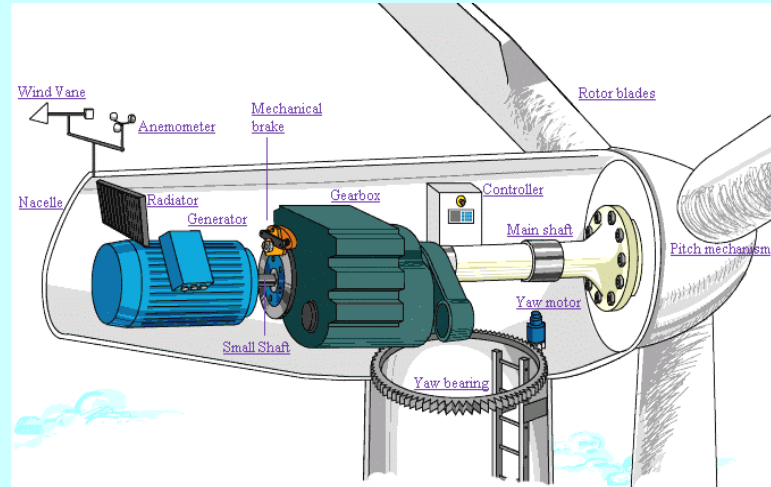


# Research Issues



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# Introduction

## A. Research main points

- 3 selected works

## B. Current research topics

- Recent activities & projects

## C. Research perspective overview

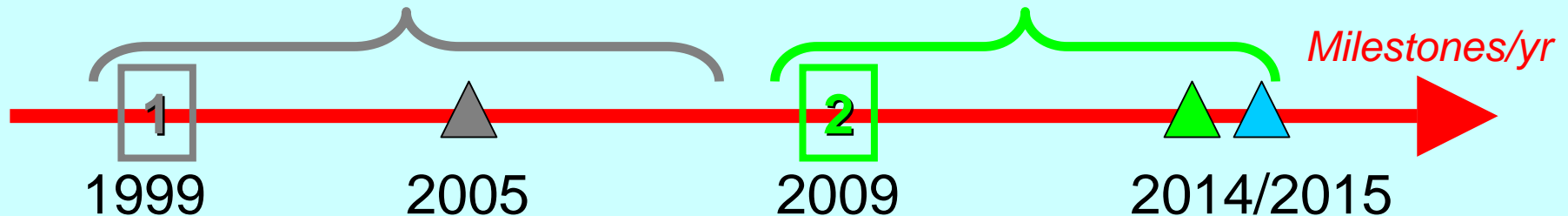
- Near, medium & long term focusses

**NEW**

# **A. Research Main Issues**

# Research Topics

- Inspired by realistic applications, case studies & projects
- **2** examples considered in the **3** papers



## 1. Gas turbine (1999)

- ABB Alstom UK (R.J. Patton, M. Grimble, UK)
- Feasibility study (2005)

## 2. Wind turbine/wind farm (2009)

- kk-electronic (DK) & MathWorks (USA)
- Int. competitions (kk-electronic, MathWorks, 2014-2015)

