Federal University of Santa Catarina
Technological Center
Department of Mechanical Engineering
Laboratory of Hydraulic and Pneumatic Systems

Modeling Renewable Power Systems
Wind and Hydro

Prof. Victor J. De Negri

10th MODPROD
Workshop on Model-Based Product Development
Linköping, February, 2016
• 4,146 power plants on operation: 142 GW of electrical power
• Under construction: 21.9 GW
  Hydro power: 15.7 GW
  Wind power: 2.8 GW

![Pie chart showing energy sources: Hydroelectric Power Plants (65.41%), Wind Power Plants (0.01%), Thermoelectric Power Plants (28.64%), Nuclear power Plants (4.54%), Photovoltaic Power Plants (1.40%)](chart.jpg)
Speed Governors for Hydroelectric Plants

- Proportional Valve
- Distributing Valve
- PV Signal
- DV Position
- Velocity
- Controller
- Voltage
- Generator
- Servomotor Position
- Servomotor
- Hydraulic Fluid
- Speed Governor
- Turbine
- Water Flow
- Hydraulic Power Unit
Wind Turbine Power Control

Rotor

Wind

Transmission

Actuator

Generator

Controller

V(t)

P mec. ($\omega^R, T^R$)

P mec. ($\omega^G, T^G$)

$\beta$ref

$\beta$

P elec. (U,I)

P elec.
### Automatic Systems:

- Applications including Control and/or Automation
- Events start the control tasks
- Behavior:
  - Continuous:
  - Discrete

![Graph showing valve opening percentage over time with different non-linear systems and control settings.](image)
Automatic Systems

- **Automatic Systems:**
  - Several components
  - Different technologies
  - System behavior depends on the interrelation between components
  - System design and operation are not trivial

- **Automatic systems have a unique fundamental structure**
Automatic Systems

### Modeling Perspectives

- **Functional model:**
  - Specifies **what the system does or should do**
  - Function describes the technical system ability to fulfil a purpose

- **Structural model:**
  - Describes **where the functions are implemented**

- **Behavioral model:**
  - Explains **how or when the functions are executed**
Hydro and Wind Power Plants

- **Functional and Structural Modeling:**
  - Applying Channel/Agency Petri Net
  - Circuit Diagrams

- **Behavioral Modeling:**
  - Applying Grafcet, Ladder Diagram, Logical Block Diagram… for event guided modeling (Discrete state modeling)

  - Applying Differential Equations, Transfer Function, Power Bond Graph, Block Diagram… for continuous state modeling.
## Channel/Agency Net


### Basic elements

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Generic name</th>
<th>Functional view</th>
<th>Structural view</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Active unit</td>
<td>Activity (function)</td>
<td>Agency</td>
</tr>
<tr>
<td></td>
<td>Passive unit</td>
<td>Resource</td>
<td>Channel</td>
</tr>
</tbody>
</table>

### Directed arcs

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Resource type</th>
<th>Symbol</th>
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<tbody>
<tr>
<td></td>
<td>Information</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Energy</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Matter</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Energy and matter</td>
<td></td>
</tr>
</tbody>
</table>

### Hidden channels

- Passive units: Channel

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### Diagram

- Directed arcs for energy flow
- Directed arcs for information flow
- Active units (agencies)
- Passive units (channels)
- Directed arcs for matter flow
- Directed arcs for matter and energy flow
Design Process: Function-Means Tree

- Hubka (1976); Andreasen (1980); Burr (1990)
- Technical systems / Mechatronic systems

• C/A Net using the Function-Means Tree perspective
The Design Process: C/A Net

- Refinement and condensation

Diagram:
- Channel 1
- Agency 1
- Channel 2
- C1.1
- a1.1
- a1.2
- c2.1
- c2.2
- c2.a1
- c2.3
- c2.a2
- c2.4

Refinement and Condensation
Example of Channel/Agency Net modelling

- Main function: Electrical energy generation
The Design Process using C/A Net

[Diagram showing the design process with water (H2O) flowing through different turbines and to a generator, with various components labeled: Francis, Kaplan, Pelton, MP, EP, and Generator.]
The Design Process using C/A Net
The Design Process using C/A Net

- Mathematical representation of Channel/Agency Nets

\[ N = (C, A, C_{ex}, A_{ex}, E_{re}, \lambda_{re}, \lambda_{ca}, K_{pre}, K_{Post}) \]

\[ C = \{c_1, c_2, ..., c_n\} \]

\[ A = \{a_1, a_2, ..., a_m\} \]

\[ E_{re} = \{r_1, r_2, ..., r_b\} \]
The Design Process using C/A Net

- Analysis of the net properties
  - Activity 1.1: Structural Coherence
  - Activity 1.2: Resource Flow Coherence

Supplier channel
- Verify at Kpre which agencies are linked to the channel
  - a1, a2, ... am
- Verify at Kpost which channels are linked to the agencies
  - c1, c2, ... cn
- Verify whether this is a consumer channel or a channel blocked by a controllable agency.
  - It is a consumer or blocked channel
  - It is not a consumer nor blocked channel
- Store relationship between supplier and consumer (or blocked) channels
- Conclusion regarding resource flow coherence

