345 kV lines due to contacts with overgrown trees, but didn't know the lines had gone out of service.

What caused the blackout (2)

- As each FE line failed, it increased the loading on other lines and drove them closer to failing. FE lost 16 138kV lines between 3:39 and 4:06pm, but remained unaware of any problem until 3:42pm.
- FE took no emergency action to stabilize the transmission system or to inform its neighbors of its problems.
- The loss of FE's Sammis-Star 345 kV line at 4:05:57pm was the start of the cascade beyond Ohio.

What caused the blackout (3)

- MISO (FE's reliability coordinator) had an unrelated software problem and for much of the afternoon was unable to tell that FE's lines were becoming overloaded and insecure.
- AEP saw signs of FE's problems and tried to alert FE, but was repeatedly rebuffed.
- PJM saw the growing problem, but did not have joint procedures in place with MISO to deal with the problem quickly and effectively.

What caused the blackout (4)

1) FirstEnergy didn't properly understand the condition of its system, which degraded as the afternoon progressed.

- FE did not ensure the security of its transmission system because it didn't use an effective contingency analysis tool routinely.
- FE lost its system monitoring alarms and lacked procedures to identify that failure.
- After efforts to fix that loss, FE did not check to see if the repairs had worked.
- FE did not have additional monitoring tools to help operators understand system conditions after their main monitoring and alarm tools failed.

What caused the blackout (5)

2) FE failed to adequately trim trees in its transmission rights-of-way.

- Overgrown trees under FE transmission lines caused the first three FE 345 kV line failures.
- These tree/line contacts were not accidents or coincidences
- Trees found in FE rights-of-way are not a new problem
  - **One tree over 42' tall; one 14 years old; another 14" in diameter**
  - **Extensive evidence of long-standing tree-line contacts**

What caused the blackout (6)

3) Reliability Coordinators did not provide adequate diagnostic support to compensate for FE's failures.

- MISO's state estimator failed due to a data error.
- MISO's flowgate monitoring tool did not have real-time line information to detect growing overloads.
- MISO operators could not easily link breaker status to line status to understand changing conditions.
- PJM and MISO lacked joint procedures to coordinate problems affecting their common boundaries.

Reliability management (1)

Fundamental rule of grid operations – deal with the grid in front of you and keep it secure. HOW?

1) Balance supply and demand

2) Balance reactive power supply and demand to maintain voltages

3) Monitor flows to prevent overloads and line overheating

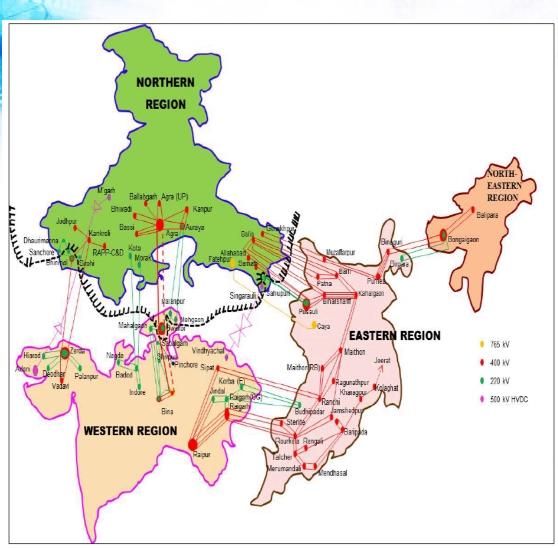
4) Keep the system stable

Reliability management (2)

5) Keep the system reliable, even if or after it loses a key facility
6) Plan, design and maintain the system to operate reliably
7) Prepare for emergencies
   - **Training**
   - **Procedures and plans**
   - **Back-up facilities and tools**
   - **Communications**
8) The control area is responsible for its system

