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Comparison of Speed Control Strategies for Maximum Power Tracking in a Wind Energy Conversion System

J. Zaragoza[1], C. Spiteri Staines[2], A. Arias[1], J. Pou[1], E. Robles[3], S. Ceballos[3]

[1] Technical University of Catalonia

[2] University of Malta

[3] Robotiker-Tecnalia

Outline

I. Introduction

II. Wind Turbine System Modeling

III. PI Vs Fuzzy Controller

IV. Simulation Results

V. Conclusion

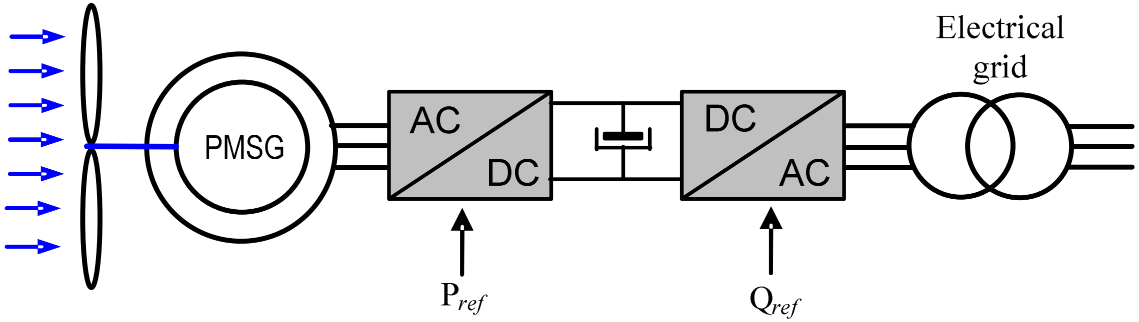
I. Introduction

Objectives of this work:

- Modeling of a wind turbine system (Matlab- Simulink)
- Tuning and analyzing of the PI controllers
- Design of a fuzzy controller (Speed Loop)
- Simulation and comparison of the both proposed controllers (PI Vs Fuzzy)

