Wind Turbine Control

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Vitoria-Gasteiz, 23rd April 2013

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Presentation Scheduling

- Our Team
  - Researchers
  - Students
  - Resources/Skills:
    - HW
    - SW
  - Relationships
    - Enterprises
- Our research domains

Our Team

- **Researchers:**
  - 3 researchers in Wind Turbine Control
  - 2 PhD students
    - In Intelligent Optimization of Control Parameters
    - In QFT wind turbine control
- **Graduate students**
  - More than 10 in the last course

Our Team

- **Resources/Skills:**
  - **HW**
    - – We have several Work Stations
    - – We have the Super Computation UPV/EHU service
  - **SW**
    - – We work with different Simulation and Control Design
      - » Matlab&Simulink
      - » FAST (NREL)
      - » Scilab
    - – Wind Turbine Control Implementations
      - » Siemens and Beckhoff
      - » In Structured Text Programmation

Our Team

- Relationships
  - Local enterprises and research centers
    - Argolabe Ingenieria SL
      - 100kW Wind Turbine
    - Optimitive SL
      - An Industrial Process Optimization SW developer
    - Tecnalia
  - More sporadic works
    - CENER
    - Aeroblade
    - Instalaciones Electricas Del Valle Aguayo

Our research domains

- **Wind Turbine Control**
  - **There are several “Control Layers”**
    - **Generator side power stage controls**
    - **Mechanical controllers**
    - **Power network side stage controls**
    - **Wind Turbine Supervisor**
  - **Each layer manages different variables and assures to the upper layer that several variables follow their set points**

Our research domains

- The generator side power stage control
  - Vector Control applied to different electrical machines
    - » DFIG
    - » Permanet Magnet Machines
    - » Asynchronous machines
  - This layer tries to follow a Power Set Point given by The Mechanical Loops controllers.
    - » The torque control assures to follow the power set point in a variable pitch wind turbine. In stall control schemes, this variables must control the rotor speed and the power control.

Our research domains

- The generator side power stage control
  - There are many works about these controls
    - A very important research domain is the Double Feed Induction Generators (DFIG)
      - » In our institution there are different groups that research in this domain:

        Oscar Barambones in UPV/EHU

        Gerardo Tapia , Haritza Camblong and Ostolaza in UPV/EHU
      - » Gonzalo Abad, in Mondragon Unibertsitatea
      - » Ekanayake, JB, Cardiff S. E.
      - » Sorensen P. DTUwind (RISO)
      - » Mikel Iribas in CENER
      - » Mario Garcia-Sanz in UPNA
  - These researchers are important as Bianchi or Bossanyi!!

Our research domains

- The generator side power stage control
  - The most important aspects for a Wind Turbine Manufacturer are:
    - The Prices of power stages and generators
      - » The most expensive ones are permanent magnet machines
      - » The cheapest and robust ones are the induction generators
      - » A possible good intermediate machine is the commutated reluctance machine
    - Mechanical aspects as: Weight, Volume, Gear box
    - Power performance vs speed

Our research domains

- The Mechanical Control
  - Rotor Speed Controllers
    - By pitch
    - By torque control (Stall control)
    - By other blade variable geometries
  - Yaw Controllers
    - This control loop tries to orient the wind turbine to “wind”
    - This variable does not change very quickly because it creates big furling problems. This variable could be a good candidate for power manipulation.

Our research domains

- The Mechanical Control
  - There are other research domains as:
    - Aerodynamics Torque Estimation
      - This variable let us to know which speed is going to be in very close time
      - It gives to the speed controller a derivative term
    - Rotor Speed Set point policies
      - It increases the captured power
      - It reduces the structural fatigue
      - In a isolated grids, it has to contribute to the power grid stability
    - There are many research domains:
      - IPC vc CPC
      - Adaptive or Robust control: QFT, automatic loop shaping

Our research domains

- Power network side stage controls
  - This control layer tries to inject a active power to the power network.
    - This is achieved by a DC bus voltage control loop
  - This control tries to inject a reactive power to the power network
    - This is achieved imposing the power factor between the current and voltage at connection point (Transformer).
    - This control perturbs the DC bus voltage.
  - Here the most important research domains are:
    - To fulfill different standards about Wind Turbine Connections to the power network.