# Application Example (1)

## Gas turbine simulator Matlab & Simulink

HTDU model  
R B P 17/9/97  
mods by AJLO 4/1/99

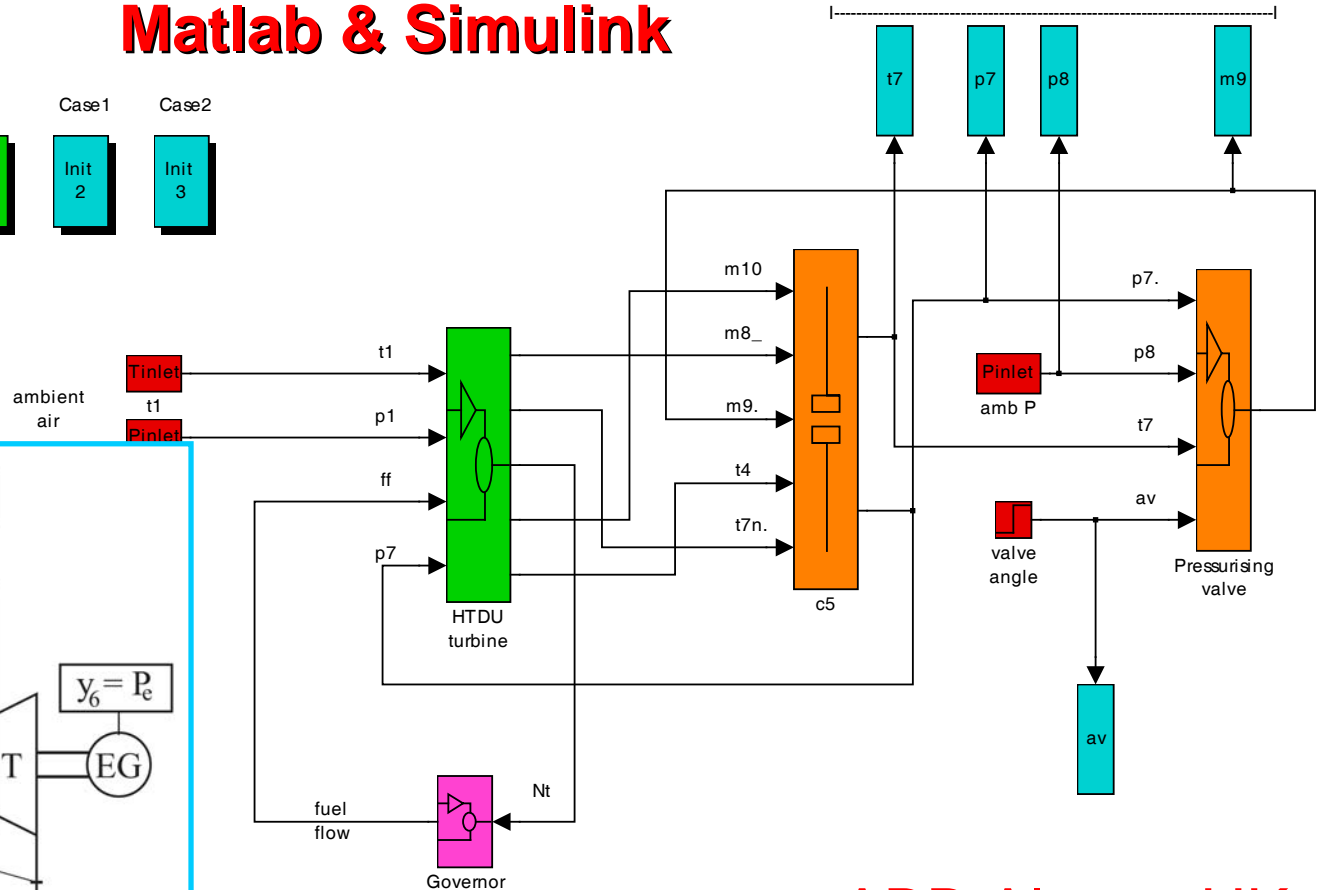
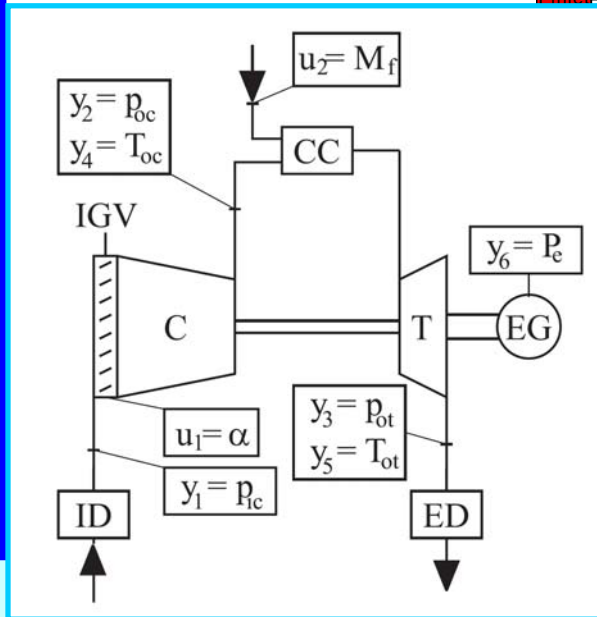
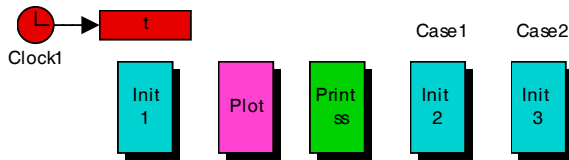
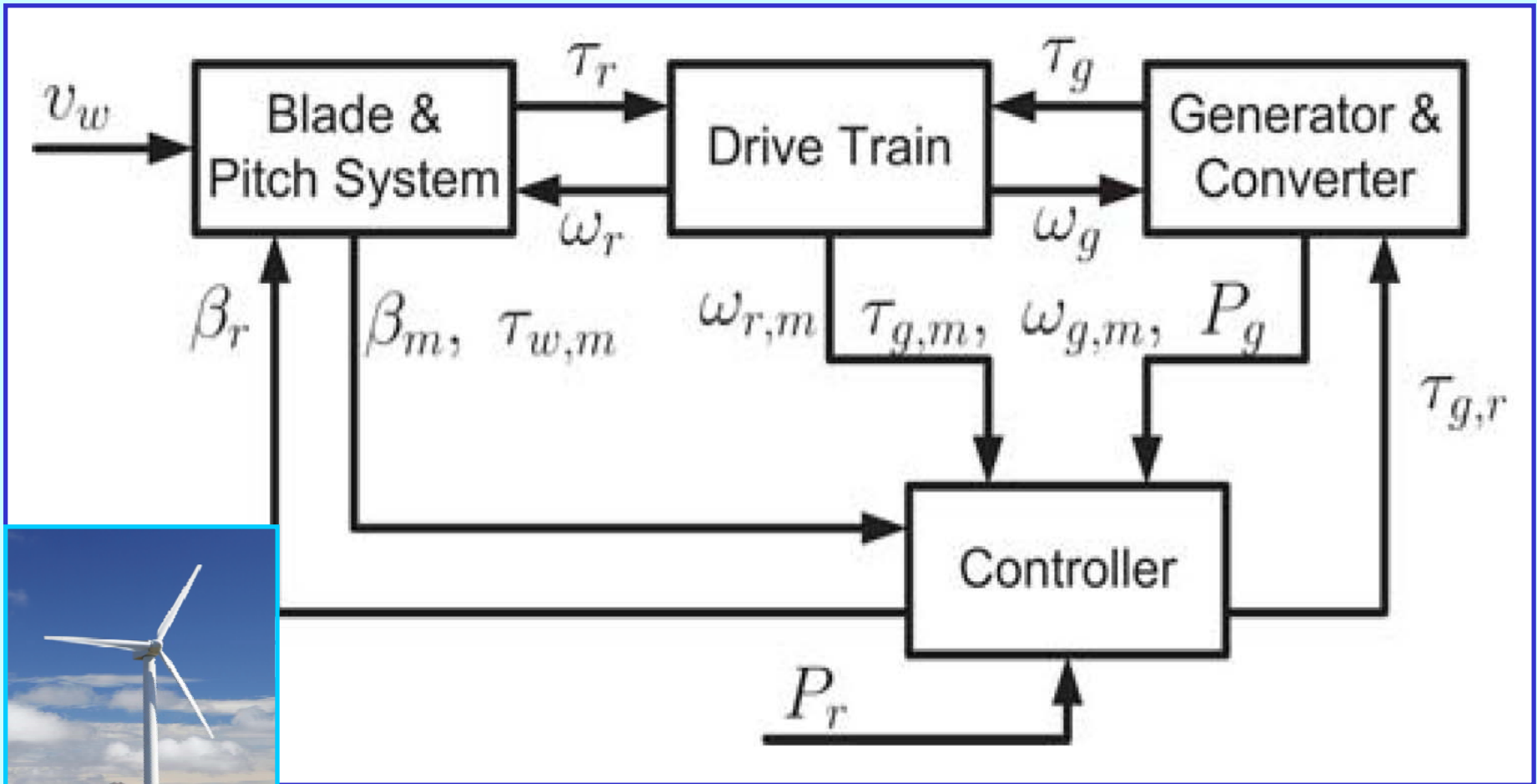


