Remedial Action Schemes for Hands-On Relay School
March 13, 2018

Daniel Goodrich
Bonneville Power Administration
Introduction

Daniel Goodrich
BSEE Arizona State University
25 years of SRP work experience (Planning, Protection, Design, Operations, Maintenance)

8 years in BPA Technical Operations, doing RAS Operation testing, and Disturbance Analysis
Registered Professional Engineer (Electrical) in Arizona
Purpose of Presentation

To answer the following questions

1. What is a RAS?
2. Why do we have RAS?
3. What Makes Up a RAS?
4. Where would we be without them?
5. Who has them?
6. WECC RASRS
A Caveat

“Look, it's not in my nature to be mysterious. But I can't talk about it and I can't talk about why.”

Rusty Ryan

Ocean’s Eleven (2001)
NERC Definition of RAS

A scheme designed to detect predetermined System conditions and automatically take corrective actions that may include, but are not limited to, adjusting or tripping generation, tripping load, or reconfiguring a System(s). RAS accomplish objectives such as:

- Meet requirements identified in the NERC Reliability Standards;
- Maintain Bulk Electric System stability;
- Maintain acceptable System voltages;
- Maintain acceptable power flows;
- Limit the impact of Cascading or extreme events
RAS--Problem ➔ Remote or Multi-Site Solution
RAS Exclusions

a. Protection Systems installed for the purpose of detecting Faults on BES Elements and isolating the faulted Elements

b. Schemes for automatic underfrequency load shedding (UFLS) and automatic undervoltage load shedding (UVLS) comprised of only distributed relays

c. Out-of-step tripping and power swing blocking

d. Automatic reclosing schemes

e. Schemes applied on an Element for non-Fault conditions, such as, but not limited to, generator loss-of-field, transformer top-oil temperature, overvoltage, or overload to protect the Element against damage by removing it from service
Exclusion a) Traditional Protection Schemes

Protection Scheme: Local Problem → Local Solution
Exclusion b) UFLS

<table>
<thead>
<tr>
<th>Document name</th>
<th>WECC Off-Nominal Frequency Load Shedding Plan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category</td>
<td>( ) Regional Reliability Standard ( ) Regional Criteria (X) Policy ( ) Guideline ( ) Report or other ( ) Charter</td>
</tr>
<tr>
<td>Document date</td>
<td>May 24, 2011</td>
</tr>
</tbody>
</table>
1b. UFLS Entities participating in the Northwest Power Pool sub-area Coordinated Plan are required to shed their first block of load as soon as frequency has declined to 59.3 Hz, with additional minimum requirements for further load shedding steps as set forth in the following table:

<table>
<thead>
<tr>
<th>Load Shedding Block</th>
<th>Percent of NWPP Sub-Area Load Dropped (Hz)</th>
<th>Frequency Set-Point (Hz)</th>
<th>Tripping Time*</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>5.6</td>
<td>59.3</td>
<td>no more than 14 cycles</td>
</tr>
<tr>
<td>2</td>
<td>5.6</td>
<td>59.2</td>
<td>no more than 14 cycles</td>
</tr>
<tr>
<td>3</td>
<td>5.6</td>
<td>59.0</td>
<td>no more than 14 cycles</td>
</tr>
<tr>
<td>4</td>
<td>5.6</td>
<td>58.8</td>
<td>no more than 14 cycles</td>
</tr>
<tr>
<td>5</td>
<td>5.6</td>
<td>58.6</td>
<td>no more than 14 cycles</td>
</tr>
</tbody>
</table>

Additional automatic load shedding to correct underfrequency stalling

<table>
<thead>
<tr>
<th></th>
<th>Frequency Set-Point (Hz)</th>
<th>Time*</th>
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</thead>
<tbody>
<tr>
<td>2.3</td>
<td>59.3</td>
<td>15 sec</td>
</tr>
<tr>
<td>1.7</td>
<td>59.5</td>
<td>30 sec</td>
</tr>
<tr>
<td>2.0</td>
<td>59.5</td>
<td>1 min</td>
</tr>
</tbody>
</table>

