Ronald B. Robie (Thermalito) Pumping Generating Plant Fire on November 22, 2012
- No Serious Injuries -

HANDS ON RELAY SCHOOL
Pullman Washington

March 21, 2014
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Presentation Highlights

• Overview of the State Water Project
• Plant & Flow Characteristics
• Impacts
  – Water Impacts
  – Generation Impacts
  – Restoration & Clean-up Costs
• Recap of the Thermalito Fire Event on November 22, 2012
  – Fire Sequence Summary
• 3 Step Root Cause Analysis: Process Overview
  – Phase I: Investigative analysis of what happened – Incident Command
  – Phase II: Forensic Analysis (Fire forensic & Relay expert analysis)
  – Phase III: Lessons Learned & Next Steps – Apply lessons learned to all SWP plants
• Technical Assessment – Derek Stewart
• 3 Step Root Cause Analysis: Current Status
  – Next Steps: SWP Fire Modernization
State Water Project (SWP)

• Planned, designed, built, operated and maintained by the California Department of Water Resources.

• SWP is the largest state-built multipurpose water project in the U.S.

• DWR’s Mission - “To manage the water resources of California in cooperation with other agencies, to benefit the State's people, and to protect, restore, and enhance the natural and human environments.”

• O&M’s Mission – “Operate and maintain the California State Water Project, to conserve and deliver water, provide flood control, recreation, and fish and wildlife enhancement, all within regulatory requirements and in an economic, reliable and environmentally-sound manner”.
State Water Project Highlights

- Department of Water Resources - State of California
  - Operations & Maintenance: 1200 Staff
    - Northern California: 2/3 rain fall
    - Southern California: 2/3 population
    - State Water Project: Deliver Affordable Water

- State Water Project Characteristics
  - One of the world’s largest water & power systems
    - Largest consumer of energy in California
    - Fourth largest producer of energy in California
  - Asset Management: 5 geographical areas from north to south California
  - 3.0 million acre-feet of water annually: 29 contractors
  - 20 Pumping Plants
  - 8 Hydroelectric Power Plants
    - 3 Pump/Generating Plants
  - 25 Dams
  - 34 Reservoirs
  - 770 Miles of aqueduct & pipelines
State Water Project (SWP)

**State Water Contractors**
- 29 water contractors (all are local public agencies)
- Provides water to 750,000 acres of crops in Central Valley
- SWP water is delivered to approximately 25 million people throughout Northern, Central, and Southern California

**SWP Water Deliveries**
- Total water supply contracts of 4.2 Million Acre - Feet
- Average SWC water delivery has been about 3 Million Acre - Feet with an approximate distribution 50/50 split between agricultural use and urban use

**SWP Facilities**
- 34 storage facilities
- 29 pumping and generating plants
- Over 700 miles of canals and pipelines
- 190 total rotating units - 155 pumps, 14 hydro pump/gens, and 21 hydro generators
State Water Project (SWP)
SWP PUMPING AND GENERATING

• SWP is the single largest power consumer in California.
  – Installed pumping capacity is approximately 2,600MW (highest peak load to date is 2,200MW).
  – About 7,000 GWHr pump load to move water through out California.
  – 40 to 60% of that power comes from our own resources.

• SWP is the fifth largest electrical utility in California.
  – Installed generation capacity about 1,700MW.
  – Similar in size to SMUD (load), about 10% in size compared to PG&E, about 4% of CAISO load.
  – Third largest generator of clean hydro power - about 14% of California’s hydropower.
• **Generation:**
  - Number of Units: 4 total (1 generator, 3 pump/generator)
  - Unit Size: 1 Kaplan type @ 36 MW (4800 cfs), 3 Francis type @ 27 MW (4200 cfs)

• **Pumping:**
  - Number of Units: 3 pump/generator
  - Unit Size: 3 @ 28 MW (3040 cfs)

• Plant has 5 floors – 1 floor at grade (Elevation 165) and 4 floors underground
Oroville Complex Water Movement

Releases from Lake Oroville (Hyatt or spill)

Low Flow Channel - 600 cfs minimum

Water to Thermalito Afterbay

Feather River Service Area diversions
Ronald B. Robie (Thermalito)
Pumping/Generating Plant Fire