ABB Alstom UK

# Application Example (2)



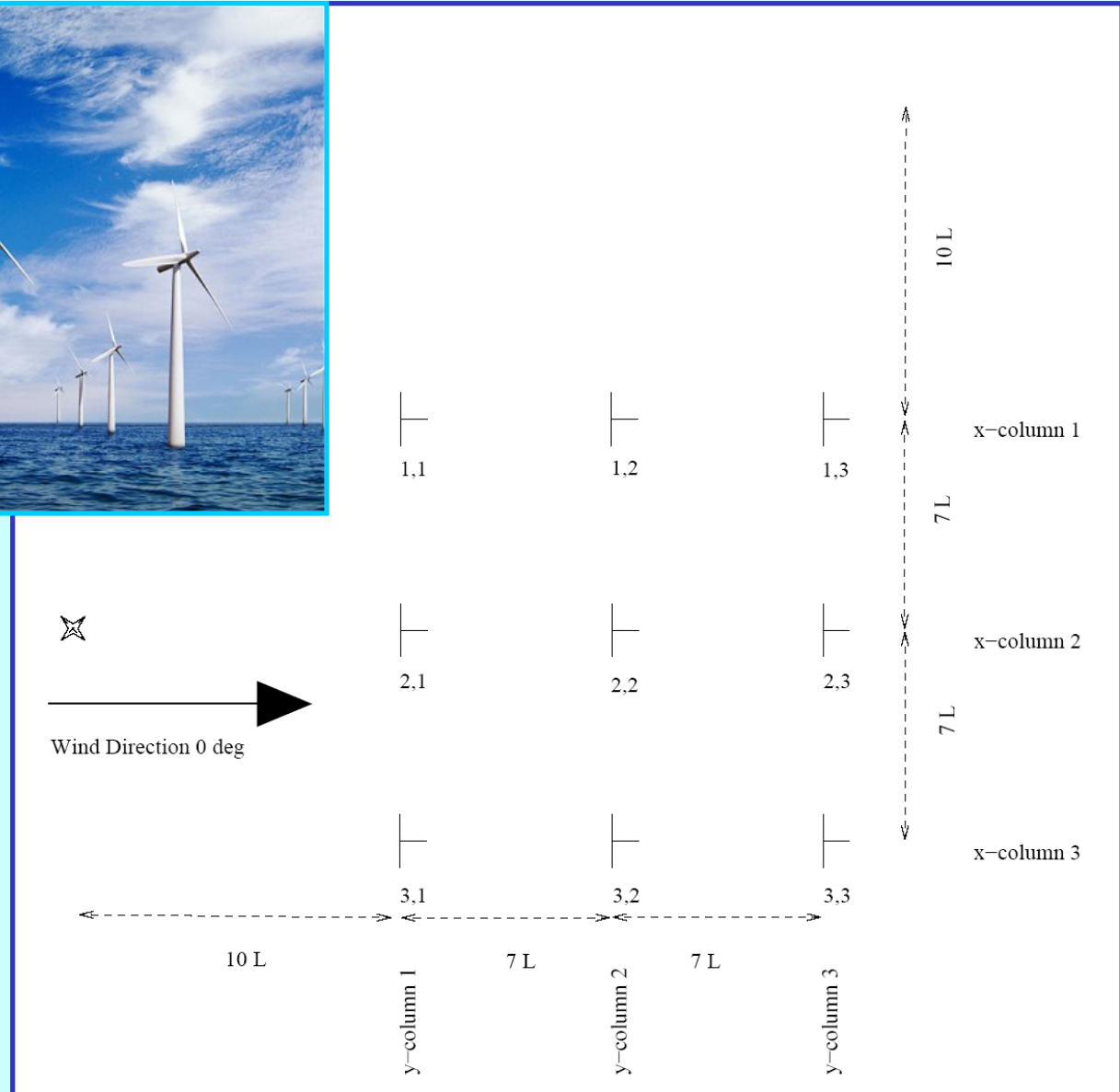
**Wind turbine simulator (Matlab & Simulink)**  
kk-electronic (DK)