I. Introduction

❑ Variable wind speed system

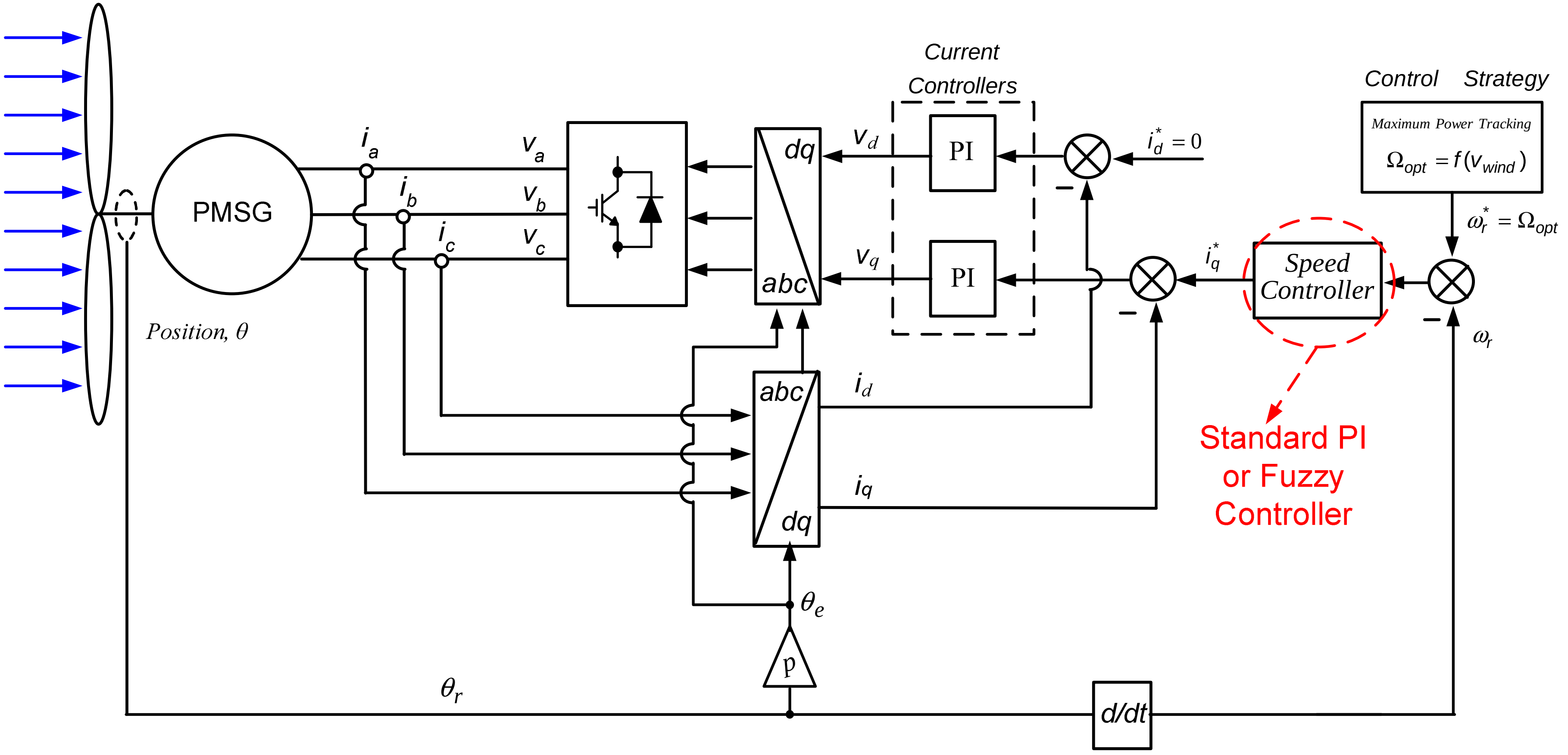


- Using a PMSG:
    - very high torque can be achieved at low speeds;
    - no significant losses are generated in the rotor;
    - lower operational noise is achieved; and
    - external excitation current is not needed.

- This work is devoted to the study of the variable speed control of the PMSG in order to improve its performance in WT systems.

I. Introduction

❑ FOC applied to the wind turbine system



Standard PI or Fuzzy Controller

II. Wind Turbine System Modeling

Wind Turbine Modeling

Tip Speed Ratio

$$\lambda = \frac{\Omega R}{v_{wind}}$$

Blade Pitch

$$\beta$$

$$C_p(\lambda,\beta) = c_1\left(\frac{c_2}{\lambda_i} - c_3\beta - c_4\right)e^{-\frac{c_5}{\lambda_i}} + c_6\lambda$$

Maximum Power Operation

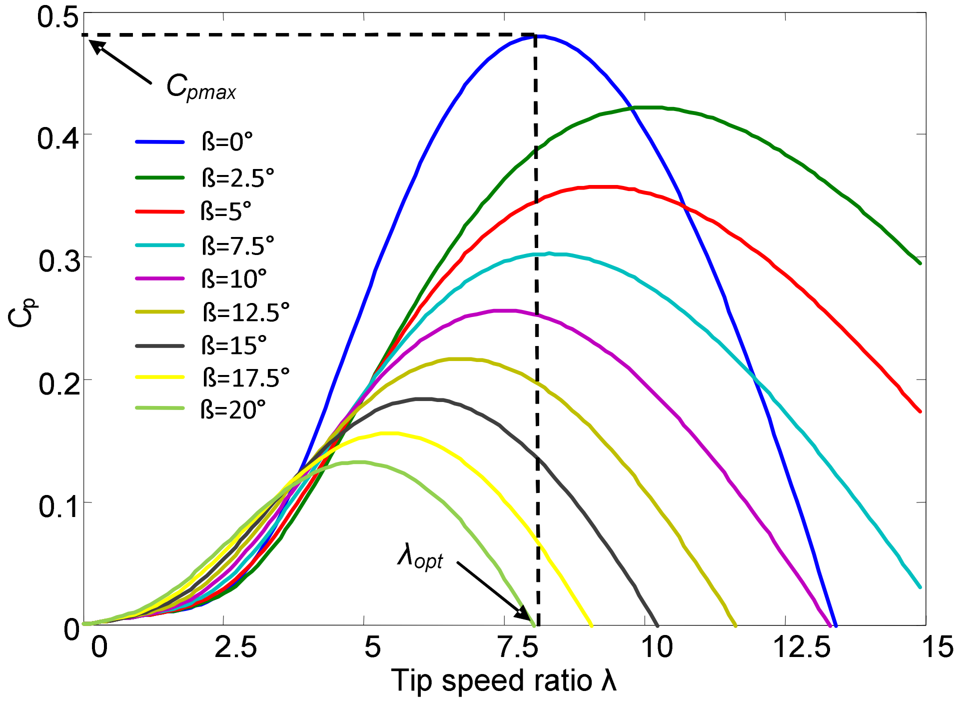
$$\Omega_{opt} = \frac{\lambda_{opt} v_{wind}}{R}$$

