Part 1, 2 and 3 Summary

- Part 1 - case study US/CA 2003 Blackout
- Part 2 - Scientific industry (STEM) renewed focus on Situational Awareness & Risk Management
- Part 3 - case study Pacific SW 2011 event
Part 1 Overview

- Overview of system and entities
- Root Cause Analysis - Key Steps
- Sequence of Events prior to uncontrollable cascade failure
- Determination of Root Causes - 3 “T”s
- Uncontrollable wide area cascade
- Joint Task Force Recommendations
Initial Conditions – 8/14/2003 Not Unusual
(thousands of key conditions captured)

Root Cause Analysis – Key Steps

- Early Capture of ALL Recordings and Logs
  - Digital & analog data, communications, email, audio, video, etc.

- Investigation Team Formation
  - Key subject matter specialists

- Document System Initial Conditions
  - Key entity data several hours prior to event

- Determine Precise Sequence of Events

- Ask endless Questions – Root of each Step in Sequence
  - Confirm answer to key Questions

- Avoid hidden agendas, off Sequence tangents, etc.
Investigation Team Overview

- **Steering Group**
- **U.S – Canada Task Force**
- **Investigation Team Leaders**
  - **Root Cause Analysis**
  - **Sequence of Events**
    - Jim Robinson – Team Leader
- **Vegetation/ROW Management**
  - **Transmission System Performance, Protection, Control, Maintenance & Damage**
  - **Generator Performance, Protection, Controls Maintenance & Damage**
- **MAAC/ECAR/NPCC Coordinating Group**
  - **MAAC**
  - **ECAR**
  - **NPCC**
  - **MEN Study Group**
- **Project Planning and Support**
  - **NERC & Regional Standards/Procedures & Compliance**
  - **Restoration**
  - **Data Requests and Management**
  - **System Modeling and Simulation Analysis**
- **Sequence Start Determination**
  - East Lake Generator #5 Trip: 1:31:34 PM
  - **Transmission Lines**
    - 765 kV
    - 500 kV
    - 345 kV
    - 230 kV

Sequence Start Determination
East Lake Generator #5 Trip: 1:31:34 PM
“Tools”
Control Area (CA) Entity - Computer Failures

- 2:14 PM - Alarm logger fails and operators are not aware
  - S. Canton - Star 345 kV line trip and reclose at 2:27 PM (both ends)

- 2:41 PM - server hosting alarm processor and other functions fails to backup

- 2:54 PM - backup server fails (2 of 4 servers down)
  - 2 servers continue to function but with long refresh (~59 second)
  - unidentified Harding - Chamberlin 345kV line outage at 3:05 PM

- 3:08 PM - IT warm reboot of servers appears to work but alarm process not tested and still in failed condition

Root Cause Analysis Phases

- 16:15 - BLACKOUT
- 16:06 - Initial Focus
  - Sammis – Star
  - Star – South Canton
  - Hanna – Juniper
  - Chamberlin - Harding
- 15:05 - Pre-Existing Conditions
  - E.g. voltages, wide-area transfers, line and generator outages, etc.
Power System High Level Sequence

- Premature failure of three 345kV lines
  - starting at 3:05 PM, three permanent outages within 36 minutes due to tree branches to close underneath heated conductors

- Northern Ohio 138kV cascade began
  - started 3:39 PM - caused by above 345kV premature failures
  - 138kV conductors severely overheated beyond design limits

- Northern Ohio 345kV high speed cascade
  - overloaded line trips 4:05:57 - 4:09:07 PM
  - accelerated by Zone 3 directional distance relays

- Eastern Interconnection Separates by 4:11PM
Hanna-Juniper (3:05:41) (3:32:03)

Star - S. Canton (3:41:35)
Situation after Initial Trips  3:05:41 – 3:41:35

Hanna - Juniper Tree Contact
Inadequate tree clearance = Premature failure
Root Cause #1 “Trees”

Transmission Owner Vegetation Management

- Transmission Owner (TO) did not adequately manage tree branch clearance under hot conductors. Conductors could not reach maximum rated temperature.

- NERC requires line rating be calculated based on most limiting element.
  - Including conductor temperature limit due to non-standard clearances (i.e. buildings, telephone wires, etc.) underneath the conductor; but prior to 2007 did not require adequate clearance to trees.

- TO did not comply with its own Utility Vegetation Management program (UVM Report page 50, #2)

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**Diagram:**

- **G** = Max Sag Ground Clearance – Determined from Line Plan & Profile
- **WSZ** = Wire Security Zone (Table 1)
- **A** = Additional Clearance to allow for Growth of Vegetation
Northern Ohio 138 kV Cascade contributes to Sammis-Star 345 kV overload

Root Causes #2 & #3 “Tools & Training”
Situational Awareness & Human Communication Training, Command & Control Tools (TOP alarms fail 2:14PM)
Directional Distance Relays

\[ V = V_0 + jX_0 \]

LINE constant impedance

\[ I = \text{current vector} \]

Relay Measurement:

\[ Z_a = \left( \frac{V}{I} \right) = (R_a + jX_a) \]

Voltage vector

System Impedance

Ra (resistance)

Zone 1

(0 delay)
Sammis-Star Zone 3 Relay Operates

Northern Ohio 345kV High Speed Cascade begins
Loss of Sammis - Star 345 kV Line 4:05:57 PM
Major Path to Cleveland Blocked
Root Causes – 3 “T”s

