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Project UpWind

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"Integrated Wind Turbine Design"

WP 5 Control Systems

DELIVERABLE 5.9.2 - DFIG modelling & LVRT

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Abstract: DFIG wind turbines have experienced a massive employment during the last years because of their capabilities to deal with grid faults, well-known generator and power converter technologies and relatively low cost. This fact motivates the implementation of an accurate model of the DFIG to study its behaviour under grid disturbances so that the fulfilment of the different Grid Codes can be analysed and the wind turbine control can be improved to reduced loads. These later studies have been done compiling this DFIG model implemented in Simulink into a dll and linking it with an aeroelastic wind turbine model developed in GH Bladed.

This deliverable includes both electrical and control parts of the DFIG and their modelling, explaining its behaviour under grid fault conditions (FRT) and showing the model validation methodology with a comparison between simulations and field tests.

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STATUS, CONFIDENTIALITY AND ACCESSIBILITY										
Status				Confidentiality				Accessibility	
S0	Approved/Released	●		R0	General public	●		Private web site	
S1	Reviewed			R1	Restricted to project members			Public web site	●
S2	Pending for review			R2	Restricted to European. Commission			Paper copy	
S3	Draft for commends			R3	Restricted to WP members + PL				
S4	Under preparation			R4	Restricted to Task members +WPL+PL				

PL: *Project leader* **WPL:** *Work package leader* **TL:** *Task leader*

1. Introduction

1.1 Objectives

Subtask 5.9.2. is part of the Work Package 5 of the UpWind project “Control Systems”. Originally, a unique subtask 5.9 was defined, dealing with “*Wind farm electrical control strategies required for achieving defined network compatibility criteria, with sample simulation results for voltage dip ride-through, including fast VAR control and optimization of cut-out strategies*”.

Subsequently, the original subtask was deleted and replaced by the two following subtasks:

- 5.9.1 Fast Var control (GEGR)
- 5.9.2 DFIG modelling & LVRT (Alstom Wind)
  - DFIG Doubly-fed Induction Generator
  - LVRT = Low-voltage ride thru

1.2 Participants

ALSTOM Wind is the leading and only participant to the subtask.
Main ALSTOM Wind Tasks are hereby listed:

- Develop Bladed model coupled with an external DLL of the electrical components
- Simulate voltage drops with this model and compare with experimental results

1.3 Outline

DFIG wind turbines have experienced a massive employment during the last years because of their capabilities to deal with grid faults, well-known generator and power converter technologies and relatively low cost. This fact motivates the implementation of an accurate model of the DFIG to study its behaviour under grid disturbances so that the fulfilment of the different Grid Codes can be analysed and the wind turbine control can be improved to reduced loads. These later studies have been done compiling this DFIG model implemented in Simulink© into a dll and linking it with an aeroelastic wind turbine model developed in GH Bladed© (Figure 1).

