Modelling of Primary Frequency Control and Effect Analyses of Governing System Parameters on the Grid Frequency

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Outline

- Introduction
- Mathematical Model of Primary Frequency Control
- Dynamic Test & Parameter Identification
- Effects of Parameters of Governing System
  - Effect of dead band
  - Effect of speed droop
Introduction

Frequency is an indicator of overall power imbalance. Power increases, frequency rises; load increases, frequency falls. Frequency deviation must be controlled within a certain range. (±0.2Hz in China)

Frequency \hspace{1cm} \begin{cases} \text{Primary frequency control} \\ \text{Secondary frequency control} \end{cases}
Introduction

Primary frequency control (speed droop control)

load increases, frequency falls \( \Rightarrow \)
frequency deviation is greater than the dead band \( \Rightarrow \)
servo-motor increases governing valve opening of steam turbine \( \Rightarrow \)
power output increases to hold back the decrease of frequency responses fast
utilizes the heat storage of boiler
has frequency error in steady state
Secondary frequency control

balances the power and load through fuel regulation responses slowly
can eliminate steady state frequency error
Mathematical Model of Primary Frequency Control

Boiler model

\[ \Delta n_{\text{ref}} \rightarrow l/\text{Speed droop} \rightarrow \text{Servo-motor} \rightarrow \text{Steam turbine} \rightarrow \text{Rotor} \rightarrow \Delta n \]

Main steam pressure is the interface between steam turbine and boiler.

Governing valve opening rises \( \rightarrow \) Main Steam pressure falls

Boiler responses slowly

Institute of Turbomachinery, Xi’an Jiaotong University
Mathematical Model of Boiler

Fuel command signal

Fuel feed and burning system

Water walls

Drum

Superheater

Flow resistance

Governing valve

Steam Turbine

\[ p_D \]

\[ p_S \]

\[ \frac{1}{sT_D} \]

\[ K \]

\[ \frac{1}{sT_S} \]

\[ p_F \]

\[ g_Q \]

\[ g_w \]

\[ g_D \]

\[ g_s \]

\[ e^{-\tau_s} \]

\[ \frac{1}{T_F s + 1} \]

\[ \frac{1}{T_W s + 1} \]
Mathematical Model of Steam Turbine

Steam Turbine: three cylinders, single reheat
Power is assumed to be proportional to the pressure before each cylinder.

\[ \frac{1}{sT_{CH}+1} \xrightarrow{\alpha_{II}} \frac{1}{sT_{RH}+1} \xrightarrow{\alpha_{I}} \frac{1}{sT_{CG}+1} \xrightarrow{\alpha_{L}} \]

\[ a_H + a_I + a_L = 1 \]
Power over-regulation of HP cylinder

Power response of actual unit can reach 60% of regulation target in the first several seconds

Power response of simulation only reach 38%
Improved model of Steam Turbine

Power over-regulation coefficient of HP cylinder:
\[ \lambda = f(\text{pressure ratio, adiabatic index}) \]
Mathematical Model of Steam Turbine

Single Unit

Test of primary frequency control:
1. static test of servo-motor for identification of $T_{act}$
2. load dump test for identification of $T_a$
3. dynamic test for identification of the time constants of steam turbine on line, increases or decreases the reference speed (by 25 rpm)
Dynamic Test & Parameter Identification

[Diagram of a turbomachinery system with labeled components and variables:]

- Pressure
- Valve opening
- Power

Variables:

- $T_{CH}$
- $T_{RH}$
- $T_{CO}$

Graph showing time (t) vs. % with lines indicating the time evolution of different parameters.
Effect of dead band

Multi-units

Tab.1 The responses of units under different load disturbance

<table>
<thead>
<tr>
<th>Dead band</th>
<th>Power percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2 r/min</td>
</tr>
<tr>
<td>2</td>
<td>3 r/min</td>
</tr>
<tr>
<td>3</td>
<td>4 r/min</td>
</tr>
<tr>
<td>4</td>
<td>5 r/min</td>
</tr>
</tbody>
</table>
Effect of dead band

Dead band = 2 rpm

Dead band = 3 rpm

Dead band = 4 rpm

Dead band = 5 rpm

Simulation results
Effect of dead band

Tab.2 The responses of units under different load disturbance

<table>
<thead>
<tr>
<th>Load disturbance</th>
<th>5%</th>
<th>7.6%</th>
<th>10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dead band /r·min⁻¹</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Freq variation max /Hz</td>
<td>-0.22</td>
<td>-0.31</td>
<td>-0.44</td>
</tr>
<tr>
<td>Freq variation Steady state /Hz</td>
<td>-0.15</td>
<td>-0.15</td>
<td>-0.2</td>
</tr>
</tbody>
</table>

Steady State Frequency deviations<0.2 Hz

Tab.3 The relationship between different dead band combination and allowed load disturbance

<table>
<thead>
<tr>
<th>Load disturbance</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
<th>e</th>
<th>f</th>
<th>g</th>
<th>h</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 r/min capacity</td>
<td>0.25</td>
<td>0.5</td>
<td>0.7</td>
<td>0.9</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3 r/min capacity</td>
<td>0.25</td>
<td>0.2</td>
<td>0.1</td>
<td>0.1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4 r/min capacity</td>
<td>0.25</td>
<td>0.2</td>
<td>0.1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>5 r/min capacity</td>
<td>0.25</td>
<td>0.1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Allowed load disturbance/%</td>
<td>7.1</td>
<td>7.6</td>
<td>7.9</td>
<td>8.3</td>
<td>8.4</td>
<td>7.6</td>
<td>6.8</td>
<td>5.9</td>
</tr>
</tbody>
</table>
Effect of speed droop

\[ \delta = \frac{n_{\text{max}} - n_N}{n_N} \times 100\% \]

\( n_{\text{max}} \) — no-load speed
\( n_N \) — full-load speed

Load increases by 10%

90% capacity

10% capacity with constant speed droop of 4%

10% capacity
Xi’an Jiaotong University is a top10 university in China, and was founded in 1896. Today, Xi’an Jiaotong University is a comprehensive research university offering programs in nine areas with a major emphasis on science and engineering.
Thank you!