Electric Energy Systems University Enterprise Training Partnership
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EES-UETP Course on Low Inertia Power Systems
Madrid, 25-26 April 2019

Organized by

Universidad Pontificia Comillas

Organizing committee

Prof. Luis Rouco
Dr. Lukas Sigrist
Dr. Javier Renedo

Description on the course

Power systems worldwide are experiencing huge transformations as the transition to carbon neutral economies progresses. Much thermal generation will be substituted by renewable energy resources (wind, solar). The power system will change from a synchronous generation based system to a system with mostly generation connected through inverters. Among the system aspects affected by this transformation is the loss of inertia of the rotating masses of thermal generators and even the loss of the notion of system frequency. This course will address problems arising in low inertia systems and even with zero rotating inertia. Island systems will be addressed as they represent real life laboratories of low inertia systems.

Program

Day 1	
9-9:30	Registration
9:30-11:00	Introduction and course overview: Prof. Luis Rouco, Universidad Pontificia Comillas
11:00-11:30	Coffee break
11:30: 13:00	Frequency Makers vs Frequency Takers: A theoretical framework for low inertia systems, Prof. Federico Milano, University College Dublin
13:00-14:30	Lunch
14:30-16:00	Towards a 100% power electronic system: a control perspective, Dr. Dominic Gross, ETH Zurich
16:00-16:30	Coffee break
16:30:18:00	Control of power converters in low inertia systems: A practical approach (Computer simulation laboratory), Dr. Agustí Egea, University of Strathclyde, Dr. Javier Renedo, Universidad Pontificia Comillas
21:00-23:00	Course dinner
Day 2	

8:30-10:00	Towards a 100 % power electronic system: a TSO oriented perspective, Dr. Guillaume Denis, RTE France
10:00-10:30	Coffee break
10:30: 12:00	Island systems, Dr. Lukas Sigrist, Universidad Pontificia Comillas
12:00-12:15	Break
12:15-13:45	Practical experiences on the application of energy storage systems in island systems, Mr. Alberto Barrado, Endesa
13:45-15:15	Lunch
15:15-16:45	Black start of wind generators, Prof. José Luis Rodríguez-Amenedo, Universidad Carlos III

Venue

School of Engineering, Universidad Pontificia Comillas
Alberto Aguilera, nº 25, 28015 Madrid, Spain

Registration fees

The course fees include lectures attendance, documentation, coffee breaks, lunches, and course dinner
Members of the EES-UETP: 245 EUR
University non-members of the EES-UETP: 600 EUR
Industry non-members of the EES-UETP: 1000 EUR

Registration

http://eventos.comillas.edu/32850/detail/ees-uetp-course-on-low-inertia-power-systems.html

Lectures and speakers

Introduction and course overview, Prof. Luis Rouco

This lecture will start introducing the fundamentals of frequency stability and control. European network codes on requirements for grid connection of generators and systems operation will be reviewed. In addition, results of a study on frequency stability of the impact of energy transition will be presented. The lecture conclude presenting the course overview.

Luis Rouco obtained MSc and PhD degrees from the Polytechnic University of Madrid in 1985 and 1990 respectively. He is Professor of Electrical Engineering in the School of Engineering of Universidad Pontificia Comillas. He has served as Head of the Department of Electrical Engineering from 1999 through 2005. Professor Rouco develops his research activities at Instituto de Investigación Tecnológica (IIT). His areas of expertise are modelling, analysis, simulation and control of the steady-state, dynamic and transient behaviour of electric power systems He has led a number of research projects for Spanish public administrations, Spanish electric utilities and other Spanish engineering and industrial companies. He has also developed research projects for foreign companies and institutions. Professor Rouco is associate editor of the IEEE Transactions on Power Systems. Professor Rouco is Senior member of IEEE and Distinguished Member of Cigré, past-President of the Spanish Chapter of IEEE Power Engineering Society del IEEE and Member of the Executive Committee of the Spanish National Committee of CIGRE. He has been visiting scientist at Ontario Hydro (Toronto, Canada), MIT (Cambridge, Massachusetts, USA) y ABB Power Systems (Vasteras, Sweden).

Frequency makers vs. frequency takers: A theoretical framework for low inertia systems, Prof. Federico Milano

The conventional power system model for transient stability analysis is based on the assumption of quasi-steady-state phasors for voltages and currents. The crucial hypothesis on which such a model is defined is that the frequency required to define all phasors and system parameters is constant and equal to its nominal value. This model is appropriate as long as only synchronous machines regulate the system frequency through standard primary and secondary frequency regulators. In recent years, however, an increasing number of devices other than synchronous machines are expected to provide frequency regulation. These include, among others, distributed energy resources such as wind and solar. However, these devices do not generally impose the frequency at their connection point with the grid. There is thus, from a modeling point of view, the need to define with accuracy the local frequency at every bus of the network.