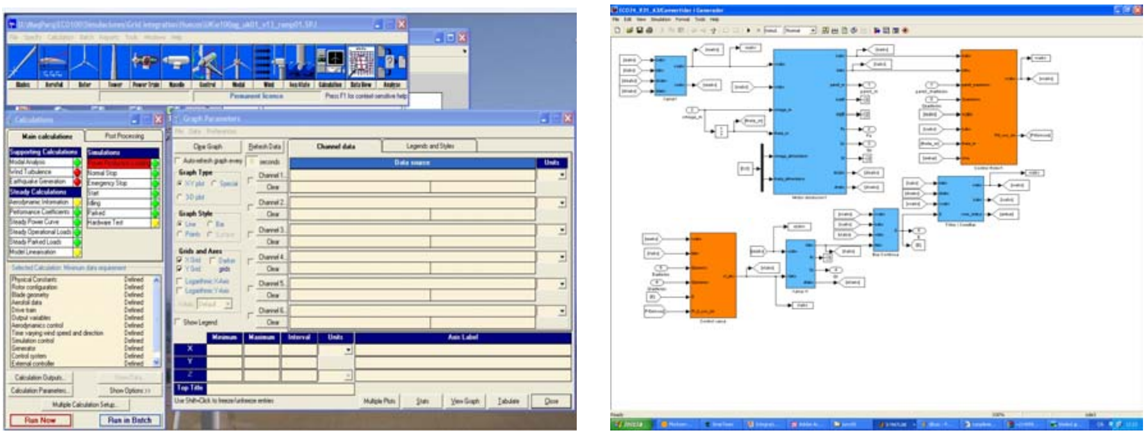


Figure 1: *GH Bladed and Simulink model interfaces*

The present work describes both electrical and control parts of the DFIG and their modelling, explaining its behaviour under grid fault conditions (FRT) and showing the model validation methodology with a comparison between simulations and field tests.

2. DFIG model: electrical and control description

The electrical system of the wind turbine consists of a generator, which is a Doubly Fed Induction Generator (DFIG), whose rotor is supplied by a bidirectional converter (Machine Side Converter (MSC) and Line Side Converter (LSC)) based on IGBT technology having three phase legs of IGBTs connected to the generator rotor windings, a DC bus and a second set of three phase legs connected to the grid by means of a power transformer. This can be seen in Figure 2.

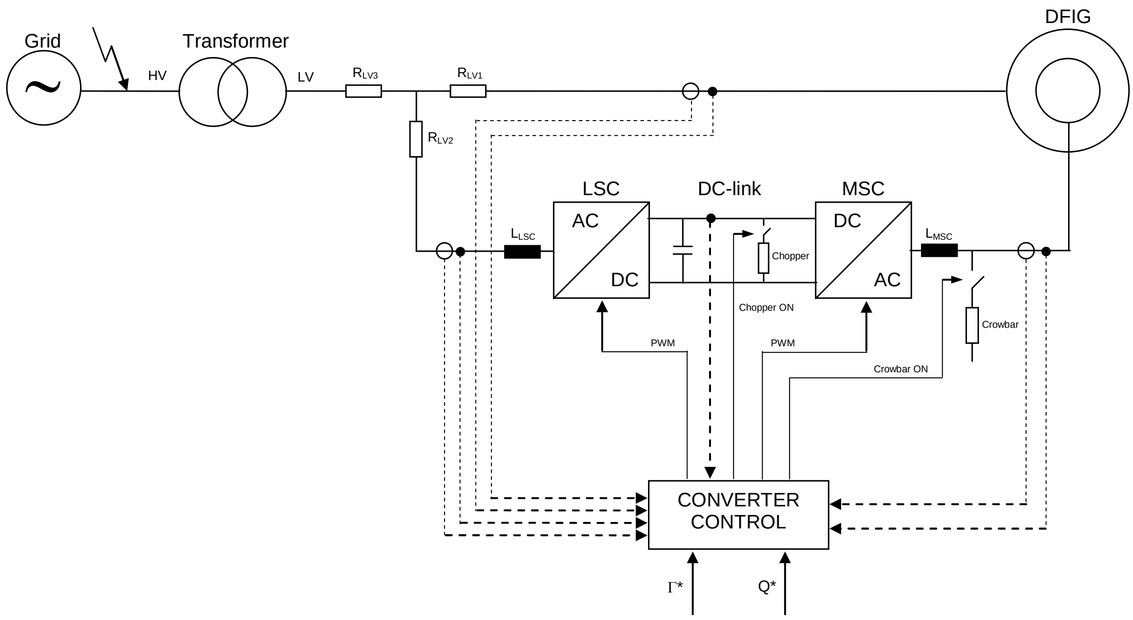


Figure 2: *Single line diagram of the wind turbine: electrical and control systems modelled.*

This system has been modelled in Simulink without considering the effects of high switching frequency components, like power converters. This means that these components are replaced with their low-frequency average counterparts, without having the computational burden of high-frequency details.