Load automatically restored from 59.3 Hz block to correct frequency overshoot

<table>
<thead>
<tr>
<th></th>
<th>Frequency Set-Point (Hz)</th>
<th>Time*</th>
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<tbody>
<tr>
<td>1.1</td>
<td>60.5</td>
<td>30 sec</td>
</tr>
<tr>
<td>1.7</td>
<td>60.7</td>
<td>5 sec</td>
</tr>
<tr>
<td>2.3</td>
<td>60.9</td>
<td>0.25 sec</td>
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</tbody>
</table>
RAS Exclusions

a. Protection Systems installed for the purpose of detecting Faults on BES Elements and isolating the faulted Elements

b. Schemes for automatic underfrequency load shedding (UFLS) and automatic undervoltage load shedding (UVLS) comprised of only distributed relays

c. Out-of-step tripping and power swing blocking

d. Automatic reclosing schemes

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RAS Exclusions

f. Controllers that switch or **regulate** one or more of the following: series or shunt reactive devices, flexible alternating current transmission system (FACTS) devices, phase-shifting transformers, variable-frequency transformers, or tap-changing transformers; and, that are located at and monitor quantities solely at the same station as the Element being switched or regulated.

g. FACTS controllers that remotely switch static shunt reactive devices located at other stations to regulate the output of a single FACTS device.

h. Schemes or controllers that remotely switch shunt reactors and shunt capacitors for voltage regulation that would otherwise be manually switched.

i. Schemes that automatically **de-energize a line for a non-Fault** operation when one end of the line is open.

j. Schemes that provide **anti-islanding protection** (e.g., protect load from effects of being isolated with generation that may not be capable of maintaining acceptable frequency and voltage).
Exclusions f) and g) FACTS
Exclusion j) Anti-Islanding Schemes

If this breaker opens, then send transfer trip

Other loads and generation

Anti-Islanding detection
RAS--Problem ➔ Remote or Multi-Site Solution

Power Flow

Problem here

Insert Series Capacitors here
RAS Exclusions

k. Automatic sequences that proceed when manually initiated solely by a System Operator

l. Modulation of HVdc or FACTS via supplementary controls, such as angle damping or frequency damping applied to damp local or inter-area oscillations

m. Sub-synchronous resonance (SSR) protection schemes that directly detect sub-synchronous quantities (e.g., currents or torsional oscillations)

n. Generator controls such as, but not limited to, automatic generation control (AGC), generation excitation [e.g. automatic voltage regulation (AVR) and power system stabilizers (PSS)], fast valving, and speed governing
Damping Controller

Pulse applied
Subsynchronous Resonance

Mohave SSR Incident (1970)
An example of SSR Torsional Interaction

- Mohave generator: 1,580 MW coal-fired in NV.
- Gradually growing vibration that eventually fractured a shaft section.
- First investigations incorrectly determined cause. After 2nd failure in 1971 cause was identified as Subsynchronous Resonance.
- An electrical resonance at 30.5 Hz excited a mechanical resonance at 30.1 Hz.
- Problem was cured by reducing compensation percentage and installing a torsional relay.
RAS--Problem $\rightarrow$ Remote or Multi-Site Solution

![Map with解决问题和解决方案标注](image)
Case 1: Simple RAS: Single Line – Single Generator
RAS

- **Remedial**: Supplying a remedy
  - Keep the system stable, even when disturbances occur

- **Action**: Trips generators; inserts capacitors

- **Scheme**: Relays, wires, breakers
Name that film!
Categorizing RAS

1. WECC RAS Reliability Subcommittee (RASRS):
   A. Wide Area Protection Scheme (WAPS)
   B. Local Area Protection Scheme (LAPS)
   C. Safety Net

2. By Detection Method:
   1. Event Based
   2. Response Based (some call it Parameter Based)

3. By arming method: Automatic or manual
Categorizing RAS

- **WAPS:**
  - A RAS whose failure to operate would result in:
    - Violations of TPL-001-WECC-CRT-3 (Planning Criteria for System Performance), or
    - Load loss ≥ 300 MW, or
    - Generation Loss ≥ 1000 MW

- **LAPS:**
  - A RAS whose failure to operate would **not** result in the above

- **Safety Net:**
  - Extreme events
WAPS vs LAPS

What it means to System Protection:

- Test interval
  - 2 years for WAPS
  - 6 years for LAPS
  - No requirement for Safety Net(?)