Speed Control Reference

$$P_{T\max} = \frac{1}{2}\rho A C_{p\max} v_{wind}^3$$

Variation of Power coefficient *Cp* with Tip Speed Ratio

(for fixed values of *β*)



PMSG Modeling

- ☐ The PMSG can be modeled by the following equations, represented in the rotating d-q reference frame:

$$v_d = R_s i_d + L_d \frac{d}{dt} i_d - \omega_e L_q i_q \quad (3) \qquad v_q = R_s i_q + L_q \frac{d}{dt} i_q + \omega_e L_d i_d + \omega_e \Psi_m \quad (4)$$

- ☐ The electrical torque (T_e) is determined by:

$$T_e = \frac{3}{2} p \left[\Psi_m i_q + \left(L_d - L_q \right) i_d i_q \right] \quad (5)$$

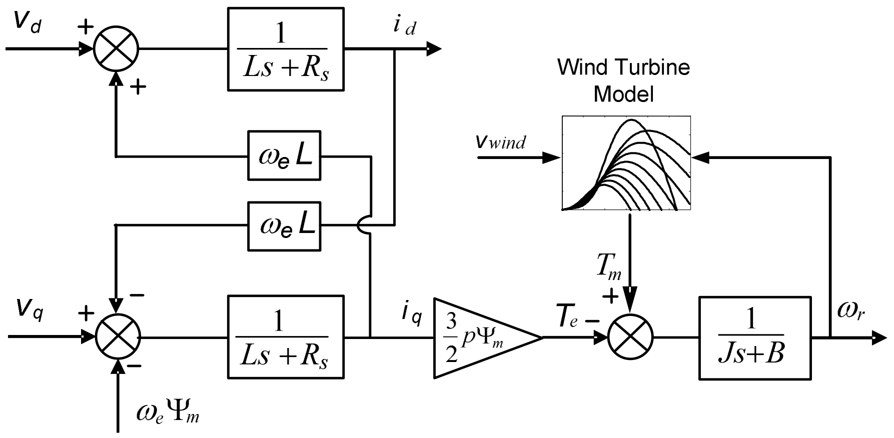
- ☐The machine's rotor dynamics are described by:

$$T_m - T_e = B\omega_r + J \frac{d\omega_r}{dt} \quad (6)$$

➢ Assuming the term $(L_d\text{-}L_q)i_d i_q$ to be negligible for two reasons; L_d and L_q are quite similar (L_d=L_q=L), and the *d* reference current is usually zero (i^*_d=0).

PMSG Modeling

❑ Model of the PMSG.



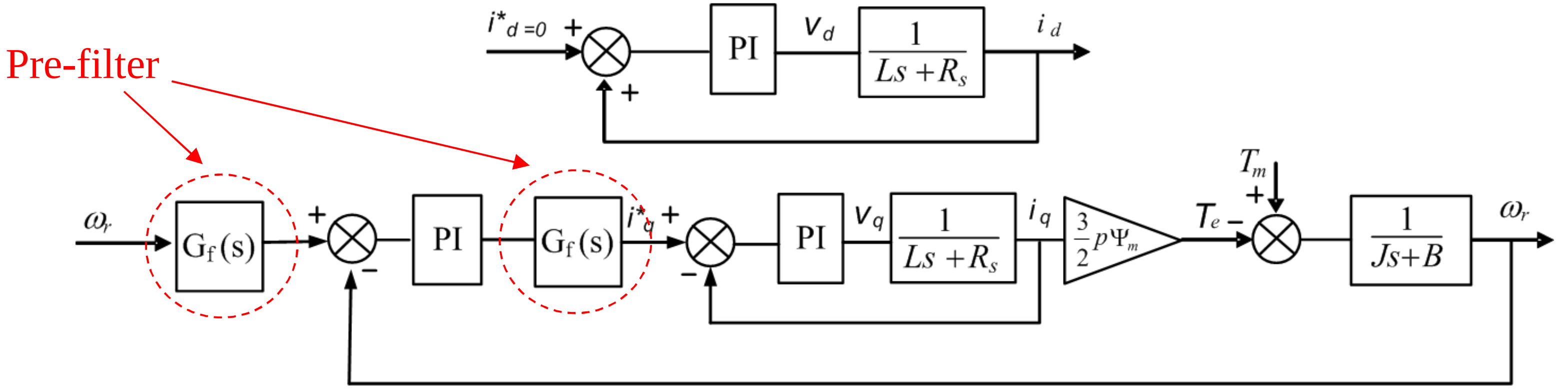
$$G_{1\_cl}(s)=\frac{\frac{k_i}{L}\left(\frac{k_p}{k_i}s+1\right)}{s^2+s\left(\frac{k_p+R_s}{L}\right)+\frac{k_i}{L}} \qquad (7)$$

$$G_{2\_cl}(s)=\frac{\frac{k_i}{J}\left(\frac{k_p}{k_i}s+1\right)}{s^2+s\left(\frac{k_p+B}{J}\right)+\frac{k_i}{J}} \qquad (8)$$