A detailed converter control diagram implemented in the model can be seen in Figure 3. The converter control receives torque (active power is also possible) and reactive power references (PF is also possible) to apply from the wind turbine control in base on an internal speed control loop (torque reference) and the current grid requirements (reactive power). These references are converted into d-q desired currents on the MSC and LSC, and by means of an internal current loop results in both d-q MSC and LSC voltages to apply by the converters.

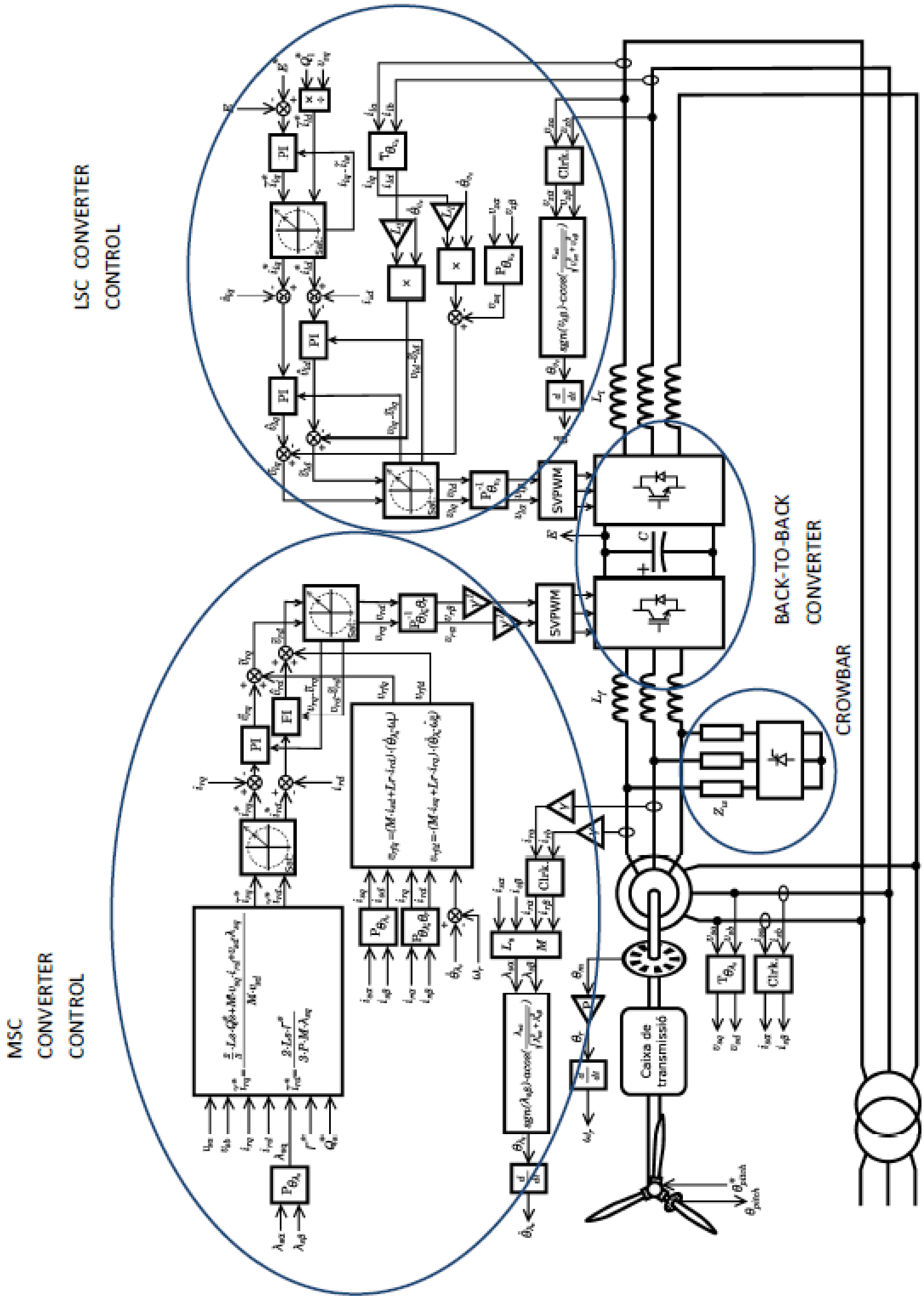


Figure 3: *Detailed converter control diagram implemented*

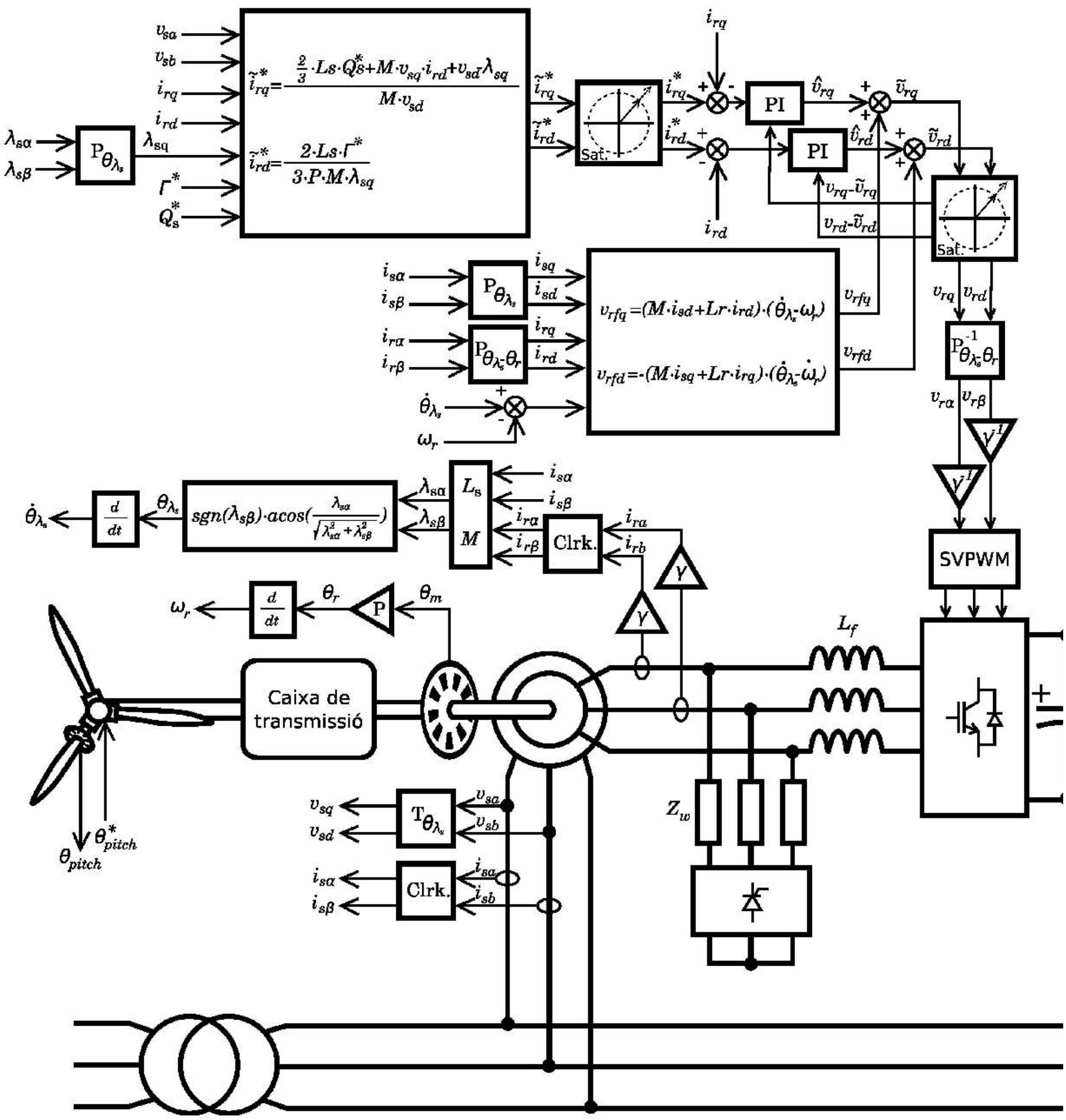


Figure 4-a: *Close-up of the MSC Converter Control, the Wind Turbine generator and the Crowbar*

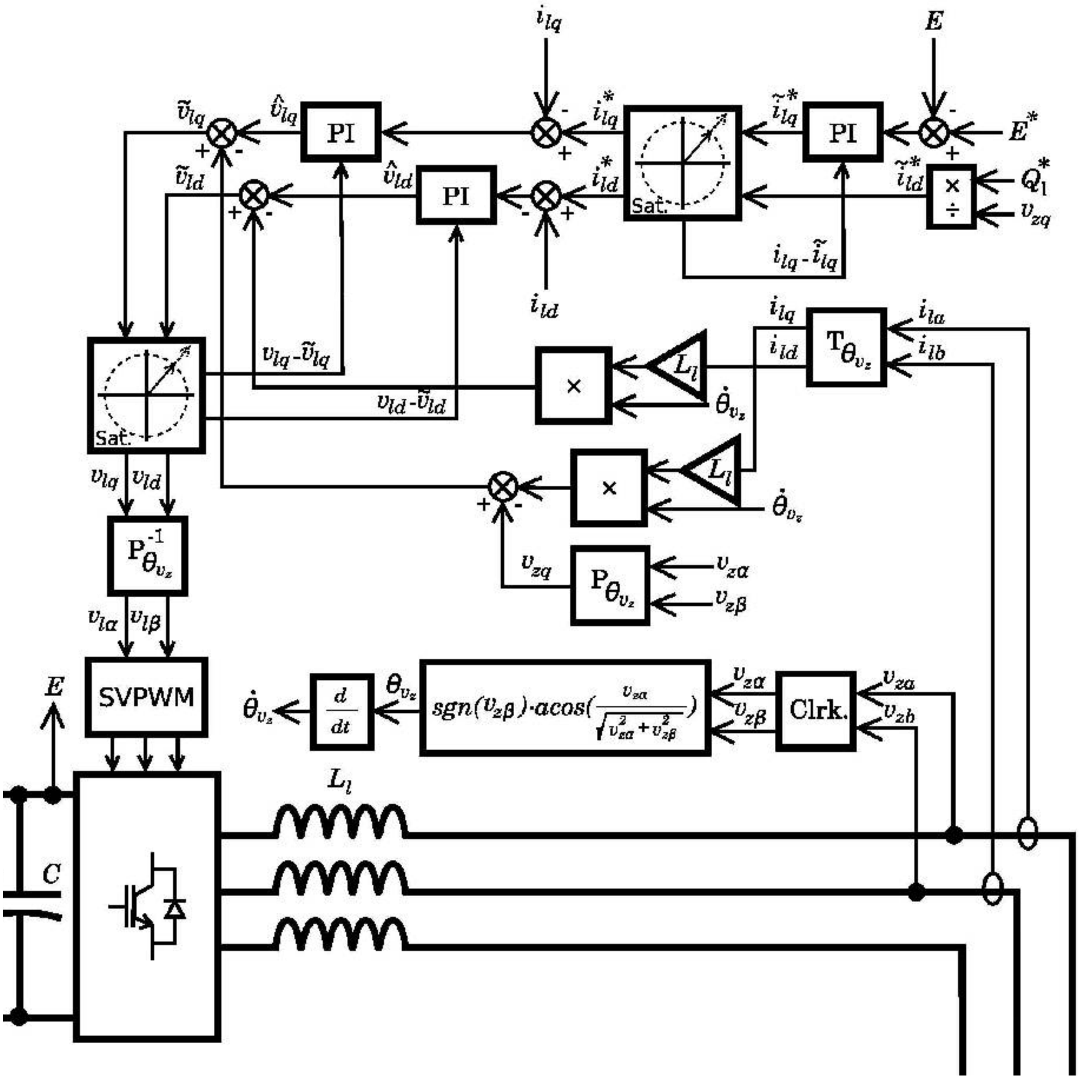


Figure 5-b: *Close-up of the LSC Converter Control*

3. Fault Ride through operation mode

3.1 Basic description

In order to withstand line faults the electrical system is equipped as shown in Figure 2. Two key elements protect the machine against overvoltages/overcurrents and permit to remain connected to the grid when a fault is provoked: a Chopper and a Crowbar.

The Chopper consists of an active switching means (IGBTs) and series-connected resistor. This element balances power fluctuations in the intermediate link of the converter caused by grid faults. Measuring the DC-voltage the Chopper is switched on when a critical DC-link voltage threshold is exceeded. Beneath a lower uncritical DC-link voltage threshold, the measuring device switches the Chopper off. The excessive power is dissipated in the Chopper resistor.

As back-up protection means for the converter in case of Chopper failure, a Crowbar is installed parallel to the MSC. It consists of three thyristors (SCR) and a three-phase series-connected damping-resistor. If the DC-link voltage exceeds a defined threshold above the Chopper threshold, a malfunction of the Chopper is detected and the Crowbar is switched on. In this case the system separates from the grid.

Once a fault is detected by the converter, an especial strategy is applied to fulfil the Grid Code of the country where the machine is installed. That means to provide active current (active power) if it is necessary and to deliver/consume reactive current (reactive power) during the fault according to the specifications. To comply with active current requirements, the wind turbine control is in charge of demanding to the converter a proper torque/power reference. On the other hand, reactive current commands are directly managed by the converter control, having parameterised a proper *voltage-reactive current* characteristic to set these reactive current commands depending on the voltage level.

3.2 Comparison between simulations and tests

A voltage dip test campaign (SAT) was carried out in the ECO100 prototype wind turbine during the second term of 2009. This has provided useful information and measurements to validate and adjust the model of this machine, taking into account the methodology followed in Figure 4.

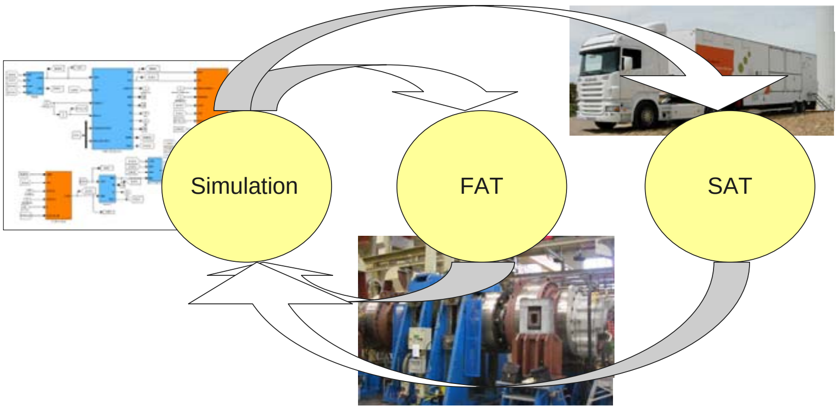


Figure 6: *Simulation and tests methodologies for the validation of models (FAT: Factory Acceptance Test, SAT: Site Acceptance Test)*

Figure 5 to Figure 7 show the comparison between simulation and test of the above mentioned wind turbine in case of a 3 phase 50% 710 ms voltage dip (included in the UK Grid Code), proving a very good agreement between them.

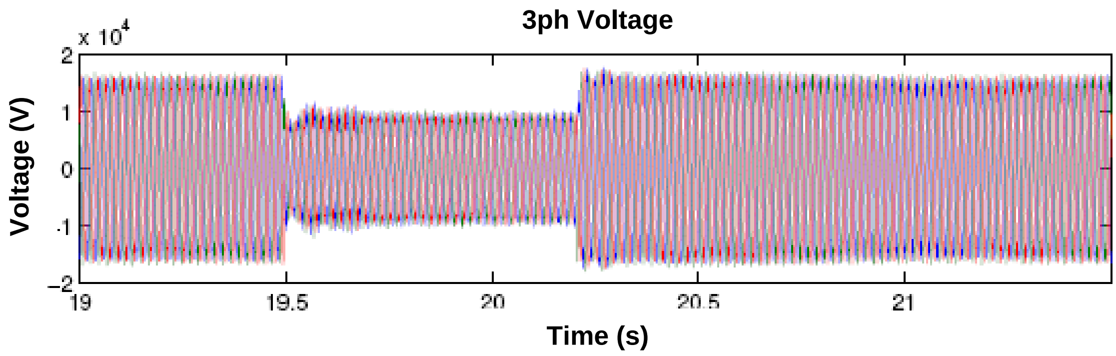
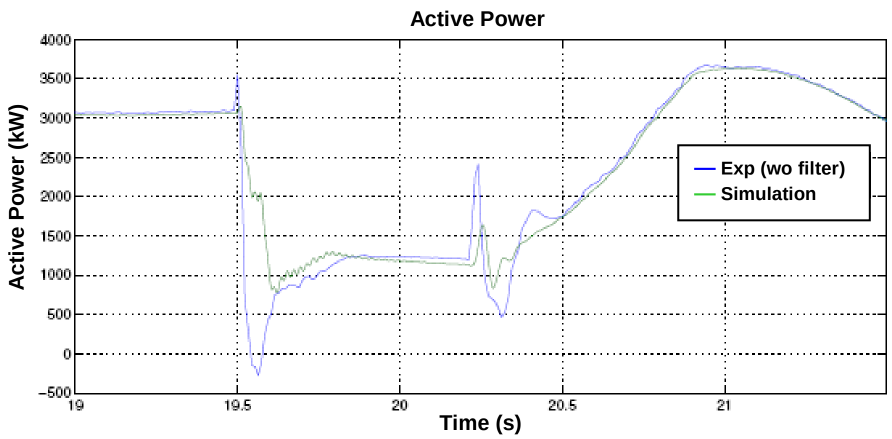
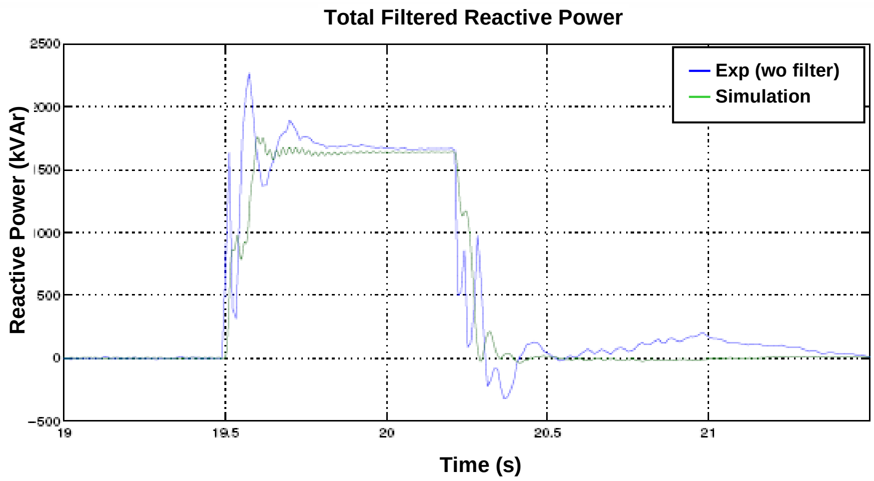


Figure 7: *A 3ph 50% 710 ms voltage dip on HV point shown in Figure 2. (both simulation and test)*



(a)



(b)

Figure 8: *(a) Active power (blue line: test, green line: simulation), (b) Reactive power (blue line: test, green line: simulation)*