# Application Example (3)



**Wind farm  
simulator  
(Matlab &  
Simulink)  
kk-electronic (DK)**



# Research Main Results (1)

- **Fault diagnosis feasibility study for a gas turbine**
- ❖ **Motivations**
  - Proposed by ABB Alstom UK (1999)
  - Ron J. Patton, Mike Grimble & S. Daley (UK)
- **Challenge of developing *effective & viable* diagnostic tools**
  - Predictive maintenance – detect slowly developing (incipient) faults in their earlier occurrence
- ❖ **Application of model-based FDI approaches**

[58] S. Simani, "Identification and Fault Diagnosis of a Simulated Model of an Industrial Gas Turbine," IEEE Transactions on Industrial Informatics, vol. 1, 202–216, 2005



# Research Main Results (1.1)

## ➤ **Main contributions**

- Complex thermodynamic model not required
  - Linear system identification methods (EE & EIV)
  - Linear output estimators for residual generation
- Advantageous in terms of **solution complexity & performance** (arbitrary trade-off)
- Robust & reliable solutions are designed
- EIV description enhances the model-reality mismatch minimisation & the fault effect maximisation
  - EIV models used for FDI purpose
- ❖ Fundamental when proper **certification & validation** procedures are under customer operation

# Research Main Results (1.2)

## ➤ **Strength points**

### □ **International cooperation**

- Technology transfer purpose

### ❖ **Viable application of model-based FDI to complex systems**

### ❖ **Methodologies assessed & applied to other systems**

- Aircraft & spacecraft simulators (PRIN)
- **EU Project (ESA, Astrium, Hull University): ROBEST - "Robust Estimation for Failure Detection", Ref: EAA.TCN.89079.ASTR**

# Research Main Results (2)

- **Fault tolerant control for wind turbines**
- ❖ **Motivations**
- International "Competition on Fault Detection and Fault Tolerant Control for Wind Turbines", award sponsored by kk-electronic (DK) & MathWorks (USA)
- **Wind turbine benchmark**
  - Developed by P.F. Odgaard (kk-electronic, DK)
- ❖ **Key issue for *offshore* wind turbine installations**
  - Guarantee proper working conditions even in case of severe malfunctions before the planned maintenance operations take place

[130] S. Simani and P. Castaldi, "Active Actuator Fault Tolerant Control of a Wind Turbine Benchmark Model," *International Journal of Robust and Nonlinear Control*, vol. 24, pp. 1283–1303, 2014

# Research Main Results (2.1)

## ➤ Main contributions

### □ Fault tolerant (“sustainable”) control (FTC) design

- ❖ Disturbance decoupled nonlinear filters for fault estimation (Active FTC – AFTCS)
  - The nonlinearity of the wind turbine is identified ( $C_p$  map)
  - A nonlinear geometric approach can be applied
  - Controller accommodation scheme exploits the on-line estimate of the faults from the nonlinear filters
- ❖ Extensive simulations are practical tools for assessing experimentally the AFTCS efficacy
  - Comparisons with different fault-tolerant schemes

# Research Main Results (2.2)

## ➤ **Strength points**

- ❖ Award & 3<sup>rd</sup> prize received @ the “Competition on Fault Diagnosis and Tolerant Control for Wind Turbines“ (IFAC SafeProcess 2012, Mexico City)
- ❖ IFAC activities, different workshops & plenaries
- ❖ Validated on more complex wind turbines
  - Reliable, effective and viable procedures for the *sustainable* control of wind turbines
- Challenging topic in Horizon 2020 (e.g. LCE calls)
  - Operation & management (O&M) highly affect the final cost of the energy production (@UniFE)

# Research Main Results (3)

- **Fault diagnosis for wind turbines & farms**
- ❖ **Motivations**
- International "Competition on Fault Detection and Fault Tolerant Control for Wind Turbines and Wind Farms"
- ❖ **Wind turbine + wind farm benchmarks**
  - kk-electronic (DK) & MathWorks (USA)
- ❖ **FDI important for *offshore* wind turbines**
  - Fundamental the detection of faults in their earlier occurrence
  - Fault diagnosis for **preventive/predictive maintenance**

[147] S. Simani, S. Farsoni, and P. Castaldi, "Fault Diagnosis of a Wind Turbine Benchmark via Identified Fuzzy Models," *IEEE Transactions on Industrial Electronics*, vol. 62, pp. 3775–3782, June 2014. Special issue "Real-time fault diagnosis and fault tolerant control"

# Research Main Results (3.1)

## ➤ **Main contributions**

- Development of a fault diagnosis scheme relying on identified fuzzy models
  - Model uncertainty & data noise
- Residual generators used for FDI
  - Organised into banks for fault isolation
  - Fuzzy identification enhances the bank design
- Monte-Carlo analysis: performance optimisation
- Comparison with different solutions from the international competition

# Research Main Results (3.2)

## ➤ **Strength points**

- ❖ Award & 3<sup>rd</sup> prize received @ the “Competitions on Fault Detection and Isolation for Wind Turbines and Wind Farm“ (IFAC WC 2011, Milan & IFAC WC 2014, Cape Town)
- ❖ **Data-driven “plug&play” strategies**
- ❖ IFAC activities, workshops & plenaries
- ❖ **Tecnology transfer projects**
  - **Fuzzy modelling applied to diesel engine real data** - "Towards the virtual motor thermal-fluid-dynamic modelling of advanced diesel engines via software tools, practical experiments, and test rigs" (application nr. DM28633, Art.12EMec)
  - **Strategies implemented in the product developed** in the “Road Wind” (2012 - 2013) & “Air Energy” (2013 - 2014)



## **B. Current Research Topics**

# Current Research Topics (1)

1. Modelling, control, fault diagnosis & fault tolerant control for **hydroelectric systems**
  - ❖ **Fuzzy & adaptive approaches**
    - Cooperation with Civil & Industrial Engineering Groups @ EnDiF
    - Local funds & technology transfer projects
2. Modelling & control of a **thermal unit**
  - ❖ **Fuzzy, MPC, NN**
    - Cooperation with Coventry & Izmir (HVAC)
    - Horizon 2020 calls (e.g. LCE, SCC)

# Current Research Topics (2)

## 3. FDI & FTC for **wind turbine installations**

- ❖ **Strategy validation & performance assessment**
- **FDI & FTC joint design (control oriented ident.)**
- **IFAC & IEEE activities, international consortium**
- **Horizon 2020 calls (e.g. LCE)**

## 4. FDI/FTC for **satellites & aircrafts**

- ❖ **Strategy validation & performance assessment**
- **Cooperation with Aerospace Dept. (UniBO)**
- **Technological demonstrator (LAURA)**
- **Horizon 2020 calls (e.g. Industrial Leadership)**

# **C. Research Perspective Overview**

**Near, medium & long term**



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# Research Perspectives (1)

## Near Term

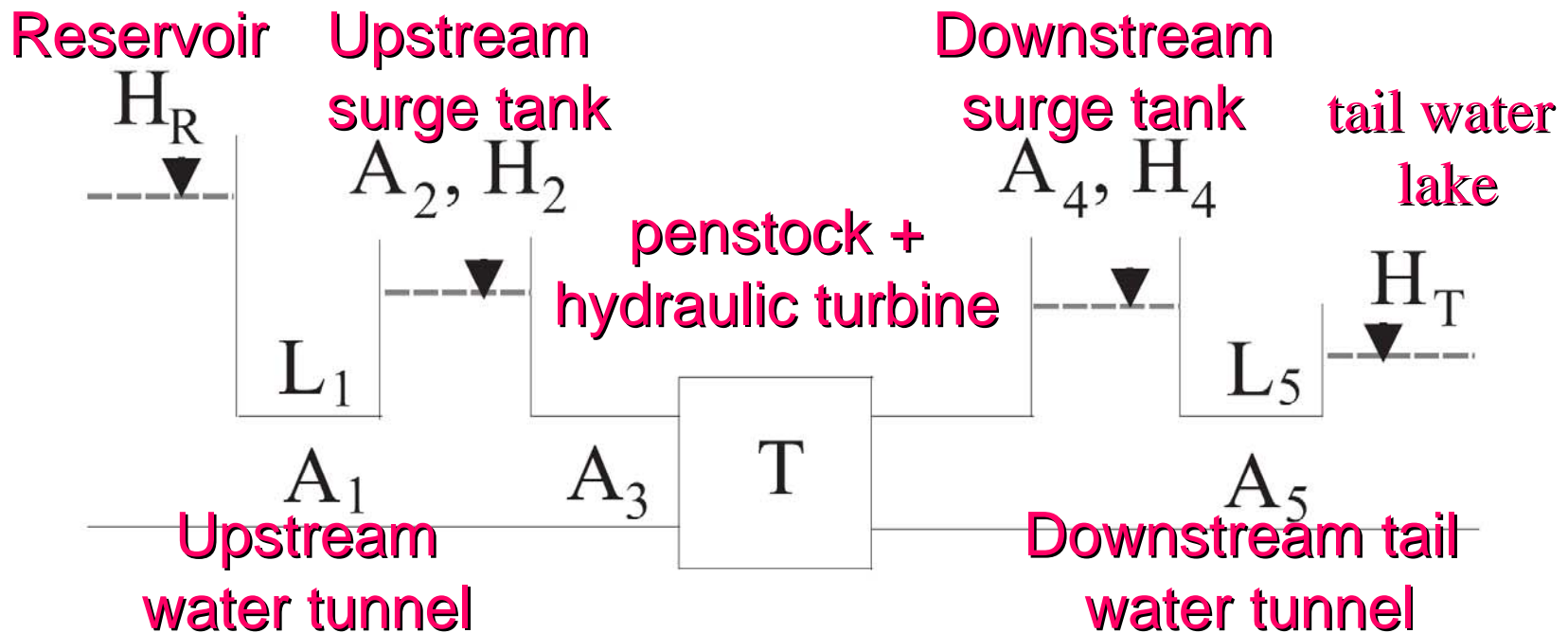
- Modelling & control methodologies to HVAC systems
  - Cooperation with Coventry & Izmir (Turkey)
  - Extension to more complex plant models
  - Smart buildings applications



# Research Perspectives (2)

## Near Term

- Control of grid-connected hydroelectric systems (extension to networks with PAT)
  - Cooperation with Hydraulic & Industrial Depts. @ UniFE
  - Modelling, FDI & FTC



# Research Perspectives (3)

## Near Term

- **FTC for wind farm installations**
  - More complex benchmark (wake/wind models)

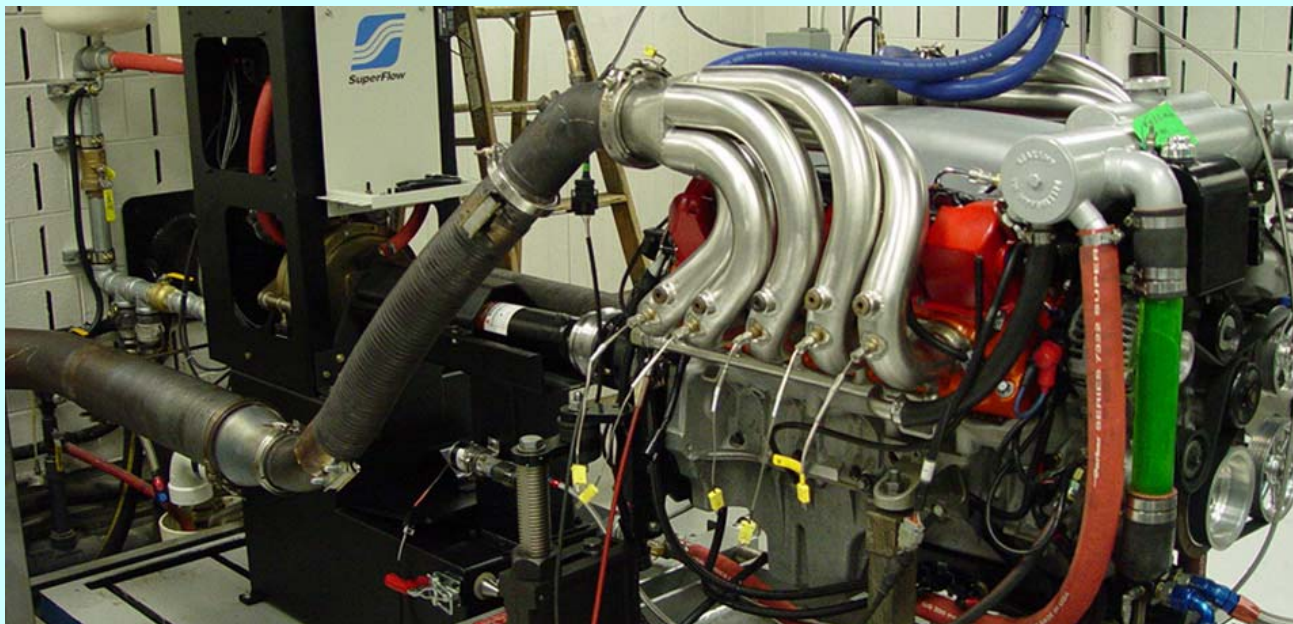


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# Research Perspectives (4)

## Near Term

- Automatic tuning of controllers for brake dynamometers of **diesel engine motor test bench**
  - Already tested for ECU (Bosch) control design
  - On-line identification for adaptive control design
  - Technology transfer project with VM Motors (FCA)

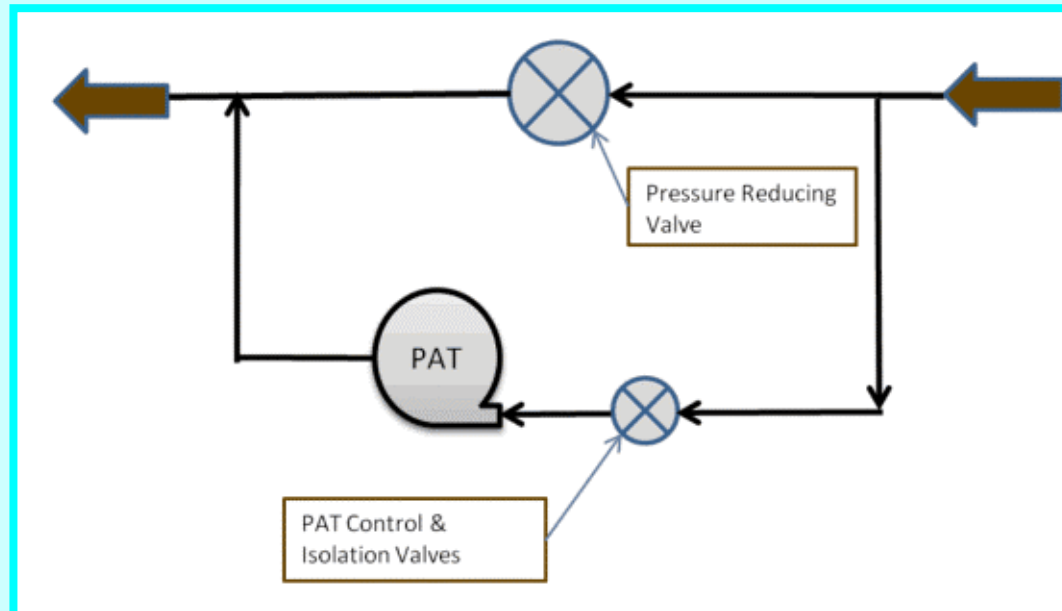




# Research Perspectives (5)

## Medium Term

- Pumps used As Turbines (PATs) to exploit *residual hydraulic energy*
  - Cooperation with Hydraulic & Industrial Depts. @ UniFE
  - **Water distribution networks + parallel PATs**
  - Cheaper than classic hydraulic turbines
  - **Challenging control issues (limit excessive pressures)**



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# Research Perspectives (6)

## Medium Term

- **Air Energy – Innovative Startup** (est. in 21/10/2015)
  - 7 partners: 3 University researchers & 4 companies
  - Harvesting energy from vehicle air flow using micro-wind turbines (placed along highways or medium-density roads)
  - Regional funds, contacts with Fondazione Torino Smart City & Associazione “Centro Studi per la Smart Economy” (TO)



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# Research Perspectives (7)

## Medium Term

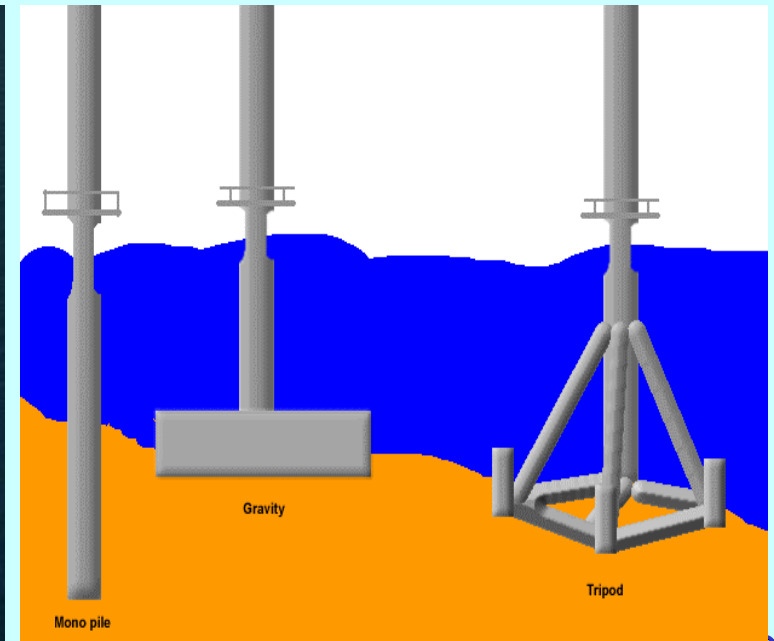
- Design of innovative solutions to improve physical & mobility impairment in frailty & elderly (Sept. 2015)
  - Control of mechanical devices & fitness tools
  - Local cooperation & funds (PRIA, Sept. 2015)



# Research Perspectives (8)

## Long Term

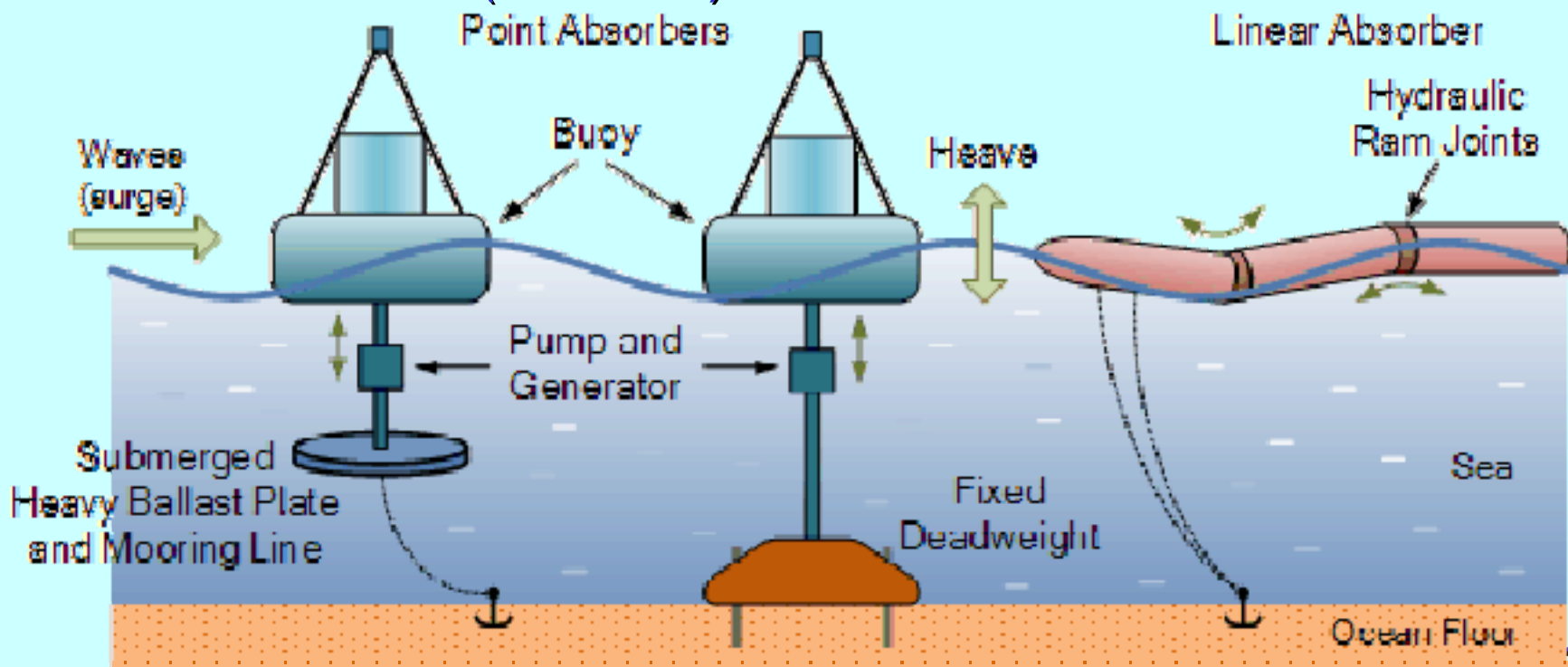
- Innovative design & control concepts for OWT
  - Smart & lighter (floating) structures
  - Large rotor disturbance + O&M reduction
  - Consortium (7 Universities + 4 industries, UniFE leader)
  - IFAC workshops, plenaries, SafeProcess 2018



# Research Perspectives (9)

## Long Term

- Wave energy conversion (WEC) systems
  - Cooperation with Hull & Maynooth Universities
  - Modelling & control issues
  - FDI & FTC (mature?)



# Research Perspectives (10)

## Long Term

### □ Laboratorio Universitario Ricerche Aerospaziali – LAURA (Forlì, BO)

- Collaboration with DEI @ UniBO
- FDI/FTC real case study
- Wind effect decoupling



*Thank You for Your Attention*