Pre-filter

$$G_f(s)=\frac{1}{\frac{k_p}{k_i}s+1} \qquad (9)$$

❑ Current and speed control loops



Speed and Current Loop Controllers

- ☐ Standard PI controllers are used for PMSM’s current loops.
  - The current plant is ‘linear’
  - Their dynamics are determined by the system’s electrical characteristics (relatively fast compared to mechanical system’s dynamics)

- ☐ The speed loop:
  - Slow dynamics and,
  - additionally, the mechanical system is nonlinear.

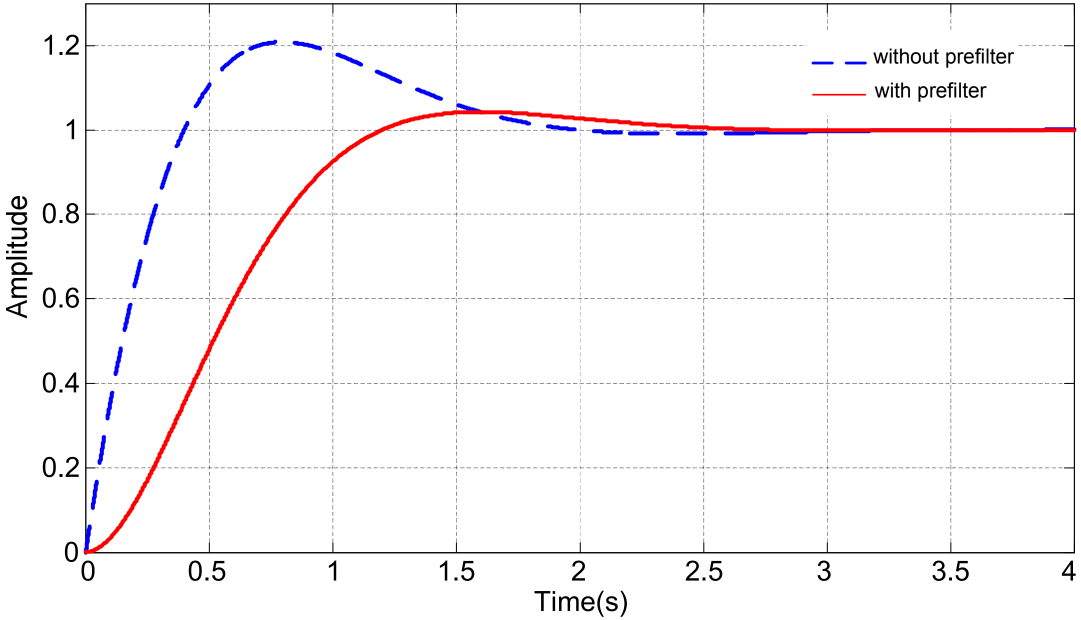
- ☐ Speed Loop is a critical control loop. Two types of regulators shall be tested;
  - a standard PI and,
  - a Fuzzy controller.

Tuning PI parameters

☐ The parameters k_p and k_i of the PI controllers are found by defining a rise time (T_r) and damping factor (D_f). In the case of the ***speed loop (figure below)***, the rise time is around 1.5 seconds and a damping factor of 0.707.

☐ In order to improve the control bandwidth, a pre-filter $G_f(s)$ can be included in the control loops. This pre-filter is designed to cancel out the zero of the closed-loop transfer function.