Indian Blackout
July 2012

Interconnection Among 4 Affected Regions



REPORT OF THE ENQUIRY COMMITTEE

ON

GRID DISTURBANCE

IN NORTHERN REGION

ON 30th July 2012

AND

IN NORTHERN, EASTERN & NORTH-EASTERN REGION

ON 31st JULY 2012

16th AUGUST 2012
NEW DELHI

Factors that led to the initiation of Grid Disturbance on 30 July, 2012

- Weak Inter-regional Corridors due to multiple outages: The system was weakened by multiple outages of transmission lines in the WR-NR interface.
- High Loading on 400 kV Bina-Gwalior-Agra link due to the overdrawal by some utilities
- Inadequate response by SLDCs to the instructions of RLDCs to reduce overdrawal by the NR utilities and underdrawal/excess generation by the WR utilities.

31 July 2012 Blackout

- Weak Inter-regional Corridors due to multiple outages.
- High Loading on 400 kV Bina-Gwalior-Agra link: The overdrawal by NR utilities contributed to high loading on this tie line.

31 July 2012 Blackout

- Inadequate Response by SLDCs to RLDCs' instructions on this day also to reduce overdrawal by the NR utilities and underdrawal by the WR utilities.

- Tripping of 400 kV Bina-Gwalior line on zone-3 protection of distance relay.

Sequence of Events Leading to the Blackouts

On 30th July, 2012, after NR got separated from WR due to tripping of 400 kV Bina-Gwalior line, the NR loads were met through WR-ER-NR route, which caused power swing in the system. Since the center of swing was in the NR-ER interface, the corresponding tie lines tripped, isolating the NR system from the rest of the NEW grid system. The NR grid system collapsed due to under frequency and further power swing within the region.

Sequence of Events Leading to the Blackouts (2)

On 31st July, 2012, after NR got separated from the WR due to tripping of 400 kV Bina-Gwalior line, the NR loads were met through WR-ER-NR route, which caused power swing in the system. On this day the center of swing was in the ER, near ER-WR interface, and, hence, after tripping of lines in the ER itself, a small part of ER (Ranchi and Rourkela), along with WR, got isolated from the rest of the NEW grid. This caused power swing in the NR-ER interface and resulted in further separation of the NR from the ER+NER system. Subsequently, all the three grids collapsed due to multiple tripping attributed to the internal power swings, under frequency and overvoltage.

Some Parts of the System Survived

- The WR system, however, survived due to tripping of few generators in this region on high frequency on both the days.
- Southern Region (SR) also survived on 31 July, 2012 with part loads remained fed from WR and the operation of few defense mechanism, such as AUFLS and HVDC power ramping.
- On both the days, no evidence of any cyber attack has been found by the Committee.

Measures that could have saved the system from collapse

- Better coordinated planning of outages of state and regional networks, specifically under depleted condition of the inter-regional power transfer corridors.
- Mandatory activation of primary frequency response of Governors i.e. the generator's automatic response to adjust its output with variation in the frequency.

Measures that could have saved the system from collapse (2)

- Under-frequency and df/dt based load shedding relief in the utilities' networks.