- Verify who is responsible for testing RAS at your utility
WECC RAS Classifications (2)
Initial Voltage

80% of initial Voltage

Fault cleared

Voltage recovery above 80% of initial Voltage within 20 seconds

WECC Criterion - TPL-001-WECC-CRT-3
WR1.3 Example
DELAYED RECOVERY
Categorizing RAS

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Event Based RAS

Event-based schemes directly detect outages and/or fault events and initiate actions such as generator/load tripping to fully or partially mitigate the event impact.

Is basically digital, not analog.
Event Based RAS

SUB #1

B1
Line 1
B2

SUB #2

B3

G1

Communications Path

Substation #1 Processor

Generator #1 Processor

Trip

B3

52B
CASE 2: Event-Based RAS which is armed based on MW Flow

MW = 550 (Via SCADA)

If Line 2 MW > 500 then Arm

Controller Processor

Arming Point

Controller Processor

Generator #1 Processor

Trip

B5
Response Based RAS

Response-based schemes monitor system response during disturbances and incorporate a closed-loop process to react to actual system conditions.

It often monitors analog quantities.
Response Based RAS

Insert Series Capacitors here

Power Flow

Problem here
Designing a RAS

- Redundant design: “A” and “B”
- Redundant and diverse communication channels
- Cyber-secure (no network connections)
- Equipment monitored 24/7 (alarm when cut out, or equipment or communication circuit fails)
- Time tagging of events (SER)
Procedure to Submit a RAS for Assessment

Information Required to Assess the Reliability of a RAS Guideline

Revised: October 28, 2013

A. RAS PURPOSE AND OVERVIEW

1) Identify the ownership of the RAS (the Reporting Party).

2) Provide the name of the RAS, the purpose and the desired in-service date. Include the specific type of system problem(s) being solved, e.g. transient stability, thermal overload, voltage stability, etc.

3) Provide the owner’s classification of the RAS as a LAPS, WAPS, or SN.
CASE #3: Multiple Lines – Multiple Generators

If Line 3 is offline and Line 1 or 2 trips, then trip all enabled units.

Line 1 offline
Line 2 offline
OR
Line 3 offline
Trip
CASE #4: Speed up The RAS

If Line 1 trips then trip G1

Line Relay -> Substation #1 Processor -> Controller #1 Processor -> Controller (PLC) -> Arming Point -> Controller Processor -> Generator #1 Processor

Trip Bus from Line Relay

52B

B1

Substation #1

Line 1

B2

SUB #1

B3

Line 2

B4

SUB #2

SLOWER

FASTER
What film is this?
Why do we have RAS?

- To Increase Path Capacity ($) without putting more wire in the air.
- To Maximize the reliability and power transfer capability
Typical South of Allston Power Flows
Hydro in Canada

Load in Portland, California

3: OVERLOAD

1: LINE FAULT
2: LINE TRIPS
Why We Need RAS
Is this path rated 1,200 MW?

G1
Gen = 300MW

G2
Gen = 300MW

G3
Gen = 300MW

Others

Line 1
Rating = 400MW
Loading = 300MW

Line 2
Rating = 400MW
Loading = 300MW

Line 3
Rating = 400MW
Loading = 300MW

Load

Load = 300MW

Load

Load = 300MW

Other Loads

Load = 300MW
Why We Need RAS: Outage Condition

Line 1
Rating = 400MW
Loading = 0MW

Line 2
Rating = 400MW
Loading = 450MW

Line 3
Rating = 400MW
Loading = 450MW

G1
Gen = 300MW

G2
Gen = 300MW

G3
Gen = 300MW

Load = 300MW
Why We Need RAS: No RAS corrective action
Generator or Load De-rate to anticipate outage

Line 1
- SUB #1
- G1: Gen = 266 MW
- B1
- Rating = 400MW
- Loading = 300MW
- SUB #2
- B2

Line 2
- B3
- Rating = 400MW
- Loading = 300MW
- B4

Line 3
- B5
- Rating = 400MW
- Loading = 300MW
- B6

Load = 266 MW
Why We Need RAS: Potential RAS
Action #1 – Load & Gen Drop
Why We Need RAS: Potential RAS Action #2 – Gen Runback

- G1
  - Gen = 200MW
  - SUB #1
  - B1
  - Line 1
    - Rating = 400MW
    - Loading = 0MW

- G2
  - Gen = 300MW
  - SUB #1
  - B3
  - Line 2
    - Rating = 400MW
    - Loading = 400MW

- G3
  - Gen = 300MW
  - SUB #1
  - B5
  - Line 3
    - Rating = 400MW
    - Loading = 400MW

- Load
  - SUB #2
  - B2
  - Rating = 300MW

  - SUB #2
  - B4
  - Rating = 300MW

  - SUB #2
  - B6
  - Rating = 300MW
RAS: Where would we be without them?
Why do we have RAS?

