Present Industry Practices with Cascading Outages

CAMS/RRPA Panel
Cascading Failures: Advanced Methodologies, Restoration and Industry Perspectives

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1. Objectives
2. Who is Idaho Power?
3. What is a Cascading Outage?
4. NERC Standards applicable to Cascading
5. Extreme Events in Cascading Analysis
6. Conclusions
1. Objectives

- Present the current industry practices in dealing with several NERC standards applicable to cascading.
- Present a comprehensive, practical approach to evaluate the ability of a system to survive extreme contingencies and identify the effects of extreme contingencies.
- Investigate how two corrective strategies generation re-dispatch and load shedding are effective in alleviating or minimizing the impact of extreme contingencies.
- Demonstrate the effects of extreme contingencies by using IEEE RTS-96 test system and an actual Idaho portion of the WECC system with respect to NERC Standards TPL-001-4 and CIP-014-1.
2. Who is Idaho Power?

• Idaho Power was born in 1916, when five companies combined assets, including water rights and hydroelectric facilities on the Snake River, to form Idaho Power.
• 500,000+ customers in states of Idaho and Oregon
• 24,000 square mile service territory
• Transmission & Distribution Circuitry:
  – 4,858 miles of transmission lines
  – 27,072 miles of distribution lines
• 3,000 MW generation capacity at 20 plant sites
• 2014 Energy Sources: Hydro 36%, Thermal 40% Purchased Power 24%
• 16 Interconnections with 5 neighboring utilities
• The 2014 Summer Peak was 3,407 MW
2. Idaho System
3. What is a Cascading Event?

- NERC defines **cascading outages** “as the uncontrolled loss of any system facilities or load, whether because of thermal overload, voltage collapse, or loss of synchronism, except those occurring as a result of fault isolation”

- IEEE CFWG definition: Cascading Failure is a Sequence of Dependent Failures of Individual Components that successively Weaken the Power System

**Cascading:**

Cascading occurs when a BES element is interrupted due to any Disturbance and the original power flow across the element is shifted to other BES elements causing those BES elements to exceed their capacity and interrupt, shifting power flow to other BES elements causing those BES elements to exceed their capacity and interrupt, and so on.
3. What is an Extreme Event?

Extreme events:

- Two or more dependent or separate events being an unplanned loss and/or failure of elements on the BES that results in the loss of multiple facilities not common to a single zone of protection.
- Extreme events can be the result of widespread cascading elements initiated by equipment failure, lightning strike, foreign intrusion, human error, the environment, contamination, sabotage, vandalism or fire or multiple element outages initiated by regional disaster events (e.g., hurricane or volcano) on transmission infrastructure.
- CIP-014 type of extreme contingencies is defined by the following criteria:
  - Transmission facilities operated at 500 kV or higher
  - Transmission facilities operated between 200 kV and 499 kV with “aggregate weighted value” exceeding 3000 units.
3. Generic Scenario of a Cascading Event

What is risk?
Risk = Probability * Consequence

0 – System State Before Cascading Event
1 – Contingency Conditions
2 – Triggering Events
3 – Power Flow Surges, Voltage problems, Overloads
4 – Protection System Trips Lines, Transformers, Generators (Insecure System State)
5 – System Separation, Instability and Voltage Collapse
6 – Blackout Event
3. Cascading and Blackouts

- Most large blackouts happening throughout the world involve a sequence of cascading outages that are complex and require adequate methodologies and tools to be addressed properly.
- Recent blackouts expose transmission planners and operation engineers to new challenges.
- To minimize the impact of cascading outages, the following mitigation measures are used: generation re-dispatch, under frequency and under voltage load shedding, controlled islanding, tie line re-scheduling, etc.

<table>
<thead>
<tr>
<th>Location</th>
<th>Date</th>
<th>Duration</th>
<th>Population affected</th>
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</thead>
<tbody>
<tr>
<td>Pakistan</td>
<td>26/01/2015</td>
<td>9 hours</td>
<td>140,000,000</td>
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<tr>
<td>Bangladesh</td>
<td>01/11/2014</td>
<td>10 hours</td>
<td>150,000,000</td>
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<td>India</td>
<td>31/07/2011</td>
<td>48 hours</td>
<td>620,000,000</td>
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<td>Brazil</td>
<td>04/02/2011</td>
<td>16 hours</td>
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<td>Brazil &amp; Paraguay</td>
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4. NERC Planning Standards

- **R3.3** states that contingency analysis should “Simulate the removal of all elements that the Protection System and other automatic controls are expected to disconnect for each Contingency without operator intervention”, including: Tripping of generators where simulations show generator bus voltages or high side of the generation step up (GSU) voltages are less than known or assumed minimum generator steady state or ride through voltage limitations. Tripping of Transmission elements where relay loadability limits are exceeded.