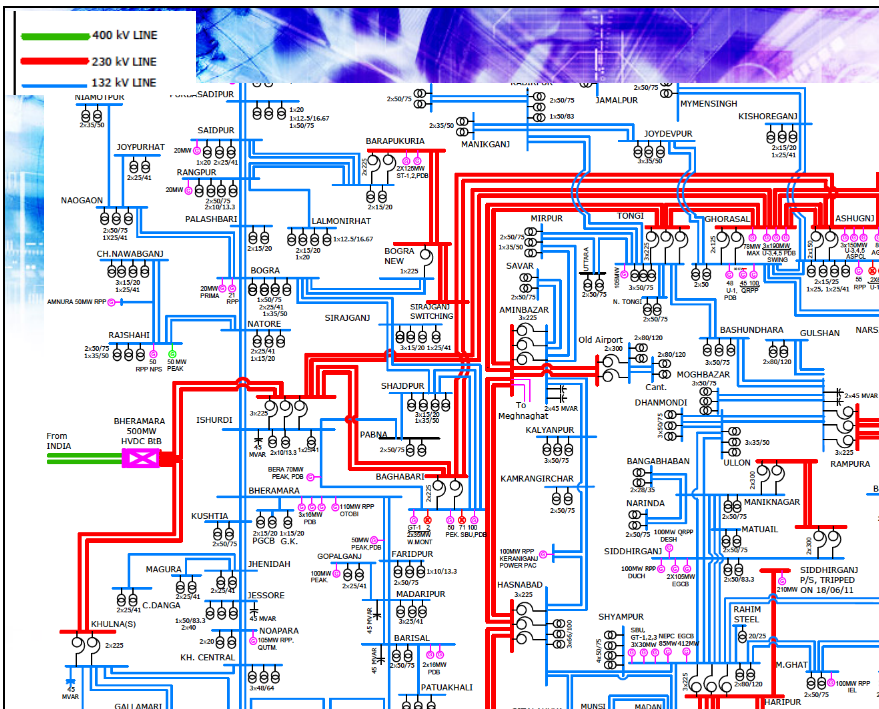
- Dynamic security assessment and faster state estimation of the system at load dispatch centers for better visualization and planning of the corrective actions.

Measures that could have saved the system from collapse (3)

- Adequate reactive power compensation, specifically Dynamic Compensation.
- Better regulation to limit overdrawal/underdrawl under insecure operation of the system.
- Measures to avoid mal-operation of protective relays, such as the operation of distance protection under the load encroachment on both the days.
- Deployment of adequate synchrophasor based Wide Area Monitoring System and System Protection Scheme.

Bangladesh Scenario


POWER GRID COMPANY OF BANGLADESH LTD. (PGCB)
400 KV, 230 KV & 132 KV GRID NETWORK (EXISTING, U/C & PLANNED)
LEGEND
DHAKA
CTG
BAY OF BENGAL


400 kV LINE
230 kV LINE
132 kV LINE
NIAMOTPUR
PURBASADIPUR
SAIDPUR
JOYPURHAT
RANGPUR
BARAPUKURIA
MANIKGANJ
JAMALPUR
MYMENSINGH
KISHOREGANJ
JOYDEVPUR
NAOGAON
PALASHBARI
LALMONIRHAT
MIRPUR
TONGI
GHORASAL
ASHUGNJ
CH.NAWABGANJ
BOGRA
BOGRA NEW
SAVAR
NATORE
SIRAJGANJ
SIRAJGANJ SWITCHING
AMINBAZAR
RAJSHAHI
BASHUNDHARA
GULSHAN
Old Airport
MOGHBAZAR
SHAJDPUR
Cant.
DHANMONDI
From INDIA
BHERAMARA 500MW HVDC BtB
ISHURDI
PABNA
To Meghnaghat
KALYANPUR
ULLON
RAMPURA
BAGHABARI
BANGABHABAN
KAMRANGIRCHAR
BHERAMARA
NARINDA
MANIKNAGAR
KUSHTIA
MATUAIL
SIDDHIRGANJ
MAGURA
JHENIDAH
GOPALGANJ
FARIDPUR
C.DANGA
JESSORE
MADARIPUR
HASNABAD
SIDDHIRGANJ P/S, TRIPPED ON 18/06/11
KHULNA(S)
NOAPARA
SHYAMPUR
RAHIM STEEL
KH. CENTRAL
BARISAL
M.GHAT
PATUAKHALI
GALLAMARI
BAGRHAT
SITALAKHYA
MUNSI
MADAN
HARIPUR

India-Bangladesh Cross-Border Power Transfer

Back-to-Back HVDC Terminal in Bangladesh

Thank You

Dr. Saifur Rahman

Joseph Loring Professor and Director
Advanced Research Institute
srahman@vt.edu

www.saifurrahman.org