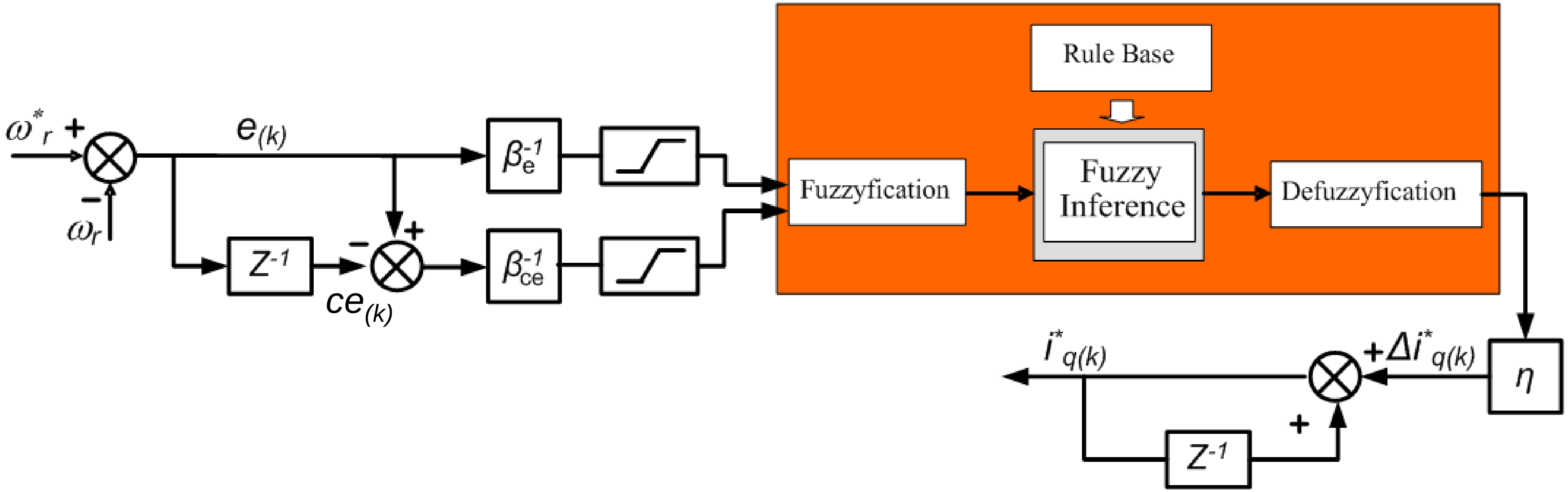
Speed Step response with and without pre-filter



Fuzzy Structure

❑ Fuzzy structure

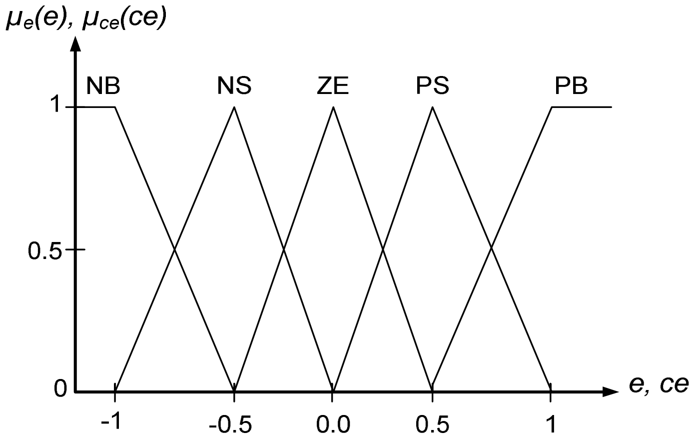
- There are two inputs; the speed error and its derivative, and one output which provides the current references (i^*_q).



- The PID-Fuzzy is suited to zero-order Takagi-Sugeno architecture
- The variable *‘e’* is the speed error and *‘ce’* is its derivative
- The β^{-1} represents scaling (gains).