- **R3.5** - Identify the planning and extreme events in Table 1 which are expected to produce more severe system impacts, and evaluate their consequences including Cascading. Conduct a cascading evaluation to develop possible actions to reduce the Cascading likelihood or “mitigate the consequences and adverse impacts”.

- **R4.5.** If the analysis concludes there is Cascading caused by the occurrence of extreme events, an evaluation of possible actions designed to reduce the likelihood or mitigate the consequences of the event(s) shall be conducted.

- **R5.** Each Transmission Planner and Planning Coordinator shall have criteria for acceptable System steady state voltage limits, post-Contingency voltage deviations, and the transient voltage response for its System. For transient voltage response, the criteria shall at a minimum, specify a low voltage level and a maximum length of time that transient voltages may remain below that level.

- **R6.** Each Transmission Planner and Planning Coordinator shall define and document, within their Planning Assessment, the criteria or methodology used in the analysis to identify System instability for conditions such as Cascading, voltage instability, or uncontrolled islanding.
4. NERC CIP-014 Standard

- **CIP-014-1** Purpose is to identify and protect Transmission stations and Transmission substations, and their associated primary control centers, that if rendered inoperable or damaged as a result of a physical attack could result in widespread instability, uncontrolled separation, or Cascading within an Interconnection.
4. CIP-014-1 PAC/APS Methodology

- **Base Case:** Summer planning case or cases representing other seasons as deemed necessary
- **Power Flow:** Cascading analysis – up to three successive iterations or as determined by the TO.
- **Power Flow Criteria:**
  - Trip lines loaded above 125% of seasonal short term emergency rating.
  - Trip generators whose terminal voltage below 0.90 p.u.
- **Transient Study:** Apply three phase fault with delayed clearing of the stuck breaker on a line or bus section that will result in the more severe system impact
- **Stability Criteria:**
  - Voltage recovery >80% of pre-contingency voltage within 30 seconds
  - Oscillations damped with 30 seconds
- **Definition of Cascading:**
  - Successive loss of transmission lines due to overloading over 125% of seasonal short term emergency rating.
  - Successive loss of generators due to terminal voltage below 0.9 p.u.
- **Definition of widespread instability:**
  - Voltage recovery <80% of pre-contingency voltage within 30 seconds.
  - Oscillations are not damped within 30 seconds

VOLTAGE PERFORMANCE PARAMETERS

- Initial Voltage
- Fault Cleared
- 20% Voltage Dip
- Maximum Transient Voltage Dip
- Time Duration of Voltage Dip Exceeding 20%

POST TRANSIENT VOLTAGE DEVIATION

FROM POST TRANSIENT POWER FLOW STUDY

MAXIMUM TRANSIENT VOLTAGE DIP (%) = \frac{\Delta V_1}{\text{INITIAL VOLTAGE}} \times 100%

TIME

0 SECONDS

10 SECONDS

1 to 3 MINUTES
5. Analysis of Extreme Contingencies

Fig. 1 Diagram of extreme contingencies by source, results, and mitigation measures.
5. Analysis of Cascading Outages

Simulation methodology is applied via the following steps

• Creating a list of Initiating Events
• Applying fast sequential contingency simulation to identify critical outages and potential cascading modes
• Outages are consecutively applied until:
  – System fails to solve due to voltage instability;
  – Thermal/voltage violations are alleviated or exceed the thresholds.
  – Islands are identified
  – Loss of load and generation is monitored and reported
• Summarizing the Results and listing the outages that lead to Cascading Instability
### 5. The Results of Cascading Analysis

<table>
<thead>
<tr>
<th>Case</th>
<th>Type of Contingency</th>
<th>Number of Initiating Events</th>
<th>Number of Occurrences of Voltage Instability</th>
<th>Number of Occurrences of Cascading</th>
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<tbody>
<tr>
<td>RTS-96</td>
<td>Sub + sub</td>
<td>2701</td>
<td>55</td>
<td>13</td>
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<tr>
<td>15HS</td>
<td>Sub + sub</td>
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6. Conclusions

- Industry needs further development of methodologies and models for analyzing cascading outages.
- Cascading outages need to be analyzed in both steady state and transient domain.
- Practical approaches need to fully simulate protective relays operation.
- Models need to incorporate RAS and operating procedures into the analysis.
- Improve visualisation and decision support tools to reduce human error and help limit the scope of the cascade (using PMU data).
- Apply controlled islanding to limit spread of blackouts and accelerate restoration.