<u>***MORE master basic syllabus***</u>

<u>Title:</u>
Modelling of wind/marine current turbine-driven electric generators

<u>Credit value:</u>
3 ECTS

<u>Mandatory/Optional:</u>
Optional

<u>Semester:</u>
2

<u>Lecturer/s:</u>
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<u>University:</u>
University of the Basque Country UPV/EHU

<u>Department:</u>
Automatic Control and Systems Engineering

<u>Rationale:</u>
Dynamical models for both the doubly-fed induction generator (DFIG) and the permanent-magnet synchronous generator (PMSG) are studied in depth. Considering that design and implementation of vector control (VC) schemes for DFIG and PMSG power control are dealt with in other courses, not only simulation models are covered, but also those for VC design. The problem of DFIG grid synchronisation is also analysed as an introductory example to VC design.

<u>Objectives:</u>

- *To provide students with a thorough knowledge of the DFIG and PMSG electrical models based on which VC schemes are designed and implemented.*
- *To provide students with the ability to implement simulation models of the predominant electric machines for offshore renewable power generation.*
- *To provide students with an in-depth understanding of the open-stator model of the DFIG and its grid synchronisation process.*
- *To introduce students to design, tuning and digital implementation of VC schemes via the problem of DFIG grid synchronisation.*

<u>Skills:</u>

Subject skills	**MORE Master Skills**						
	L2.1	**L2.2**	**L2.3**	**L2.4**	**L2.5**	**L2.6**	**L2.7**
L3.1. Students know and assimilate reasoned and rigorously the mathematical models of the dominant electric generators for offshore renewable energy production, based on which vector control schemes can be designed. 35%	X		X				
L3.2. Students are able to build detailed simulation models of the addressed electric generator variants, aimed at assessing the suitability of the vector control schemes designed to command them. 35%	X		X			X	
L3.3. Students know and assimilate reasoned and rigorously the open-stator operation of the doubly-fed induction generator (DFIG), as well as an algorithm for its grid synchronisation. 20%	X		X		X		
L3.4. Students are able to implement and analytically tune a digital algorithm for grid synchronisation of the DFIG. 10%	X	X					

Teaching and learning methods:

The subject is 3 ECTS credits, corresponding to 75 hours of student work. An approach to the distribution of student effort may be as follows:

- *Lectures, where the lecturer explains the main concepts of the subject to the whole group, projecting presentations which are complemented with additional considerations, figures and mathematical derivations on the blackboard, as well as with computer simulations: 16 hours*
- *Computer practices of 2 hours per session, where, if possible, each student works individually in a computer, implementing and testing the electric generator models and grid synchronisation algorithms under study: 12 hours*
- *A laboratory practice, where the lecturer implements and tests, by means of rapid control prototyping, on a 7-kW DFIG bench, the grid synchronisation algorithm previously validated in simulation during computer practices: 2 hours*
- *Personal student work (45 hours), comprising*
  - *Self-study, for assimilation of the content taught during lectures: 24 hours*
  - *A computer practice assignment consisting in the implementation of the simulation model for an electric generator variant not covered during lectures and computer practices: 21 hours*

Allocation of student time:

	Attendance (classroom, lab…)	**Non attendance (lecture preparation, self study…)**
Lectures and self-study	16 hours	24 hours
Computer practices	12 hours	21 hours
Laboratory practice	2 hours	0 hours

Assessment:

Achievement of subject skills L3.1, L3.3 and L3.4 will be assessed by means of a written examination, to which a 65% of the final mark will be assigned. The remaining 35% of the final mark will correspond to a computer practice assignment and its associated oral examination, which will allow assessing achievement of subject skill L3.2. The oral examination will consist in personal interviews with students on the simulation model built during the computer practice assignment.