Remedial Action Schemes are designed to relieve three types of power system problems:

1. **Thermal overloads** (must mitigate in minutes)

2. **Voltage Stability** (seconds to minutes)

3. **Transient Stability** (cycles to seconds)
Thermal Limitation

- Usually caused by loss of parallel transmission.
- Not usually an instantaneous problem.
  - Transmission lines limited by continuous loading sag limit
  - Current flow may be above continuous rating instantaneously after the outage, but it takes time for heating of line to reach its sag limit
Transmission Sag Limit

LINE SAG INCREASES WITH CURRENT

Minimum Clearance

Sag limit at maximum operating temperature determines current carrying capability of line
Thermal limits for Lines

Time vs Conductor Temperature

- Conductor Temp
- Max Operating Temp (MOT)
- Current

RAS required if MOT reached before 20min.
Thermal Limit

- If there is less than 20 (some new standards say 30) minutes for dispatcher response before the thermal sag limit is reached, operating limits are lowered or generator dropping (if effective and available) is used to automatically unload the limiting line.
What film?
Voltage Stability Problem

- 500 kV transmission lines reach their surge impedance loading (SIL) long before thermal problems.
- SIL typically reached at 800-1400 MW loading for a 500 kV line (thermal capacity is typically 2100-4000 MW).
- When a 500 kV line is loaded above its SIL it acts like a reactor (pulls the voltage down) and put the system at risk of a voltage collapse if loading increases significantly.
- Switching reactive and dropping generation by RAS is used to maximize transfer capability
Fast or Slow Collapse?

- **Winter**
  - Load profile:
    - Prominent Resistive Heating Loads
    - More heat loads with motors coming online
    - Highest load peaks
  - Collapse:
    - Slow?

- **Summer**
  - Load profile:
    - Many AC units (motor loads)
    - Experiencing Higher peaks
  - Collapse:
    - Fast
Megawatts on path

Per Unit Voltage on a Bus

Outage Contingencies

MW Flow

Voltage

Megawatts on path
System Compensation effects on Voltage Stability

- Shunt Capacitors: High risk of system failure, sometimes called “Cliff Effect”
- Series Capacitors or New Transmission
- System with no Compensation

Graph showing the relationship between Per Unit Voltage and Power Transfer Capability.
Megawatts on path Per Unit Voltage on a Bus Outage Contingencies
Transient Stability Problems

- Large angle needed to transfer large amounts of power across the system.
  - It is a function of your angle, receiving and sending end voltage, and system impedance.
  - A higher system impedance requires a larger angle to transmit the same amount of power.

- Loss of parallel transmission lines increases the system impedance and therefore the angle.

- Higher angle is an indication of higher system stress.

- Fast remedial action response is needed (8-30 cycles) to maintain a stable system.
Transient Stability

- 3-phase fault with no RAS
- UNSTABLE
Transient Stability

- 3-phase fault at with 600 MW generator dropping
- Stable with low frequency
Transient Stability

- 3-phase fault with 1400 MW Chief Jo brake inserted for 0.5 seconds
- Stable and frequency normal
Chief Joseph Braking Resistor

- 1,400 MW three phase resistive load
- The world’s largest toaster
Manual Arming

- If a RAS is not automated, a Dispatcher must watch the line flows and outage conditions, and arm the appropriate RAS.
Monitors and Alarms

Alarms monitored with Sequence of Event Recorders

- Line Loss
- Comm fail

- Cutout
- Equipment trouble

Substation #1 Processor

Controller Processor

SCADA Line 2 MW

Controller PLC

If Line 2 MW > 500 then Arm

Arming Point

Controller Processor

Generator #1 Processor

Trip

Alarms monitored by SCADA
Film name?
When does the System Protection World care about RAS?