Our research domains

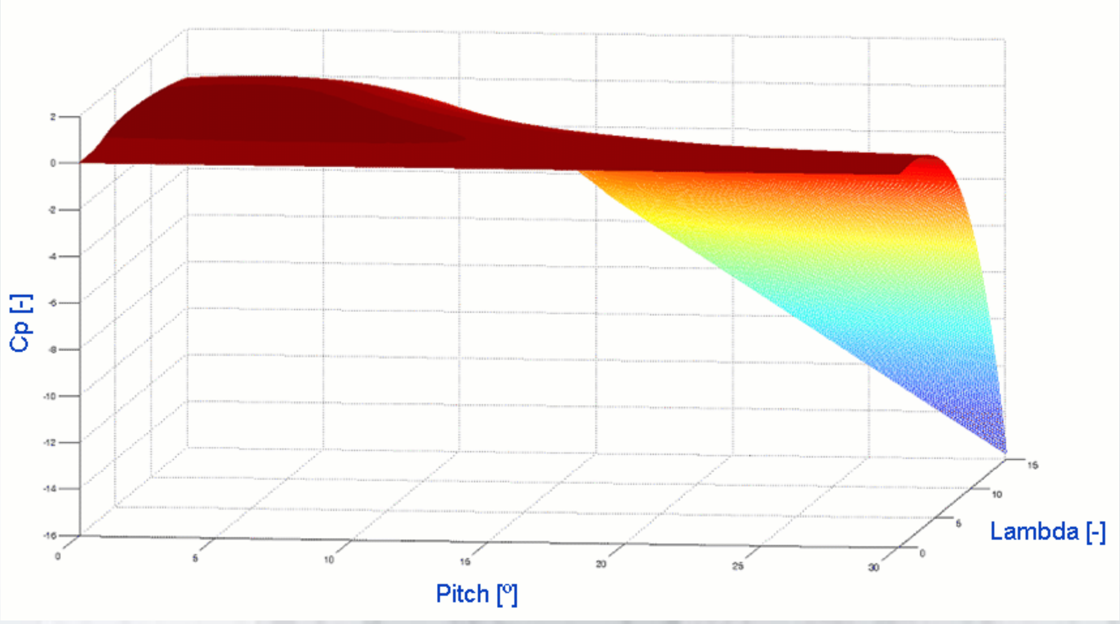
– **Wind Turbine Supervisor**
  - **Wind turbines can works in different types of power networks.**
    - – **Stable networks with connection standards**
      - » **Behavior to symmetrical and non symmetric electrical faults.**
    - – **Isolated power networks: They need to have a hybridization with different technologies and contribute to power network stability.**

Our research domains

- Optimization problem
  - How to adjust the control parameters
    - Evaluation (cost functions)
    - How to choose generate different possible solutions
  - Answer: Computational Intelligence
    - Swarm techniques:
      - Particle Swarm Optimization
      - Differential evolution
      - Genetic algorithms
    - Reinforcement Learning:
      - Q-learning
      - Markov Decision Processes

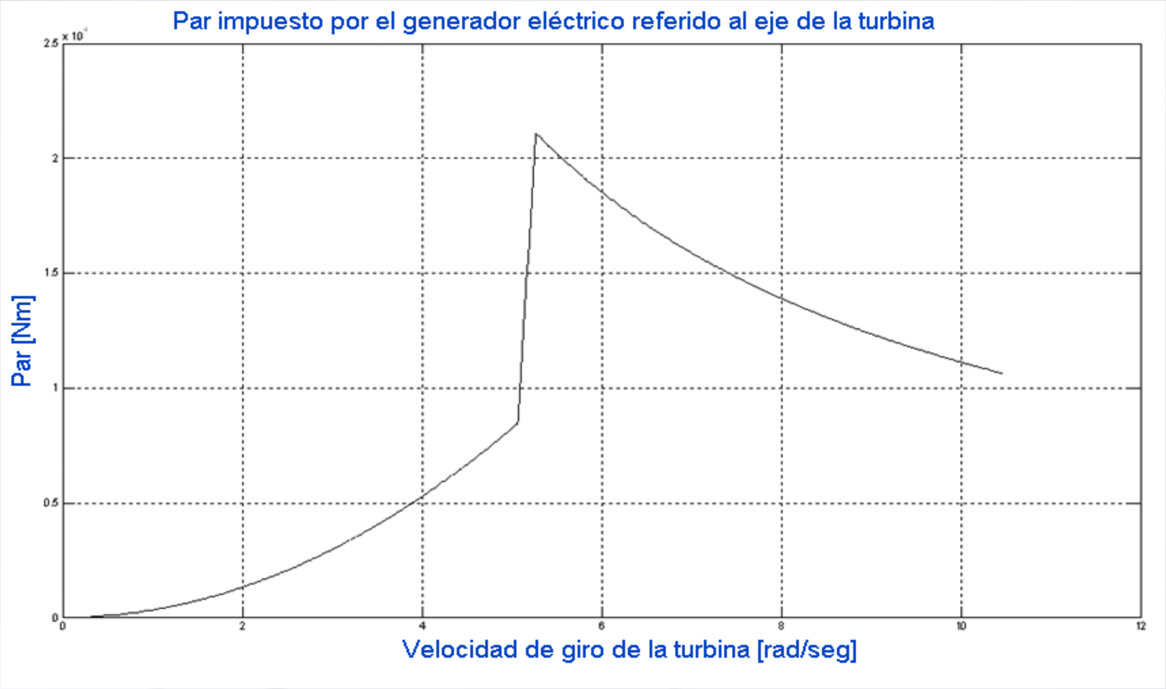
Our research domains

- **An example:**
  - **In a 100kW wind turbine**
    - **Variable speed**
    - **Variable pitch**
  - **Power coefficient**



Our research domains

- **An example:**
  - **Torque Controller**



$$T_{electrico} = \frac{C_{p,optm} . \pi . \rho_{aire} . R^5}{2 . i . \lambda_{optim}^3} . w^2 \qquad T_{electrico} = \frac{P_{nominal}}{i . w}$$

Our research domains

- **An example:**
  - **Rotor Speed Controller**

$$\beta^* = K_p\left(error + \frac{1}{T_i}error_{integral}\right)$$

$$error = w - w^*$$

$$error_{integral} = \begin{cases} -L_{integral} : -L_{integral} > \int_0^t error.dt \\ \int_0^t error.dt : \quad -L_{integral} < \int_0^t error.dt < L_{integral} \\ L_{integral} : L_{integral} < \int_0^t error.dt \end{cases}$$

Our research domains

- **An example:**
  - **Rotor Speed Controller**
    - **Gain Scheduling**

$$K_p = \frac{2\xi}{\omega_n}\frac{K\Omega_0}{i.\frac{30}{\pi}}\left(-\frac{\partial P}{\partial \beta}\right)^{-1} \qquad T_i = \frac{2\xi}{\omega_n}$$

$$K = \omega_n^2$$

We need to know the design parameters

$$\omega_n \; \xi$$

Our research domains

- The optimization problem
  - How to adjust the control parameters
    - Evaluation (cost functions)
      - Captured Mean Power
      - Over Speeds (higher rotor speed than rated speed)
      - Pitch Activity
  - Answer: Computational Intelligence
    - Swarm techniques:
      - Particle Swarm Optimization

Our research domains

- **The optimization problem**
  - **How to adjust the control parameters**
    - **Evaluation (cost functions)**
      - **Captured Mean Power**
      - **Over Speeds (higher rotor speed than rated speed)**
      - **Pitch Activity**

$$Cost = \lambda_1 P_{med} + \lambda_2 Error_{Velo} + \lambda_3 Activity_{pitch}$$

$$P_{med} = \frac{1}{T_{simulation}} \int_0^{T_{simulation}} P \cdot dt$$

$$Error_{Velo} = \frac{1}{T_{simulation}} \int_0^{T_{simulation}} Error_{Waltas}.dt$$

$$Actividad_{pitch} = \frac{1}{T_{simulacion}} \int_0^{T_{simulacion}} \left| \frac{d\beta}{dt} \right| .dt$$

$$Error_{Waltas} = \begin{cases} \left| w^* - w \right| : w > w^* \\ 0 : w < w^* \end{cases}$$

Our research domains

- **The optimization algorithm**
  - **Particle Swarm Optimization (PSO)**
    - **This algorithms does not impose high restrictions to the optimization problem**
      - **The function does not need to be continuous or differentiable**
      - **It does not assures that you obtain a global optimum**
      - **It works well in a restricted parameter subdomain**
    - **It needs more computation time**
      - **So, it has to be a off line algorithm**

Our research domains

- **The optimization algorithm (PSO)**
  - **Steps**
    - **1 Initializes randomly N particle positions and evaluates its particle.**
      - **Each particles stores its actual position, its best position till now, and their scores.**
      - **The global best actual position is calculated (Position, Score)**
    - **2 The algorithm proposes new positions for each particle**

$$\vec{p}_i(k) = \left[\omega_{n,i}, \xi_{n,i}\right]^t$$

$$\vec{p}_i(k+1) = \vec{p}_i(k) + \vec{v}_i(k)\Delta t$$

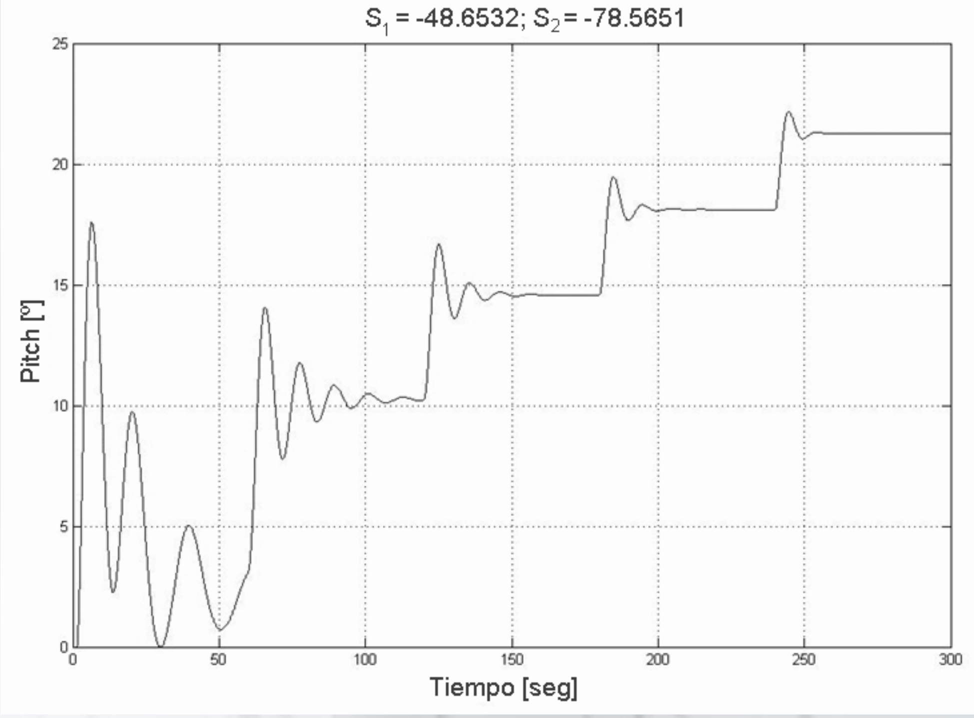
$$\vec{v}_i(k+1) = I_i \vec{v}_i(k) + \varphi_1 r_1 \left(\vec{p}_{i,optimal}(k) - \vec{p}_i(k)\right) + \varphi_2 r_2 \left(\vec{p}_{global}(k) - \vec{p}_i(k)\right)$$

Our research domains

- The optimization algorithm (PSO)
  - Steps
    - 3.-Repeat the second step until a Stop condition is fulfilled
      - A Maximum Iterations number
      - It arrives to a acceptable cost
      - It does not change enough the global optimal position

Our research domains

- **Proposed solution by PSO algorithm**
  - **Particles: 15 , iterations: 100**
  - **Coefficients of inertia: 0.00009**
  - **Simulation horizon 300 (s)**



  - **Wind speed step profile from 12 m/s to 20 m/s.**