Impacts – water and generation

- Flows are being bypassed around the plant utilizing the plant bypass gate (capacity 8,000 cfs).
- Anticipated that regulatory releases will be maintained.
- Do not anticipate any water supply curtailments.
- Estimated lost generation is between $6.5 Million to $10.6 Million yearly – dependent on State Water Project water deliveries.
- Cost of cleanup approximately - $90 Million.
- Estimated cost to restore plant operability - $75 to $100 Million.
Plant Assessment Restoration: Cost Estimate

- The estimate includes costs necessary to recover the plant to the condition that it was prior to the fire.
- The estimate has an accuracy range of +30 to +50%. Some activities have higher contingencies, while others have lower contingencies.
- Equipment estimates obtained from vendor quotes are considered more accurate. Labor and material estimates tend to have higher contingencies.

### Thermalito Fire Recovery Cost Opinion
(Shown in Millions of $)

<table>
<thead>
<tr>
<th>SYSTEM</th>
<th>UNIT 1</th>
<th>UNIT 2</th>
<th>UNIT 3</th>
<th>UNIT 4</th>
<th>COMMON</th>
<th>TOTAL</th>
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<tr>
<td>Main Electrical System</td>
<td>0.58</td>
<td>0.24</td>
<td>0.60</td>
<td>0.25</td>
<td>0.60</td>
<td>0.25</td>
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<td>AC Station Service</td>
<td>0.20</td>
<td>0.07</td>
<td>0.17</td>
<td>0.06</td>
<td>0.13</td>
<td>0.06</td>
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<td>DC Systems</td>
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<td>Plant Service Systems</td>
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<tr>
<td>Main Units</td>
<td>12.09</td>
<td>5.78</td>
<td>10.61</td>
<td>4.92</td>
<td>10.80</td>
<td>5.02</td>
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<tr>
<td>Control Boards</td>
<td>0.62</td>
<td>0.34</td>
<td>0.62</td>
<td>0.23</td>
<td>0.62</td>
<td>0.23</td>
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<td>Supervisory Controls</td>
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<td>Communications</td>
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<td>Maintenance Systems</td>
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<td>Environmental Systems</td>
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<tr>
<td>Fire Fighting Systems</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Balance of Plant</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td><strong>TOTAL COST</strong></td>
<td><strong>$13.49</strong></td>
<td><strong>$6.44</strong></td>
<td><strong>$12.01</strong></td>
<td><strong>$5.46</strong></td>
<td><strong>$12.16</strong></td>
<td><strong>$5.56</strong></td>
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Ronald B. Robie (Thermalito) Pumping/Generating Plant Fire

November 22, 2012

Fire Sequence Summary
Ronald B. Robie (Thermalito) Pumping Generating Plant

Fire Sequence Summary

- 0650: Beginning of multiple SCADA alarms resulting in Unit trips of 1, 2, & 3, all forced out of service.
- 0720: Operator Apprentice directed to site reports to Oroville Field Division Area Control Center heavy smoke on second floor and indication that CO2 systems had discharged.
- 0731: Cal Fire/Butte Co. ECC received 911 call and dispatched full alarm. Fire resources on scene at 0742 and assumed Incident Command.
- 1300: Cal Fire stood down firefighting efforts due to significant smoke and fire conditions for fire fighter safety.
  - Prior to evacuating the plant, Cal Fire installed an unmanned cellar nozzle to continue to fight the fire – ultimately extinguished the fire
  - Plant sustained significant damage to the control room, electrical cables/systems in cable gallery with concrete spalling/damage to the plant structure.
Photo Sequence of Fire (CalFire After Action Review Presentation) 11/22/2012

0808

0918
Photo Sequence of Fire (CalFire After Action Review Presentation) 11/22/2012

0921

0930
Photo Sequence of Fire (CalFire After Action Review Presentation) 11/22/2012

1053

1104
Photo Sequence of Fire (CalFire After Action Review Presentation) 11/22/2012
Fire Extinguished: 11/23/2012

Clean-up Phase: 02/2013
Fire Summary

- Plant sustained significant damage to the control room, electrical cables/systems in cable gallery with concrete spalling/damage to the plant structure.
- **Origin of Fire**: Elevation 136 directly below the Control Room
Clean-up Phase
January – October 2013
Ronald B. Robie (Thermalito) Pumping Generating Plant Fire