Logical operation "OR" between rows
VLKpre, VLKpost, VCKpre, VCKpost
- VLKpre – VL Kpost
- VCKpre – VCKpost
- Eliminate non-zero elements
- Analyze non-zero elements

Logical operation "OR" between columns
• Kpre
• Kpost
• Supplier and consumer channels
• VCRes
• VLRes
• VCRRes

Verify whether this is a consumer channel or a channel blocked by a controllable agency.
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The Design Process using C/A Net

- Equivalence between C/A net and circuit diagrams

**Angle_{max} = 15°**
Response = 100 ms

From conceptual to detailed design

Controller gains:
- $K_P = 2; K_I = 0.1$

Position sensor:
- $K_S = 300$ V/m

Cylinder: $d = 30$ mm

Valve: $q_{Vn} = 32$ L/min
($\Delta p = 10$ bar)

Mathematical analysis of hydraulic, pneumatic, and electric circuits
Reliability Analysis on the Automatic System Design

2007
Henri C. Belan
2009
Gilson Porciúncula

Electric Diagram

Hydraulic Diagram

Grafce
Hydro and Wind Power Plants

- **Functional and Structural Modeling:**
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- **Behavioral Modeling:**
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  - Applying Differential Equations, Transfer Functions, Power Bond Graphs, Block Diagram... for continuous state modeling.
Continuous State Mathematical Models

- Hydrostatic Transmission for Wind Turbines
  - Fixed displacement pump coupled to the rotor;
  - Variable displacement motor coupled to the generator;
  - Charging circuit, to avoid cavitation and compensate leakage;

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```
- GS
- U
- V
- W
- M
- S
- Z
- Controller Z1
- Synchronous generator
- Wind turbine rotor
```
Dynamic Modeling and Simulation

- **AMESim model**
  - Wind torque; Hydraulic circuit; Control System; Electrical grid

- Synchronous generator directly connected to the grid

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2012  
Eduardo Flesch

2015  
Henrique Raduenz
Prototype Design and Construction

- **Structural model (3D CAD):**
  - 8.5 m high: include the effects of height difference;
  - 28 kW;
  - Using off-the-shelf components;
  - Generated electricity delivered to the grid;
  - Electrical motor act as wind turbine rotor

- **Behavioral model (AMESim):**
  - Study of control strategies;
  - Analysis of the system connection to the grid;
  - Improve the overall efficiency and achieve a cost effective solution;
Wind Turbine Blades: Pitch control and Force Emulation

- Matlab/Simulink
  - System simulation
  - Blade pitch control
  - Real-time force calculation

Pitch control

Force calculation

Force emulation
Wind Turbine Blades: Pitch control and Force Emulation

- Illustrative block diagram
- Test bench

![Illustrative block diagram of Wind Turbine Blades](image)

- Force calculation
- Aerodynamics
- Wind speed
- Pitch control
- Force emulation
- Simulation system
- Emulation force system
- Pitch angle control system

\[ \beta = f(v, \omega) \text{ for constant power} \]
Hydraulic System Design Using Biodegradable Hydraulic Fluids

2013
Yesid Asaff

- Illustrative model of the fluid ageing:
  - Expert system development for the system design support
  - Software Function Block Diagram:

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MODPROD2016 - Modeling Renewable Power Systems – Wind and Hydro
Models for Hydro and Wind Power Systems

- Electrical Generation
- Automatic Systems
- Speed and Power Governors
- Functional and Structural Modeling:
- Behavioral Modeling:

![Diagram of Hydro and Wind Power Systems]
2016 Conferences on Fluid Power in Brazil

3rd Workshop on Innovative Engineering for Fluid Power

WIEFP is a successful meeting between industry and academy in the field of fluid power, driver, actuation, mechatronics, and control systems. It is focused on promoting collaboration in technology, education, innovation management, and methods for system design.

Keynote speakers from Industry, research centers and universities
Audience: Engineers and Managers, Professors, Master and Ph.D. students, Undergraduate students

WIEFP2016 is organized by:

9th FPNI Ph.D. Symposium on Fluid Power

FPNI is a well recognized forum for researchers from all over the world, from academia and industry, to exchange ideas on current research and future developments in fluid power. It is a valuable opportunity to establish R&D cooperation with industry and academy.

Oral presentations from select papers from Master and Ph.D. students
Keynote speakers from industry researchers and professors
Audience: Industry and academy professionals; Master and Ph.D. students

FNPI2016 is organized by:

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Santa Catarina Island - Florianópolis

Hercilio Luz Bridge

Santa Catarina Island

Public Market

Conceição Lake

Dunes

Praia dos Ingleses
English`s Beach
Federal University of Santa Catarina
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Victor J. De Negri
victor.de.negri@ufsc.br