Assessment Matrix:

Subject skills	**Assessment method**		
	Written examination	**Practical assignment**	**Oral examination**
L3.1	100%		
L3.2		70 %	30%
L3.3	100%		
L3.4	100%		

Programme:

Lesson 1	*Modelling of the Doubly-Fed Induction Generator (DFIG)* *Mechanical and three-phase electrical models. "Quadrature-Phase Slip-Ring" (QPSR) model. Arrangement of the global electromechanical model in state equations for simulation.* *Distribution: 4 h theory + 4 h computer*
Lesson 2	*DFIG Model for Vector Control* *Expression of the DFIG QPSR model in a single generic reference frame. Particularisation to the stator flux/voltage-oriented reference frame for vector control (VC).* *Distribution: 4 h theory*
Lesson 3	*Modelling of the Permanent-Magnet Synchronous Generator (PMSG)* *Rotor flux-oriented model of the PMSG: Analogy with the stator flux/voltage-oriented DFIG model. Arrangement of the global electromechanical model in state equations for simulation.* *Distribution: 4 h theory + 4 h computer*
Lesson 4	*Synchronisation and Grid Connection of the DFIG* *Grid voltage-oriented model of the open-stator DFIG. Rotor current set-points leading to grid synchronisation. VC of the DFIG rotor-side converter (RSC) for grid synchronisation.* *Distribution: 4 h theory + 4 h computer + 2 h laboratory*

Resources:

- *A classroom, equipped with a blackboard and audio-visual resources (laptop/computer with Matlab/Simulink installed and Internet connection + projector), for the lectures. A blackboard and a projector may be sufficient if the lecturer uses her/his own laptop.*
- *A computer room with Matlab/Simulink installed, equipped with a blackboard and a projector, for the computer practices. It is assumed that the lecturer uses her/his own laptop or one of the computers in the room.*
- *A laboratory, equipped with a 7-kW DFIG test-bench connected to a rapid control prototyping platform compatible with Matlab/Simulink, for the laboratory practice. This equipment is currently available in the Laboratory of Models of the Faculty of Engineering – Gipuzkoa (University of the Basque Country UPV/EHU).*
- *Library resources provided by the University of the Basque Country UPV/EHU, including inter-centre book loan and Internet-based access and retrieval of journal articles.*

Bibliography:

Basic textbooks

- P. Vas, *Sensorless Vector and Direct Torque Control*. New York: Oxford Univ. Press, 1998.
- A. Tapia, G. Tapia, J. X. Ostolaza, and J.R. Sáenz, "Modeling and control of a wind turbine driven doubly fed induction generator," *IEEE Trans. Energy Convers.*, vol. 12, no. 2, pp. 194–204, Jun. 2003.
- S. Li, T. A. Haskew, and L. Xu, "Conventional and novel control designs for direct driven PMSG wind turbines," *Electric Power Syst. Res.*, vol. 80, no. 3, pp. 328–338, Mar. 2010.
- G. Tapia, G. Santamaría, M. Telleria, and A. Susperregui, "Methodology for smooth connection of doubly fed induction generators to the grid," *IEEE Trans. Energy Convers.*, vol. 24, no. 4, pp. 959–971, Dec. 2009.

Deepening bibliography

- R. Peña, J. C. Clare, and G. M. Asher, "Doubly fed induction generator using back-to-back PWM converters and its application to variable-speed wind-energy generation," *IEE Proc.-Electr. Power Appl.*, vol. 143, no. 3, pp. 231–241, May 1996.

- G. Abad, J. López, M. A. Rodríguez, L. Marroyo, and G. Iwanski, *Doubly Fed Induction Machine: Modeling and Control for Wind Energy Generation*. Hoboken, NJ: IEEE Press, 2011.
- M. Chinchilla, S. Arnaltes, and J. Burgos, "Control of permanent-magnet generators applied to variable-speed wind-energy systems connected to the grid," *IEEE Trans. Energy Convers.*, vol. 21, no. 1, pp. 130–135, Mar. 2006.
- H.-W. Kim, S.-S. Kim, and H.-S. Ko, "Modeling and control of PMSG-based variable-speed wind turbine," *Electr. Power Syst. Res.*, vol. 80, no. 1, pp. 46–52, Jan. 2010.
- A. D. Hansen and G. Michalke, "Modelling and control of variable-speed multi-pole permanent magnet synchronous generator wind turbine," *Wind Energy*, vol. 11, no. 5, pp. 537–554, 2008.

Internet addresses of interest

https://egela1516.ehu.eus. Support material in *eGela* platform
http://en.wikipedia.org/wiki/Doubly_fed_electric_machine
http://www.intechopen.com. Open-access scientific publications

Specific journals

IEEE Transactions on Energy Conversion
IEEE Transactions on Industrial Electronics
IET Renewable Power Generation
IET Electric Power Applications
IEEE Transactions on Power Electronics
IEEE Transactions on Power Systems
Electric Power Systems Research
Energy Conversion and Management
Wind Energy

Further comments: