Application of advanced control functions for double regulated turbines at the Jirau power plant

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Summary

• Introduction
• Issues in the process control
• Advanced control solutions
  • Adaptive control
  • Operating point limiters
  • Disturbance detection
• Control functions for the hydraulic actuators
  • Reduction in runner blades movement
  • Frequency response test
• Current status at the power plant
Jirau Hydro Power Plant

- Jirau hydro power plant in Madeira River
- Rated at 3,750 MW - fourth biggest hydro power plant in Brazil
Jirau hydro power plant

- 50 turbines rated at 76.5 MW each
- Biggest Bulb turbines in the world
- Runner diameter of 7.5 m
Bulb turbine

- Two hydraulic actuators
  - Wicket gates
  - Adjustable runner blades
Governors

• Control generating unit speed and output power to follow their desired values
• Manipulate the two hydraulic actuators: wicket gate opening and runner blades angle
• Wicket gate opening changes flowrate across the turbine
• Runner blades angle is corrected to maximize efficiency
Hydraulic actuators control

- Proportional valve → Distributing valve → Main actuator
- Combination curve for determining runner blades reference according to wicket gates
Introduction

• Left bank: 22 units
• Original governors were subcontracted by the turbine manufacturer, not by the plant owner
• Customer dissatisfied with governors
  • Long setup time for putting the units into service
  • A conventional governor is not proper for this application
  • Behaviour not adequate for customer needs
• Governors replacement
  • Detailed analysis of the process
  • Customized solutions for the issues
  • New governors commissioning and testing
Singular characteristics in Jirau

- **Hydraulic actuators**
  - Combination error
  - Wicket gates: 15 s
  - Runner blades: 30 s

- **Water column**
  - High flowrate
  - High time constant $T_w$
  - Head variation
    - 9 to 20 m
    - $T_w$ wide operating range
  - Operating limits

- **Machine**
  - Fast
  - Low inertia time constant (2H)

- **Load**
  - Low damping

**Typical vs. Jirau**

<table>
<thead>
<tr>
<th></th>
<th>Typical</th>
<th>Jirau</th>
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<tbody>
<tr>
<td>$2H/Tw$</td>
<td>&gt; 2.5</td>
<td>1</td>
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**HVDC converters**
- (2 x 3750 MW)
- Jirau and Santo Antônio (100 x 70 MW)
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### Control solutions

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<tr>
<th>Hydraulic actuators</th>
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- Combination error limiter
- Adaptive control
- Operating limiters
- Monitoring screen with hill chart
- Disturbance detection
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Control solutions

Operating point limiters

Combination error limiter

PID

Limiter

Wicket gate PID

Runner blades PID

Adaptive Control

Disturbance detection

Head Opening

Frequency Power

W

W_ref

P_ref

P_e

b_p
Adaptive Control

- Turbine head dynamics ($T_w$) depends on head and flowrate

$$T_w = T_{w_{\text{rated}}} \frac{\text{Flowrate (pu)}}{\text{Head (pu)}}$$

- Tuning for the worst condition (max $T_w$) is not adequate for other operating points
- Behaviour is improved when parameters are updated according to operating point
- This leads to more regular values for performance indicators such as overshoot, stabilizing and rising times
- Adapting rules may be tuned to make responses more aggressive or more conservative
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Disturbance detection

- Changes in operating scenario
  - HVDC converters frequency stabilization is disabled
  - Frequency disturbance
  - Load rejection in the transmission line
- This changes control stability margins
- Such conditions require adapting the gains

\[
\text{Frequency} \quad \text{Power} \quad \text{Disturbance detection} \quad \text{Governor} \\
bt, Td, Tn, RefPe
\]
Hill chart

- **Maximum opening limit**
- **Cavitation limit**
- **Minimum power limit**
- **Operating point**
- **Maximum power limit**

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Runner blades motion reduction

- Runner blades positioned according to wicket gates to optimize efficiency
- A small combination error does not cause cavitation and the efficiency loss is negligible
- Under steady-state time, the blades might remain fixed

Advantages
- Prevent excessive oil consumption
- Avoid mechanical wear in the actuators
- Reduce oil pumps operating hours
- Increase equipment lifespan
- Reduce maintenance shutdowns
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Runner blades motion reduction

Runner blades position

Runner blades distributing valve

Runner blades control signal

Runner blades reference

Active power

Wicket gates position

Graph showing time series data for Runner blades position, Runner blades distributing valve, Runner blades control signal, Runner blades reference, Active power, and Wicket gates position.
Meeting of advanced control functions for double regulated turbines at the Jirau power plant

- Frequency response tool
  - Automatic application of sinusoidal signals with varied frequencies
    - Excitation signal may be summed at various points of the control loop
Frequency response tool

- Real time calculation of gain and phase
  - Analysis may be performed for many input/output signals of the control system
  - No need for external equipment
- Applications
  - System identification: deadband, dynamics, non-linear
  - Control system performance indicators: gain margin, phase margin, cutoff frequency
  - Identify valve sticking
Current operating status

• The governors have been operating since February 2015

• System event in 2015
  • During the validation time of the first governor
  • Outage of all units in Jirau and Santo Antônio (50 x 70 MW) power plants, except for this unit
  • The unit was able to sustain the auxiliary power supply of the whole power plant, which feeds emergency and supervision systems
  • Analysis confirmed this was due to the advanced functions installed

• 16 units in the left bank of the power plant are already using the new governor with advanced functions

• Other 6 units are to be commissioned this year

• Jirau is the plant with the highest power availability in the Brazilian system, with an average of 99.1% in 2016
Thank you for your attention.

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