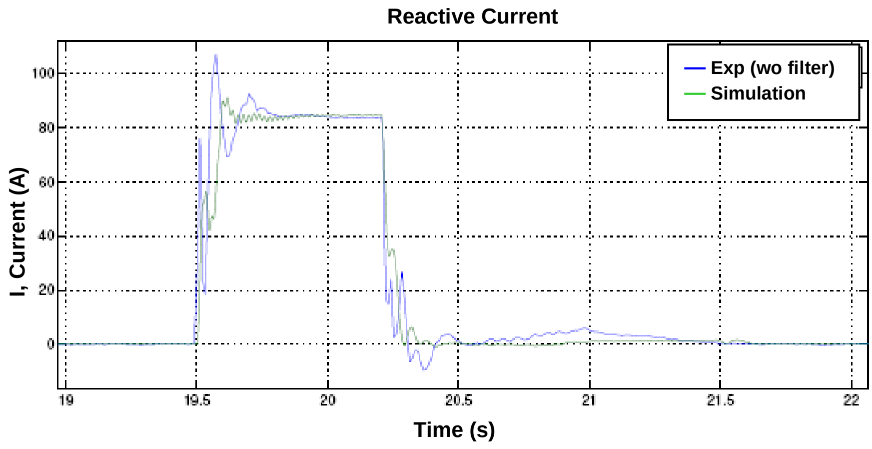


Figure 9: *Reactive current (blue line: test, green line: simulation)*

4. Conclusions

This work has demonstrated how the coupled dynamics of the turbine structure, control system and electrical system can be modelled accurately and in sufficient detail to allow grid code requirements to be fully taken into account during the design of the whole system.

References

[1] "Voltage dip testing campaign in the ECO100" Montserrat Mata Dumenjó, Orio Caubet Busquets, Marc Sala Lluma, Techwindgrid'09, 20 Apr 2009 Madrid.

[2] "Study of doubly-fed WTG behaviour for grid perturbations using integrated model", Montserrat Mata Dumenjó, Javier Sanchez Navarro, Michelle Rossetti, Marc Sala Lluma, Oriol Gomis Bellmunt, Adrià Junyent, EPE Wind 2009, 24 Apr 2009 Oslo.

[3] "Integrated simulation of a Doubly Fed Generator Wind Turbine", EPE 2009, 8 Sep 2009 Barcelona.

[4] "Integrated Simulator Used for Certification of Ecotencia 100: the New Wind Turbine of Alstom Wind", Montserrat Mata Dumenjó, Javier Sanchez Navarro, Oriol Caubet Busquets, Marc Sala Lluma, China Wind Power 2009, Oct 2009, Beijing.

Appendix

Certification Normatives for LVRT

Spain (REE)

- P.O. 12.3 Requisitos de respuesta frente a huecos de tensión de las instalaciones eólicas
- P.O. 12.2 (Draft Nov2010) Instalaciones conectadas a la red de transporte y equipo generador: Requisitos mínimos de diseño, equipamiento, funcionamiento, puesta en servicio y seguridad.
- REE-Procedimientos de verificación, validación y certificación de los requisitos del PO 12,3 sobre la respuesta de las instalaciones eólicas ante huecos de tensión (versión 6-10/07/2009)

Germany (E.ON)

- E.ON-Grid Code.High and extra high voltage. (1/04/2009)

- FGW-Technische Richtlinien für Erzeugungseinheiten.Bestimmung der Elektrischen Eigenschaften von Erzeugungseinheiten am Mittel-, Hoch- und Höchstspannungsnetz.(Rev 19. 14/01/2009)

UK (National Grid)

- Guidance Notes for Power Park Developers, Issue 2 (09/2008)
- The Grid Code.Issue 4 Rev 3 (06/09/2010)

Canada –QUEBEC (Hydro Québec)

- General Validation Test Program for Wind Power Plants Connected to the Hydro-Québec Transmission System. (05/2009)

USA (FERC –NERC)

- 18 CFRT Part 35 Docket No. RM05-4-001, Order No. 661-A (12/12/2005)

International

- IEC-61400-21 Ed 2.0 2008