Fuzzy Structure

- ❑ Membership functions for *‘e’* and *‘ce’*



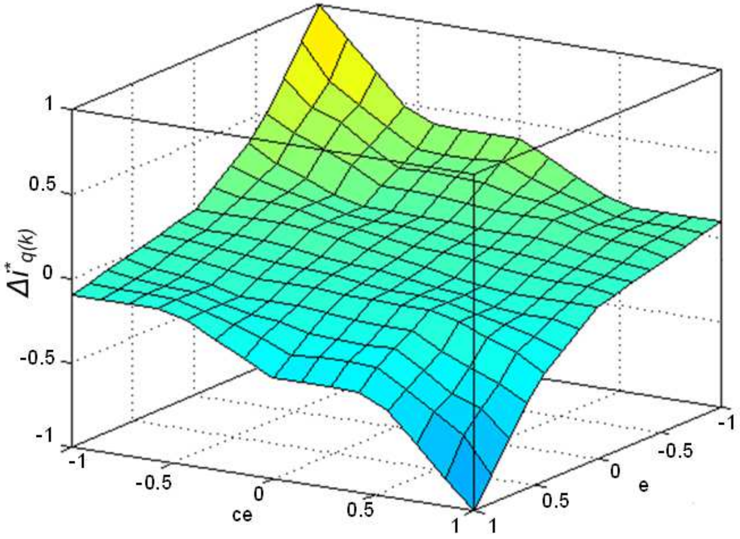
- ❑ Rule Table of the Fuzzy Controller

$e_0\backslash ce_0$	NB	NS	Z	PS	PB
PB	-0.3	-0.35	-0.45	-0.65	-1
PS	0	-0.1	-0.2	-0.35	-0.5
Z	0.2	0.1	0	-0.1	-0.2
NS	0.5	0.35	0.2	0.1	0
NB	1	0.65	0.45	0.35	0.3

- ❑ The final output includes integral action

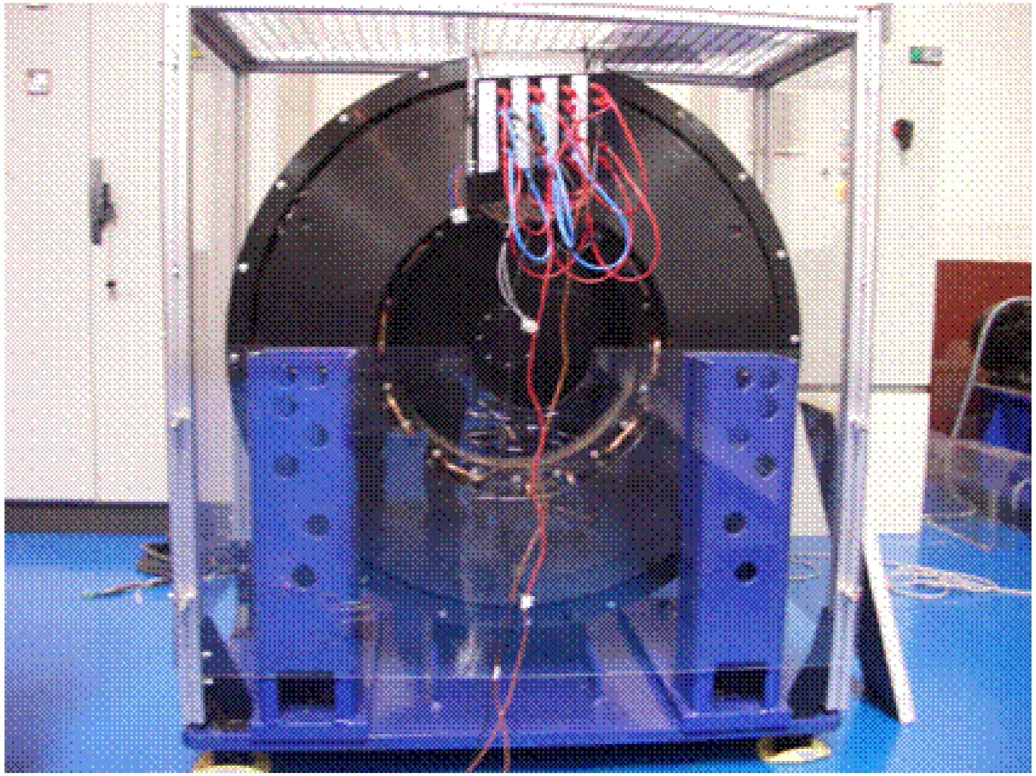
Resulting input-output surface

Fuzzy Input-output supervisor surface



Simulation Results

Wind generator with an external rotor



Data of the PMSG used in simulation results

PMSG	Value
P_N(kW)	13.5
w_N (rpm)	120
T_m (Nm)	1,074
Rated voltage (V)	400
Pole pairs (ρ)	10
L (mH)	16.416
J ($kg \cdot m^2$)	206.5
B ($kg \cdot m^2/s$)	1.5
R_s (Ω)	0.686

