Corps of Engineers Hydro Optimization
in the
Pacific Northwest

Presentation for:
Southwestern Federal Hydropower Conference
Kansas City, Missouri
16 June 2011

By
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US Army Corps of Engineers
PRESENTATION OUTLINE

- HOT INTRODUCTION AND HISTORY

- TYPE I (Unit) OPTIMIZATION
  - Cam Curve Verification
  - 3-D Cam Controllers
  - Inputs and Telemetry
  - Gate-Blade Optimizer

- TYPE II (Powerhouse) OPTIMIZATION
  - Economic Dispatch
  - Unit Commitment
  - Absolute Flow Measurement
  - Benefits Summary

- QUESTIONS
Hydropower Optimization Team (HOT)

HOT is joint effort between BPA, COE, and BOR to maximize use of available water for hydropower generation.
HOT History

- Early 1990’s, BPA purchasing energy on the open market
- A push to ‘get more from existing assets’
- HOT created circa 1997
  - Chartered to propose and implement ways to ‘get more’
- Reports to the Joint Operating Committee
HOT Structure

- **MEMBERS**
  - BPA Project Managers
  - COE Project Managers from 3 Districts (Portland, Seattle, Walla Walla)
  - Hydroelectric Design Center (Engineering)
  - Representative(s) from each Powerhouse

- **DECISION PROCESS**
  - By Consensus
  - Anyone can suggest an investigation / program
Within NWD, HOT efforts have been primarily at plants located on Columbia and Snake Rivers:

- 10 major hydropower plants in 3 Districts
- 121 generating units (94 Kaplan & 27 Francis)
- Generators ranging from 43 MW to 135 MW
- Total rated generating capacity of 11,600 MW
HOT Programs

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Cam Curve Verification

- Confirm that the installed Kaplan Cams are correct
- Performed on 8 Plants
- 94 Units
- 14 Index tests
- 10 Different Unit Designs (A ‘Family’)
- Started 1998; Finished 2004
Index Testing – Kaplan Units

The Dalles Powerhouse
Unit 21
Unit Performance Test

Relative Overall Unit Efficiency (%)

<table>
<thead>
<tr>
<th>Generator Output (kW)</th>
<th>40000</th>
<th>45000</th>
<th>50000</th>
<th>55000</th>
<th>60000</th>
<th>65000</th>
<th>70000</th>
<th>75000</th>
<th>80000</th>
<th>85000</th>
<th>90000</th>
<th>95000</th>
<th>100000</th>
<th>105000</th>
<th>110000</th>
<th>115000</th>
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</thead>
<tbody>
<tr>
<td>Relative Overall Unit Efficiency (%)</td>
<td>84.0</td>
<td>84.5</td>
<td>85.0</td>
<td>85.5</td>
<td>86.0</td>
<td>86.5</td>
<td>87.0</td>
<td>87.5</td>
<td>88.0</td>
<td>88.5</td>
<td>89.0</td>
<td>89.5</td>
<td>90.0</td>
<td>90.5</td>
<td>91.0</td>
<td>91.5</td>
</tr>
</tbody>
</table>

1 % Performance Improvement

- Existing Cam, as measured 10 Sept 2001
- Revised Cam, as measured 18 Sept 2001
Cam Curve Verification (2)

- Findings
  - Cam Curve Correction averaged approximately 2%
  - Some Head measurements off by 3% (not typical).
HOT Programs

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3D Cam Controller Improvements

► Mechanical Governors (installed 1950s -1980s)
  • Blade position follows gate position
  • Blade position based on shape of hard cam (cam plate)
  • Hard cam valid only for single head
3D Cam Controller Improvements

► Add-on retrofitted to existing Mechanical Governors
  - Originally installed late ‘80s - early 90’s.
  - Newer version installed 2001 to 2004 (HOT initiative).
  - Stepper Motor used to rotate cam plate
  - Stepper Motor driven by cam tables loaded into a separate computer: Position a function of Head and Gate Opening
  - Same functionality as a Digital Governor
HOT Programs

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Inputs and Telemetry

The Problem

- Only One head measurement per powerhouse: does not capture variation across powerhouse.
- Only one gate position feedback—not configured to provide electronic information
- Blade Position Feedback: coarse, lots of vibration.
- Lack of redundancy throughout system
Improved Telemetry

► Individual Unit Head Sensing

- Replaces plant gauges --- typically located @ one end of plant
- Builds redundancy in system
Improved Telemetry