- **“T”rees**
  - Failure to manage tree growth in ROWs
    - to achieve maximum conductor design temperature

- **“T”ools**
  - Inadequate Situational Awareness
  - Failure of Reliability Coordinator’s diagnostics
  - Lack of load shedding capability

- **“T”raining**
  - Lack of effective situational communication
  - Lack of decision & orders to shed line load

Reliability Standard Violations

- Failure to return system to safe operating state within 30 minutes
- Failure to notify others of impending emergency
- Adequate contingency analysis not performed
- Inadequate training
- Reliability Coordinator did not notify others
- Reliability Coordinator did not have adequate monitoring capability
Uncontrollable Cascade Begins at 4:06PM

- Premature failure of three 345kV lines
  - starting at 3:05 PM, three permanent outages within 36 minutes due to tree branches to close underneath heated conductors

- Northern Ohio 138kV cascade began
  - started 3:39 PM - caused by above 345kV premature failures
  - 138kV conductors severely overheated beyond design limits

- Northern Ohio 345kV high speed cascade of overloaded lines 4:05:57 - 4:09:07 PM
  - accelerated by Zone 3 directional distance relay loadability

- Eastern Interconnection Separates by 4:11PM
Generation Trips 4:09:08 – 4:10:27 PM

345 kV Zone 3 Relays Accelerate Cascade
Argenta-Battle Creek lines trip 4:10:36 – 4:10:37PM
Three 345 kv Lines trip from 4:10:37.5 - 4:10:38.6 PM
New Phase Begins - “Transient Instability”

Power Transfers Shift at 4:10:38.6 PM
Eastern Michigan (Detroit) Transient Instability
MW & Voltage Swings (& N-S Pole Slipping)

Northeast Island Completes Separation from Eastern Interconnection  4:10:43 – 4:10:45 PM
End of the Cascade

Area affected by blackout – pockets of generation and load remain on

Outage Summary

By **Generation** type:

- Conventional steam units: 67 plants (39 coal)
- Combustion turbines: 66 plants (36 combined cycle)
- Nuclear: 10 plants
  
  (7 US and 3 Canadian, totaling 19 units)
- Hydro 101
- Other 19
Operation Summary

- Line and Transformer operations from 3:05 PM to 4:13 PM
  - Line outages - 404
  - Transformer outages - 20
- 50 million people
  - 8 states and 2 provinces
- 60-65,000 MW of load initially interrupted
  - 11% of Eastern Interconnection

Joint Task Force Report 4/5/04 - Chapter 10

Forty-six Recommendations

- Group I - Institutional Issues Related to Reliability
  - Recommendations 1-14
- Group II - Support and Strengthen NERC’s Actions of February 10, 2004
  - Recommendations 15-31
- Group III - Physical and Cyber Security of North American Bulk Power Systems
  - Recommendations 32-46
- Group IV - Canadian Nuclear Power Sector
  - Recommendations 45-46
Joint Task Force Report 4/5/04 - Chapter 10

Group I - Institutional Issues Related to Reliability
Recommendations (1-14)

- Make reliability standards mandatory and enforceable, with penalties for noncompliance (1)
- Strengthen institutional framework (3)

Group II - Support NERC 2/10/04 Actions

- **Strategic Initiatives:**
  - Vegetation Management standards & performance (16)
  - Strengthen Compliance Enforcement Program (17)
  - “Control Area” & “Reliability Coordinator” audits (18)
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Situational Awareness & Risk Management

- Why did the Control Area and Reliability Coordinator lose “Situational Awareness”?
- Why did the first three 345kV lines trip prior to reaching maximum rated conductor temperature?
- Why did operators fail to jointly take heroic action?
Part 2 Overview
during ‘Chat & Chew’ time

- **Keynote** speaker - Dave Nevius
- **Risk Management** - Jim Robinson
  1. **Failure Modes** (identification & likelihood)
  2. **Consequences** (of each Failure Mode)
  3. **Costs** (to improve step 1 or 2, or both)

- Professional Scientist (STEM) are key in performing **Risk Management** evaluations

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The Over-Protected Kid

New research shows he’ll grow up to be more fearful and less creative.

*By Hanna Rosin*
Part 2 Overview
during ‘Chat & Chew’ time

- **Risk Management** (3 above steps) may be quick & easy OR require formal study.
  - DO NOT miss any of the 3 steps

- During the next blackout or failure mode resulting in major consequences, will you be included?

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**Slides to remember . . . “Trees”**

- *G* = Max Sag Ground Clearance – Determined from Line Plan & Profile
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Slides to remember . . . "Tools & Training"

Situational Awareness & Human Communication Training, Command & Control Tools (TOP alarms fail 2:14PM)

Slides to remember - Directional Distance Relays

\[ R_L + jX_L \]

LINE constant impedance

\[ I_L \]

(current vector)

Relay Measurement:

\[ Z_a = \left( \frac{V}{I_L} \right) = (R_a + jX_a) \]

\[ X_a \]

Zone 1

(0 delay)

\[ R_a \]

(resistance)

System Impedance

Voltage vector
Keynote speaker – Dave Nevius

Risk Management – Jim Robinson
1. Failure Modes (identification & likelihood)
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Any Questions ??