Systemdynamik und Leittechnik in der elektrischen Energieversorgung

High Lights
Figure 1.1. Schematic diagram of different time scales of power system controls.
Figure 1.2. The structure of the hierarchical control systems of a power system.
Maximum and minimum power demand

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Selected values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date of data: 21/08/2006</td>
<td>Time: 14:15</td>
</tr>
<tr>
<td>Minimum power demand: 32689 MW</td>
<td>Power demand: 49695 MW</td>
</tr>
<tr>
<td>Maximum power demand: 51204 MW</td>
<td>P.D. forecast: 50450 MW</td>
</tr>
</tbody>
</table>

Date of data: 21/08/2006

www.rte-france.com
The consumption figures shown in the diagram are taken from real-time measurements. These are raw data, and may be corrected subsequently. To view records of consolidated figures, click here.

www.rte-france.com
Forecast of wind power production, western Denmark
Figure 1.5. Duration curve showing the use of different kinds of power plants.
Figure 2.1. The frequency in different locations in an electric power system after a disturbance.
Figure 2.2. Simplified representation of a power system consisting of a single generator connected to the same bus as the load.

\[ \Delta \omega = \frac{\omega_0^2}{2HS_B \omega} (P_m - P_e) \]
Figure 2.4. Linearized inertia of the power system.

\[
\Delta f = \frac{f_0}{2HS_B} (\Delta P_m - \Delta P_{load})
\]
Figure 2.6. Model of power system without control.
Figure 2.7. Frequency responses of uncontrolled power system (theoretical) to step in $\Delta P_{load}$. 
Figure 2.8. Basic control structures of electric power systems.
Figure 2.9. Temporal structure of control reserve usage after a disturbance.
Figure 3.1. Schematic drawing of the primary control installed in a thermal unit. HP = High Pressure Turbine. LP = Low Pressure turbine.
Figure 3.3. Static characteristic of primary control.

\[
S = - \frac{f - f_0}{P_m - P_{m0}^{set}}
\]
Figure 3.8. Two generator system.
Figure 3.9. Speed droop characteristics for a two-machine system.
Figure 3.11. Dynamic frequency model of the power system with primary-controlled power plants.
Figure 3.14. Two-area dynamic model including tie-line flows.
Figure 3.17. Steam turbine configurations and approximate linear models. Nonreheat and tandem compound, single reheat configurations.
**Figure 3.22.** Schematic drawing of hydro turbine with water paths.
Bernoulli’s equation:

\[ \int_{P_1}^{P_2} \frac{\partial \vec{v}}{\partial t} \cdot d\vec{r} + \frac{1}{2}(v_2^2 - v_1^2) + \Omega_2 - \Omega_1 + \int_{P_1}^{P_2} \frac{1}{\rho} dp = 0 \quad (3.37) \]

Assumptions:

- \( v_1 = 0 \), since the reservoir is large and the water level does not change during the time scale that is of interest here.
- The water velocity is non–zero only in the penstock.
- The water is incompressible, i.e. \( \rho \) does not change with water pressure.
- The water pressure is the same at \( P_1 \) and \( P_2 \), i.e. \( p_1 = p_2 \).
The system can be written in standard form:

\[
\begin{align*}
\dot{x} &= \frac{gh}{L} - x^2 \frac{1}{2Lu^2}, \\
y &= \rho A \frac{x^3}{2u^2}.
\end{align*}
\]
Transfer function:

\[
\Delta y = \frac{y_0}{u_0} \cdot \frac{1 - 2T_w s}{1 + T_w s} \Delta u .
\]

with \( u_0 T = a_0 T/A \) as \( T_w \)
Figure 3.24. The variation of the produced power, $\Delta y$, after a step change in the control valve.
Figure 3.26. Model of turbine governor for hydro turbine.
Figure 3.27. Frequency variation after a step in $\Delta P_{\text{load}}$. 
Figure 4.1. Two area system with AGC.

\[ P_{T1} = \text{Tie line power for Area 1} = \sum_{j \in \Omega_1} P_{T1}^j = \text{Sum over all tie lines} \]
Figure 4.2. Controller for AGC.

\[
ACE_i = \sum_{j \in \Omega_i} (P_{i,j}^j - P_{i,j}^{T0i}) + B_i (f - f_0) \quad i = 1, 2, \ldots, N
\]

\[
ACE_i = \Delta P_{Ti} + B_i \Delta f \quad i = 1, 2, \ldots, N
\]

\[
\Delta P_{AGCi} = -(C_{pi} + \frac{1}{sT_{Ni}}) \Delta e_i
\]
Figure 4.6. Dynamic model of two-area system with AGC.
Figure 5.1. Definition of quantities in Park’s transformation.
Figure 5.2. Schematic picture of the transformed system.
Figure 5.4. Graphical description of the voltage equations and the coupling between the equivalent circuits.
Voltage Control in Power Systems

Reactive Power

\[ \uparrow \downarrow \]

Voltage
Factors Influencing the Voltages

- Terminal voltages of synchronous machines
- Reactive shunt elements
- Turns ratio of transformers
- Control of FACTS devices
- Impedances of lines
- Loading of transmission lines
Figure 6.1. Schematic picture of synchronous machine and associated control systems.
Static Load Models

\[ P = P_0 \left( \frac{U}{U_0} \right)^\alpha \]

\[ Q = Q_0 \left( \frac{U}{U_0} \right)^\beta \]

\[ P = P_0 \sum_i k_i \left( \frac{U}{U_0} \right)^{\alpha_i} \]

ZIP – Model:

\[ \alpha_0 = 0 \]
\[ \alpha_1 = 1 \]
\[ \alpha_2 = 2 \]
\[ k_i = 0; i \neq 0,1,2, \]
Figure 7.5. Transient behaviour of dynamic load.