Three Step Root-Cause Analysis—Process Overview

• Phase I: Record of Events: Investigative analysis of what happened
  • Document events before, during, and after fire
    • Sequence of Events
    • Equipment History
    • Lessons Learned
• Phase II: Post Fire Forensics: Investigate origin and cause of fire
  • Document investigation and analysis
    • Post Fire Expert Investigation/Analysis (Origin of Fire)
    • Relay/Breaker Expert Analysis (Cause of Fire)
    • Lessons Learned
• Phase III: Lessons Learned & Next Steps: SWP Fire System Modernization
  • Prioritize recommendations from Part I and II
  • Recommendations from Hyatt/Thermalito Fire Detection System Project
  • State Fire Marshal Review/Engagement
  • Management review, prioritize, and Implement recommendations at SWP plants/facilities (phased approach)
Technical Assessment

- Timeline
- Design Review
- Breaker Testing
- Recreate the Event
Timeline - Sources

- Relay oscillography (Event Reports)
- Relay time stamped events (Sequential Event Reports)
- Plant and Unit RTUs
Plan A

Bill and Luis,

I spoke with Robin regarding having SEL retrieve any event reports and SER data from the relays at Thermalito. Here is the process:

1. Get the serial numbers and send them to Robin.
2. Robin will provide an RMA.
3. Ship to SEL.

You should be able to get #1 from the commissioning test reports, which I do not have access to. Please have someone get the SN's for all 300G, 387 and 710 relays for any unit in service at the time of the event, then send to Robin: robin_jenkins@selinc.com

Best regards,
[Signature]
Plan B
Design Review – Circuit 19

- Data collection
- Fault calculations
Fault Calculations – Arcing

<table>
<thead>
<tr>
<th>Calculate fault current and arc resistance for a 1.0 mm gap</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zg = 1 arcng gap in mm</td>
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<tr>
<td>1/2 Fault Bolted = 478.1 Use 1/2 of the bolted fault current as the starting point for the iterative calculations.</td>
</tr>
<tr>
<td>0.88</td>
</tr>
<tr>
<td>90.052 × 10⁻³ Ω</td>
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<tr>
<td>VTH · DCA</td>
</tr>
<tr>
<td>RTH · DCA + RKT19 + Rarc</td>
</tr>
<tr>
<td>572.9 amsps</td>
</tr>
<tr>
<td>Rarc = (20 + 0.534 Zg)</td>
</tr>
<tr>
<td>Iarc</td>
</tr>
<tr>
<td>0.88</td>
</tr>
<tr>
<td>76.8 × 10⁻³ Ω</td>
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<tr>
<td>VTH · DCA</td>
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<tr>
<td>RTH · DCA + RKT19 + Rarc</td>
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<tr>
<td>608.8 amsps</td>
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<tr>
<td>Rarc = (20 + 0.534 Zg)</td>
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<tr>
<td>Iarc</td>
</tr>
<tr>
<td>0.88</td>
</tr>
<tr>
<td>72.799 × 10⁻³ Ω</td>
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<tr>
<td>VTH · DCA</td>
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<td>RTH · DCA + RKT19 + Rarc</td>
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<tr>
<td>620.6 amsps</td>
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<td>Rarc = (20 + 0.534 Zg)</td>
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<td>Iarc</td>
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<tr>
<td>0.88</td>
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<tr>
<td>71.585 × 10⁻³ Ω</td>
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<tr>
<td>VTH · DCA</td>
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<td>RTH · DCA + RKT19 + Rarc</td>
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<td>624.2 amsps</td>
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<td>Iarc</td>
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<td>0.88</td>
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<tr>
<td>71.216 × 10⁻³ Ω</td>
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<tr>
<td>VTH · DCA</td>
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<td>RTH · DCA + RKT19 + Rarc</td>
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<td>625.3 amsps</td>
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<td>Rarc = (20 + 0.534 Zg)</td>
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<td>0.88</td>
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<tr>
<td>71.104 × 10⁻³ Ω</td>
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<td>VTH · DCA</td>
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<tr>
<td>RTH · DCA + RKT19 + Rarc</td>
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<tr>
<td>625.7 amsps</td>
</tr>
</tbody>
</table>

Arcing current and resistance for a 1.0 mm gap converge to the values above.
Battery Energy

- **Energy in Joules for a fully charged 1,000 amp*hour battery**
  - \((1000 \text{ amp} \cdot \text{hours}) \cdot 125 \text{ VDC} = 125,000 \text{ watt} \cdot \text{hours}\)
  - \((125,000 \text{ watt} \cdot \text{hours}) \cdot \frac{\text{Joule}}{1 \text{ watt} \cdot \text{Second}} \cdot \frac{3,600 \text{ seconds}}{1 \text{ hour}} = 450 \text{ Mega Joules}\)

- **How high can it lift my 1,270 kg Civic?**
  - Potential Energy (J) = mass \cdot gravity \cdot height
    - \(h = \frac{450 \times 10^6 \text{ Joules}}{1,270 \text{ kg} \cdot 9.8 \text{ m/sec}^2} = 36.2 \text{ kilometers, or 22.5 miles}\)
The fault calculations revealed that if the positive and negative conductors from circuit 19 were faulted together through a resistance in the form of an arc, the total fault clearing time could be significantly increased. In the molded case circuit breakers (MCCBs) used at Thermoauto and commonly supplied throughout the industry, two separate internal elements can operate to trip the breaker for an overcurrent condition. For low levels of overload, a relatively slow-acting thermal element (bimetallic strip) heats up and trips the breaker in a matter of seconds or minutes depending on the degree of overload. For high short-circuit fault currents an MCCB internal electromagnetic coil operates in less than 0.2 seconds to trip the breaker. The thermal and coil elements each have their own operational time-current characteristics, which are plotted on a single graph to characterize the MCCB performance as a system. The MCCB, being a mechanical system does not have a bright dividing current line below which the thermal element will trip the breaker and above which the fast-acting coil element will trip the breaker. Rather fault clearing time for a current value within this indeterminate region depends on the individual breaker.
Breaker Testing

- MCCB Parts
- Test Set
- Test Results
What’s in an MCCB

- Trip bar
- Current rating
- Bimetallic strip (51 element)
- Braided copper cable
- Coil and plate (50 element)
- Moving Contact
- Fixed Contact
- Arc Chutes
Test Set
Event Recreation

- Positive-to-Negative faults
- Series arcing faults
Positive-to-Negative Faults

Test #1
3.5 mm gap
Single strand short
Series Arcing Fault @ 2.5 amps
3 Step Root Cause Analysis: Current Status

• Phase I: Investigative analysis of what happened – Incident Command
  • Incident Command Report: Completed April, 2013

• Phase II: Forensic Analysis (Fire forensic & Relay expert analysis)
  • Forensic Analysis Report: Completed July 2013
  • **Fire Root Cause Conclusion:** From the investigations performed by fire forensic experts, DWR is confident that Thermalito’s fire point of origin occurred on Elevation 136 in the cable tray gallery.
    • Because so much evidence was incinerated by the fire, along with the complexities and limitations of a root cause fire forensic and laboratory testing analysis, the root cause of the fire could not be conclusively determined.

• Phase III: Document Fire Investigation and lessons learned
  • DWR Report: Completed August, 2013
  • Apply lessons learned to all SWP plants
  • SWP Fire Systems Modernization - Next Steps
SWP Fire Systems Modernization Project(s)

- Project 1: SWP Fire Systems Enhancement and Implementation Plan
  - Enhancement: Goals 1 – 3
    - **Goal 1**: Review and rank the suggested corrective measures and lessons learned, as identified in the Incident Command and DWR Thermalito Fire reports. Use this information to supplement and enhance Goals 2 – 6.
    - **Goal 2**: Develop a quick-hit list, and document actions completed. With assistance from hydroelectric power plant fire systems consultants, provide a list of proactive fire systems actions to be accomplished for SWP plants during 2013/14.
    - **Goal 3**: Continue to work with consultant to address fire risk at Hyatt Power Plant, adjusting tasks to align with future implementation plan (Goal 5).
  - Implementation Plan: Goals 4 – 5
    - **Goal 4**: Perform the following tasks with help of consultants who specialize in hydroelectric power plant fire systems, risk methods, and the California Fire Code.
      - Develop an SWP risk-based fire systems scoring method.
      - Determine and establish current California fire code requirements for SWP plants/facilities.
    - **Goal 5**: Develop an implementation plan for modernizing fire systems statewide for the SWP Phase I plants only (14 main stem plants)
    - **Goal 6**: Develop an implementation plan for modernizing fire systems statewide for the SWP Phase II plants only (remaining 14 plants)

- Project 2: SWP Fire Systems Design and Construction