- NERC Required Annual RAS Test
  - Sending inputs from field sites to controllers
  - Assisting with overall test directed by Operations
- Setting changes in field sites
- New RAS Installations
  - Assists with writing the procedure, and performing output site testing when required
- Alarm and event response
# RAS Timing: From Fault Inception to Generator Drop

<table>
<thead>
<tr>
<th>Fault Inception to time sent (msec)</th>
<th>Travel time</th>
<th>Processor time</th>
<th>PLC time</th>
<th>Processor time</th>
<th>Travel time</th>
<th>Breaker Time</th>
<th>Overall Time</th>
<th>Overall Cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>20</td>
<td>8</td>
<td>30</td>
<td>8</td>
<td>20</td>
<td>50</td>
<td>161</td>
<td>9.7</td>
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</table>
Outage Considerations

- Cannot take both primary controls out of service without adjusting the system (limiting paths) before the outage
- When taking one controller or monitor, must consider what remains in service
What can be taken out?

- Monitor B1A and B
- Monitor B1A
- Monitor B1B
- Monitor B2A
- Monitor B2B

SUB #1

SUB #2
Common RAS Problems (about one per year)

- Customer changes out generator breaker, forgets to re-connect RAS trip input.
- DC ground induces temporary signal input to processor, triggering RAS
- Equipment left cut out, or wires lifted and not laid down
- Wrong unit armed to trip
- Communications failures in bad weather cause false indication of line loss
Summary

Hopefully you now know:

1. What is a RAS?
2. Why do we have RAS?
3. What Makes Up a RAS?
4. Where would we be without them?
5. Who has them?
WECC Meeting Room
<table>
<thead>
<tr>
<th>Name</th>
<th>Organization</th>
<th>Role</th>
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<tbody>
<tr>
<td>Leghari, Noor</td>
<td>Alberta Electric System Operator</td>
<td>Member</td>
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<tr>
<td>Flores, Al</td>
<td>Arizona Public Service Company</td>
<td>Member</td>
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<tr>
<td>Damron, Kevin</td>
<td>Avista Corporation</td>
<td>Member</td>
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<tr>
<td>Kerr, John</td>
<td>Bonneville Power Administration</td>
<td>Member</td>
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<tr>
<td>Barone, Ralph</td>
<td>British Columbia Hydro &amp; Power Authority</td>
<td>Member</td>
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<tr>
<td>Subakht, Dede</td>
<td>California Independent System Operator</td>
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<td>Smith, Tyler</td>
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<td>Imperial Irrigation District</td>
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<td>Kirby, Douglas</td>
<td>Los Angeles Department of Water and Power</td>
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<td>Kachmanik, Daniel</td>
<td>NorthWestern Energy</td>
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<td>Henneberg, Gene</td>
<td>NV Energy</td>
<td>Chair</td>
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<td>Erwin, Davis</td>
<td>Pacific Gas and Electric Company</td>
<td>Member</td>
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<td>Patzkowski, Milton</td>
<td>PacifiCorp</td>
<td>Vice Chair</td>
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<td>Nuthalapati, Sarma</td>
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<td>Dhillon, Malkiat</td>
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<td>Zhang, Bill</td>
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<tr>
<td>Head, Wilson</td>
<td>Western Area Power Administration</td>
<td>Member</td>
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</tbody>
</table>

WECC RASRS
WECC Meeting Activity

- New RAS (or modification of existing)
  - Purpose and categorization
  - Design of the system
  - Planning study results
  - Communications

- Results
  - Approval
  - Conditional Approval (must come back and fill in missing info)
  - Rejection or Deferral
Western Interconnection

- About 350 RAS
  - 140 trip generation
  - 30 ramp generation
  - 70 do load shed
  - 30 trip or insert reactive devices
  - 20 arm on configuration; 80 arm on MW flow
  - 150 trigger on loss of line or transformer

- About 30 entities
Takeaways

- RAS is typically “problem here, solution over there”.
- Find out where your company has RAS (if they will reveal the information), and how they work, and what problem they solve.
- Find out which department tests RAS at your company.
- How do you tell the RAS a line is out for maintenance and to ignore the inputs?