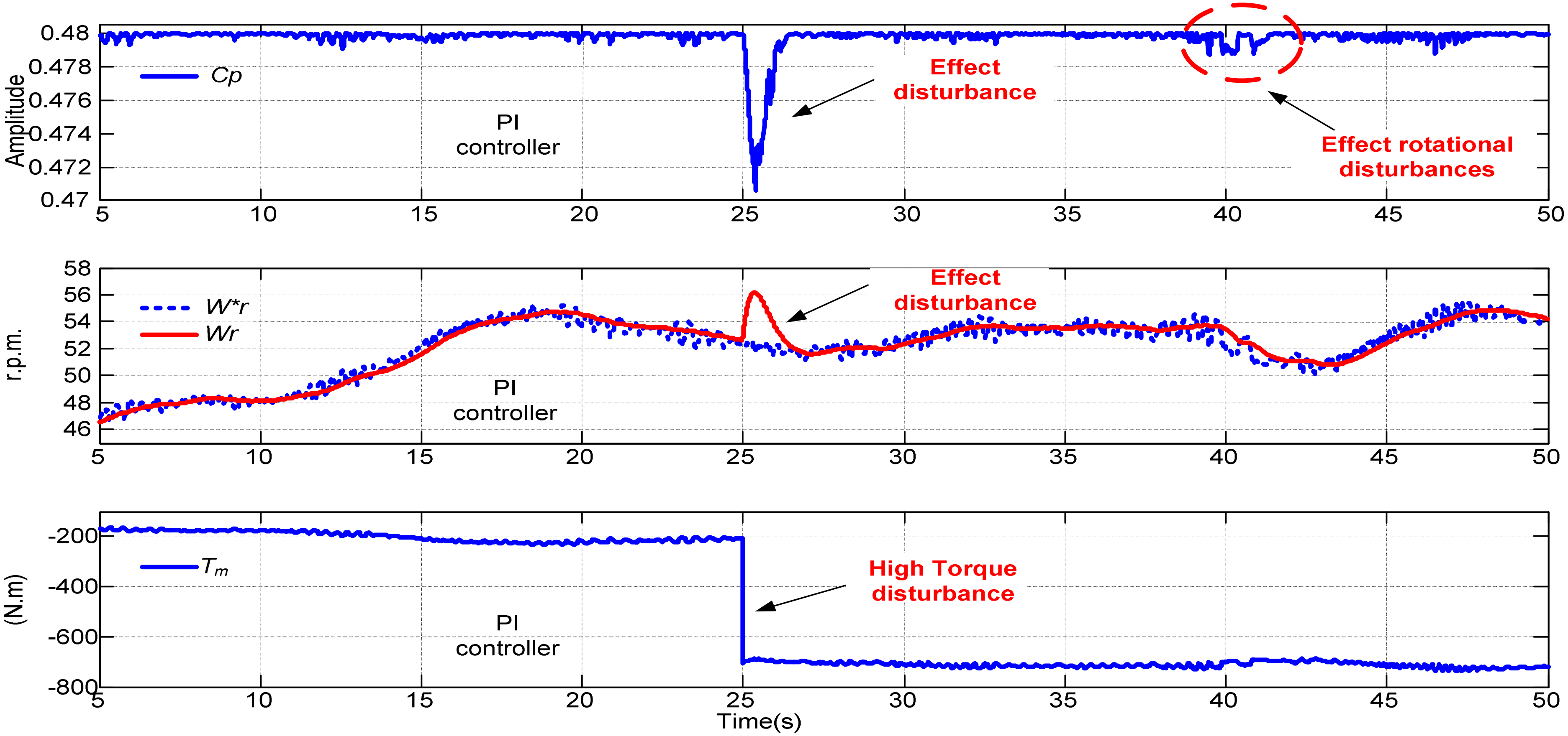
Eider Robles, Jordi Zaragoza, Salvador Ceballos, Ionel Vechiu, Octavian Curea "Innovative Permanent Magnet Generator for an Easy Integration into Direct Drive Wind Turbines". European Wind Energy Conference, EWEC 2007.

Wind speed data for Simulations: from wind model developed by RISØ National Laboratory assuming operating conditions of: low average wind speed, turbulence intensity of 10%, and sample time of 0.05 s.

Simulations Results

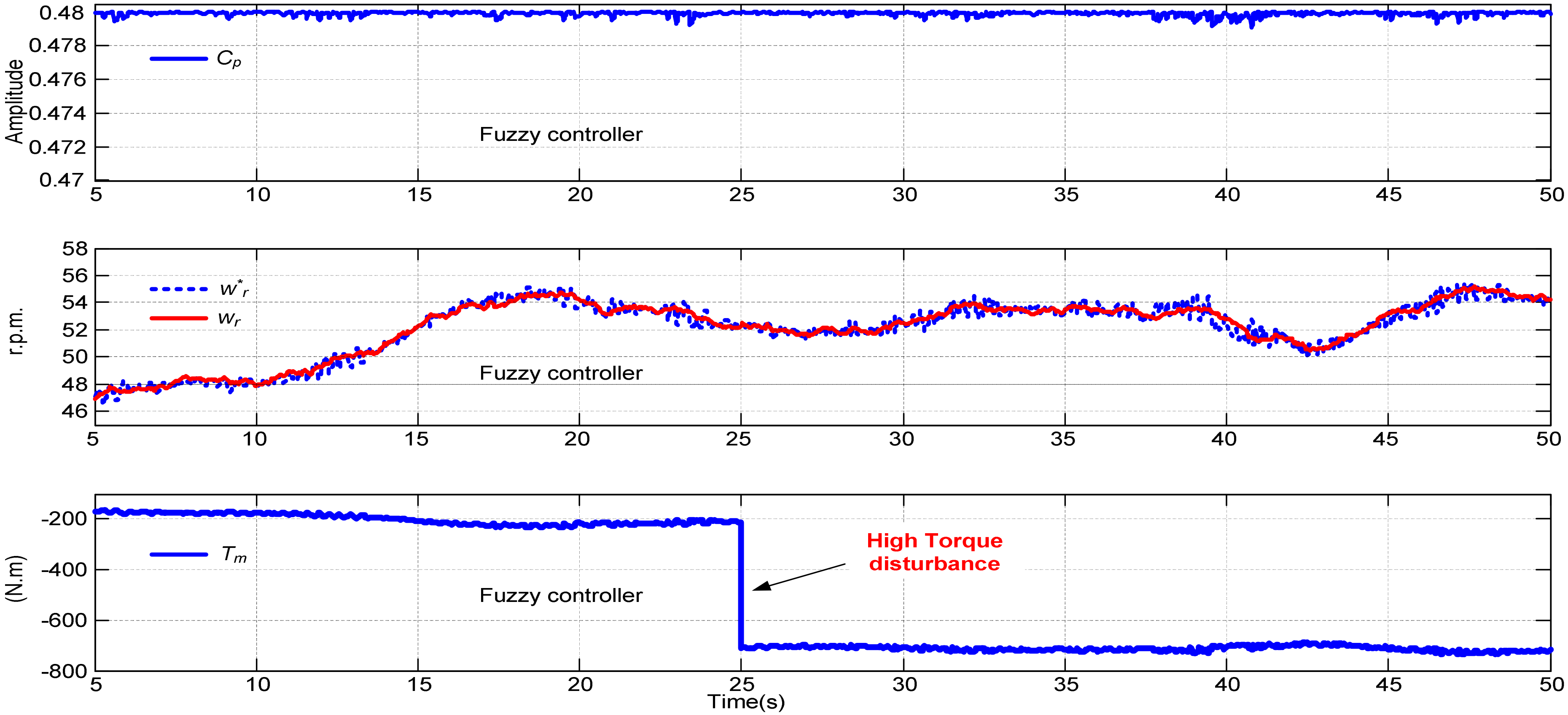
❑ PI controller results

- Variation of Power Coefficient Cp
- Reference and Actual Speed (Speed variation - RISØ Lab Wind Model)
- Torque



Simulations Results

- ❑ Fuzzy controller results
  - Variation of Power Coefficient Cp
  - Reference and Actual Speed (Speed variation - RISØ Lab Wind Model)
  - Torque



Comparison of Simulations Results

- Fuzzy Input-output supervisor control surface was determined to adjust and apply different control actions to obtain good performance under differing disturbances and wind operation. The surface control actuation is: smooth for small speed errors and large for large errors.

- Results show that for small changes in speed demand, similar responses are obtained for both standard PI and Fuzzy types of controllers.

- Results show that for large changes in speed reference, Fuzzy controller obtains a better response (control surface used to tune the fuzzy controller to respond rapidly to large speed errors).

- Results show that during addition of high torque disturbance, PI controller produces a relatively high overshoot in the speed and a decrease of the *Cp* coefficient. The torque disturbance has little effect on the fuzzy controlled system.

V. Conclusion

- A Matlab/Simulink model of the a wind turbine system has been modeled taking into account the WT aerodynamics, PMSM and its FOC control.
- Two different speed controller types, PI and Fuzzy, have been presented.
- The simulation results show that the fuzzy controller achieved better transient responses when operating under large and small disturbances.
- As future work, the controllers presented in this work will be implemented by experimental results.

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Thanks for your attention

First Author: ***Jordi Zaragoza*** *zaragoza@eel.upc.edu*
Presenter: ***Cyril Spiteri Staines*** *cjspit@eng.um.edu.mt*