► Rotary encoders for blade position and wicket gate position feedback
► 3 Per unit, redundancy
► Digital feed to 3–D Cam controllers
Improved Telemetry

Blade Position Feedback

- New Rotary encoders
- New Mounting arrangement
- Located at top of unit above oil head
- Removed blade position feedback rod
HOT Programs

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Index Testing – Kaplan Units

- The Situation
  - At each plant, testing limited to single unit from each turbine family
  - Turbine performance results/ cam table considered representative for turbine family

- The Problem
  - Differences exist between turbines of same family, individual unit performance curves needed
  - Index testing labor intensive, testing 97 individual units not easily accomplished / not inexpensive task
GBO Approach

► Develop individual unit performance information in cost effective method

► Gate/Blade Optimizer (GBO) is smart data acquisition device intended to operate in an unattended, automated fashion
  • Continuous monitoring of unit operation for steady state conditions
  • Introduces blade angles variations (deviations from cam table)

► Collects data for follow on, off-line evaluation (not self-optimization)
Data collection underway

Estimate 3-4 years for new cam tables for 97 individual units expected to be in-place
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Plant Optimization Type 2 (T2)

- COE developed software that is part of the SCADA system
  - Suggestive tool for powerplant operator use
  - Unit commitment (which units to place on-line) and Economic Dispatch (where to load units)
  - Coordinated with Utility dispatch request and generation forecast
Type 2 Optimization

Challenge: Most Efficient Configuration to supply 300 MW

3 X 100
4 X 75
3 X 70 + 1 X 90
5 X 60

Choices influenced by:
Need for spinning reserve
Expected load in near future
It Gets More Complex

Dispatch 600 MW from the plant shown
How many from Units 1-5, at what power?
How many from Units 6-10, at what power?
Machine Specific Performance

- So Far, have assumed all machines in a family have the same performance
- We know this is not the case
- How much variation is there between ‘identical’ machines?
Plant Optimization Type 2 (T2)

- To make proper unit commitment decisions / gain full benefits from T2, **absolute flow measurement** needed.

The Dalles
Unit 1-14
Case Study

Based on Current Meter Testing
HOT Programs

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Absolute Flow Measurement – Francis Units

- Chief Joseph
  - 27 Francis units
  - 25 ft diameter penstock
  - Code approved flow measurement (Time of Flight) installed on 2 units (2002)

- Cost effective methods needed
Absolute Flow Measurements – Kaplan Units

➢ Comparative Flow Test – Lower Granite Unit 4

ASFM in gate slot

ToF on 3 bays

Slide from D. Lemon, ASL
Absolute Flow Measurement – francis Units

- Comparative flow measurement testing conducted 2008 (Unit 15)

- Acoustic Scintillation Flow Method (ASFM) in intake

- ToF method used as reference flow
Absolute Flow Measurement – Francis Units

- Retest Unit 15 scheduled Spring 2011
- Along with test of 2nd unit (Unit 11)
Absolute Flow Measurements – Francis Units

- Comparative Flow Test – BC Hydro’s Kootenay Canal
  - CEATI HPLIG sponsored testing
    - COE co-sponsor
  - Three methods tested in convergent intake
    - Acoustic Time of Flight
    - Acoustic Scintillation
    - Current Meter

- Initial results indicate all three methods warrant further consideration for incorporation into test code
## Estimated Gains

<table>
<thead>
<tr>
<th>ACTION</th>
<th>POTENTIAL GAIN/LOSS</th>
<th>GAIN (MW) FINAL EST.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Index Testing &amp; Tuning Units (Kaplan units only)</td>
<td>~ 0.0% - 6% η gain</td>
<td>50.1 aMW</td>
</tr>
<tr>
<td>Gate / Blade Optimizer</td>
<td>0.7% - 1.3% η gain</td>
<td>Under Development 29-54 aMW</td>
</tr>
<tr>
<td>Economic Dispatch Benefit</td>
<td>~0.2% η gain</td>
<td>22-26 aMW</td>
</tr>
<tr>
<td>Unit Commitment Benefit (Correct Number of Units Generating)</td>
<td>~ 0.2% - 0.9% η gain</td>
<td>35-70 aMW</td>
</tr>
<tr>
<td>No Feed Forward AGC</td>
<td>~ 0.15% - 0.25% η loss</td>
<td>Benefit included in Unit Commitment</td>
</tr>
<tr>
<td>TOTAL BENEFIT</td>
<td></td>
<td>136-200 aMW</td>
</tr>
</tbody>
</table>

Excerpted from Benefits Document, T. Murphy, BPA
QUESTIONS ?