PG&E System Overview

Headquarters
San Francisco, CA

Service Area
70,000 square miles in northern and central California

Service Area Population
16 million people

Distribution Customer Accounts
5.1 million electric
4.3 million gas

Employees
Approximately 24,000

System
• 160,000 miles of electric transmission and distribution (T&D) lines
• 48,000 miles of natural gas T&D pipelines
• 7,700 megawatts of utility-owned generation
PG&E's Hydroelectric System covers much of Northern California Sierra Nevada Mountains.

66 Powerhouses
106 Generators
~ 3,900 MW of generating capacity
97 Reservoirs
73 Diversions
169 Dams
>400 miles of canals, tunnels, penstocks, flumes, and natural waterways
16 River basins
Helms Pumped Storage
1212 MW Grid Scale Battery
Helms is in its 36th Operating Year

Helms is located about 50 miles east of the city of Fresno California
Built inside of the Sierra Nevada Mountains.
The project was commissioned June 30, 1984 to pair with Diablo Canyon
Helms Pumping and Generating Modes

- 1,212 MW of generation
- 930 MW of pumping load
- 3 units are housed in a chamber 1,000 feet underground
- Water travel:
  - 9,000 CFS
  - 22,000 feet long 27’ diameter supply tunnel
  - 1,744 feet head
- In pumping mode, the units reverse and pump water from Wishon Lake into storage at Courtright Lake
- Enough storage for several days at full load
- Units have fast operating capability:
  - Dead stop to full generation (up to 1,212 MW) in 6.5 to 8 minutes
  - From dead stop, can parallel in 3-4.5 minutes
  - From parallel, can ramp 0 to full load in 2 minutes with Operator intervention or 80MW/min without.
  - Dead stop to full pump in less than 10 minutes
Helms Operational Characteristics

- Common to change states (pumping vs generate) several times per day
- Helms can start all 3 units in Gen-mode at once and ramp to full load in minutes
- Helms can only start 1 pump at a time with a short delay between start commands of consecutive pumps
- If 1 or 2 units in pump mode, can shut down and start remaining unit in Gen-mode immediately
- Going from Gen-mode to Pump mode = 20 minute delay for tunnel pressure to stabilize and unit brakes to come on
California ISO Market

- Helms bids into the California ISO markets.
- Bids for energy consist of a startup cost per unit, minimum load cost, and incremental energy costs. Also included are bids for ancillary services (regulation up and down, spinning reserve and non-spinning reserve.)
- Bids are also submitted for the pump.
- Each unit is bid separately.
- Bids are for Day Ahead, Fifteen Minute (FMM), and Five Minute markets (5MM).
- The CAISO market software co-optimizes energy and ancillary services simultaneously and results in the most economic mix of all products.
California ISO Market – Example Results

Helms’ schedule is determined by CAISO based on Helms’ bids.

Helms’ schedule is a mix of energy and ancillary services.

Solar has depressed prices mid-day resulting predominance of mid-day pumping.
Increased Cycling

• Originally designed to Generate by day and Pump by night, 2 start/stop cycles

• Now generates or pumps depending on grid demands with high renewables penetration, allowed to start/stop 5 times per day. ISO push for even more cycles and more flexibility

• Equipment, in general, requires less frequent overhaul cycles under steady state conditions, not the case at Helms

• Thermal and mechanical stress occur each time a unit is cycled on or off and this cycling increases the probability of component failure

• Planned Maintenance needs to account for this activity; including increased or early repairs and overhauls, forced outages….all which lead to increased costs
Managing more start/stops:

- VOM (variable operations and maintenance fee, usually $/mwh)
- Startup cost (to incorporate start related variable maintenance costs)
- Sequencing of units to balance starts and run time, aka firing order based on bidding units
- Study in progress to forecast impacts from increased cycling of units
Hydropower Fleet Intelligence: Use Case 1 – O&M Effects of Intensifying Variability In Cooperation with Pacific Gas & Electric

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Dr. Stephen Signore
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Hydropower Technology
Oak Ridge National Laboratory

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Distribution of Unit Starts
Source ORNL with data provided by PG&E

Average Unit Starts by Day of Week (1/1/17 to 10/8/18)
Distribution of Start Events by Daily Frequency over 593 days*

*(1/1/17 to 10/8/18 with 53 days of missing data)

Source ORNL, data provided by PG&E
Helms, Conventional Hydro, and CAISO Market

Monthly Graphs

Blue = Energy Component of hourly Market Price
Red = Helms
Green = Conventional Hydro

Source ORNL, data provided by PG&E
Increased Equipment Monitoring

- There is need to monitor equipment to more accurately plan for maintenance
- Need for More Flexible Operation
- Recent project to install several turbine accelerometers and pressure devices: headcover, runner band, draft tube, scroll case, air depression and other critical locations that see cycling of pressure and vibration
- This added instrumentation will be added to the plant DCS along with other data such as Excitation, Governor, Temperatures, and Operating Parameters to trend in real time and help plant personnel better plan for maintenance as well as learn if other operational modes can be achieved
Components at Higher Risk of Failure

• Typically equipment that sees movement via rotation or actuation as well as mechanical vibration needs more attention

• Generator rotors, Generator breakers, Disconnect Switches, Wicket Gates and Servos, TSV’s, Some Piping Systems, etc.
Helms has not identified any additional damage to the turbines themselves as a result of cycling but it may be a long term affect.

Helms has seen issues with turbine components. Any moving parts such as servos, wicket gate bushings, wicket gate seals, TSV components, Governor pumps.

Most equipment that sees movement or actuations as a result of starting/stoping the unit or swinging loads more often.

Leads to extensive overhauls more often.
Helms Turbine Shutoff Valves

• Helms has plans to replace the original TSV’s.

• TSV’s open/close on every start/stop. This allows the downstream seal to be closed which, when not generating, prevents water from leaking past wicket gates and eroding the wicket gate face, and closed when starting pumping operation to “prime”.

• Reason for TSV replacement: Nearing 40 year life. Helms is seeing wear that includes leaky trunnions, failed bypass valves, seized US mechanical locks, increased leakage past US and DS seals and worn control components.

• The TSV mechanical locks have an increased tendency to bind over the last several years and are not serviceable without draining the common power tunnel. Redesign in the works.
Helms Equalizing Lines

Balance the upward and downward force on the thrust bearing

Cycling and Vibration cause this component to fail often
Five Pole Reversing Switches allow for changing direction (Pump and Generate)

Cycling multiple times each day causes excessive wear
Failure of the internal operating rod on the generator breaker caused Unit 1 to unintentionally motor in 2011.
This coupling connects the operating mechanism to the 3 interrupters allowing the breaker to interrupt current to all phases simultaneously. The right is a photo of a good rod end for comparison.
An operations (cycles) based maintenance plan was developed in coordination with the OEM, which decreased the time between overhaul cycles.
Cutaway View of the Generator

Pacific Gas and Electric
Helms Pumped Storage Project

Westinghouse Generator-Motor
Helms discovered cracking in the rotor rims - October 2011
Non Destructive Exam Results

Indications on Unit 3 Rotor

Grinding on Unit 2 Rotor prior to final smoothing of the ground surface
Development of plastic deformations in the rotor rim in the presence of one long continuous crack with 10 mm depth.

Gray colored areas are plastic strains larger than yield strain (> 0.2 %)

Begin of large global plastic deformations (loss of integrity)

Remark: Calculation includes strain hardening based on design strength values

Runaway rotation speed

504 rpm

Synchronous speed is 360 rpm
All three rotors were replaced in 2015
OEM modeled the effect of cycling through the use of Finite Element Analysis (FEA), particularly at the connection points between the poles and the rotor rim. Modeling showed that the new design with three Tee heads per pole could meet PG&E’s specification of 55,000 start stop cycles.

OEM and Independent company both performed FEA of lower rotor spider support ledge as well. PG&E had long term fatigue concerns related to the lower ledge due to start/stop cycles.
Helms Rotor Concept

Spider arms

Rim support lips extending from base of spider

72°
Building the Rotor
Powerhouse Main Deck View – Closing Slide