The presentation is divided into three parts. The first part presents an accurate yet simple and computationally inexpensive formula, namely, the frequency divider, to estimate such frequencies and, thus, improve the fidelity of the conventional power system model for transient stability analysis. The second part focuses on a relevant application of the frequency divider, namely, the estimation of the rotor speeds of synchronous machines by means of phasor measurement units. This estimation is aimed at on-line monitoring of electro-mechanical transients and transient stability analysis. The dynamic state estimation is formally stated as a convex optimization problem and a thorough discussion of the sensitivity analysis of the optimal solution is provided. The third part extends the estimation problem to non-synchronous devices and provides a novel interpretation of the rate of change of power injected at a bus. A practical definition of “frequency maker” and “frequency taker” devices is proposed. The results of several case studies serve to illustrate the behaviour of the frequency divider formula as well as the robustness against noise and bad data of the estimation of machine rotor speeds and the identification of frequency maker/taker devices.

Federico Milano received from the Univ. of Genoa, Italy, the ME and PhD in Electrical Eng. in 1999 and 2003, respectively. From 2001 to 2002 he was with the University of Waterloo, Canada, as a Visiting Scholar. From 2003 to 2013, he was with the University of Castilla-La Mancha, Spain. In 2013, he joined the University College Dublin, Ireland, where he is currently Professor of Power Systems Control and Protections and Head of Electrical Engineering. He was elevated to IEEE Fellow in 2016 for his contributions to power system modeling and simulation, and to IET Fellow in 2017. He has been an editor of several international journals published by IEEE, IET, Elsevier and Springer, including the IEEE Transactions of Power Systems and the IET Generation, Transmission & Distribution.

Towards a 100% power electronic system: a control perspective, Dr. Dominic Gross

An inevitable consequence of the transition of power systems towards nearly 100% renewable-based generation is the loss of conventional bulk generation by synchronous machines, their inertia, and accompanying frequency and voltage control mechanisms. This gradual transformation of the power system to a low-inertia system leads to critical challenges in maintaining system stability. Novel control techniques for power converters, so-called grid-forming strategies, are expected to address these challenges and replicate functionalities that so far have been provided by synchronous machines.

In this presentation, we will first review several grid-forming control strategies and discuss their basic operating principles and theoretical foundation. Even though the main operating principles appear to differ, we highlight that, under suitable assumptions, most of the control strategies are expected to exhibit the same behavior. Next, we restrict our focus to virtual oscillator control and discuss analytic stability certificates that provide sharp bounds on the achievable performance and explicitly includes the dynamics and transfer capacity of the transmission network.
The second part of the talk discusses ancillary services, such as virtual inertia and fast frequency response, that are provided by grid-forming power converters and highlight crucial differences in how the different controls handle limitations of power source feeding the converter and of energy storage devices. Finally, we present an optimization algorithm that can be used to answer the question of where to place grid-forming converters in a large-scale system and how to optimally tune their controls.

Dominic Gross a Postdoctoral Researcher at the Automatic Control Laboratory at the Swiss Federal Institute of Technology (ETH) Zürich, Switzerland. He received his Dr.-Ing. degree in Electrical Engineering from the University of Kassel in 2014, and a Dipl.-Ing. degree in Mechatronics from the University of Kassel in 2010. From 2014 to 2015 he was with Volkswagen Group's Research Division in Wolfsburg, Germany. His research interests are centered around distributed control and optimization in complex networked systems with a focus on control, stability analysis, and resilience of low-inertia and converter-based power systems.

Towards a 100 % power electronic system: a TSO oriented perspective, Dr. Guillaume Denis

The share of inverter-interfaced generation from renewable sources is now greater than 100% of the electrical demand in some countries. To allow stable operation of electrical systems with a high share of converter interfaced generation, some of present or future inverters will need to upgrade their classical grid following controls into grid forming controls. Amongst others, the grid forming function characterizes the ability of an electrical source to contribute to frequency and voltage stability by making their variation throughout the system smoother. Several control designs claim to provide a grid forming function to systems but their effective contribution to stability are usually not highlighted from the system operator perspective.

The presentation will cover two main aspects of the TSOs challenge with high penetration of power electronics. A first part will detail the grid-forming function performances as expected from the point of common coupling of electrical sources. Without internal control knowledge, the definition of both test-cases and checking sheets should allow TSOs to ensure proper behavior and operation of the interconnected system. Example of interoperability of such well-designed grid-forming controls will be illustrated, as well as their compatibility with traditional synchronous generators. The first part will end with a proposal of a frequency-based methodology to discriminate experimentally the grid-forming behavior from the grid-following behavior, with a black-box approach. The second part will focus on the stability analysis of large power-electronics based system. The preliminary question of the models will be addressed. The limits of RMS models must be understood to explore new possible reduced models. Then, the changes in stability analysis will be investigated. In small-signal analysis, the fast power-electronics based devices shift the traditional dynamics of power system. New instabilities arise and must be predicted. During transient events, the current-limiting strategy of converter based grid-forming sources leads to new type of instability issues that must be defined. In the end, the stability issues will be illustrated on the example of the Irish system with 100 % of power-electronics interfaced sources.

Guillaume Denis holds an engineering degree from MINES ParisTech, France, and received a PhD in Electrical Eng. in 2017. Since, he has joined the R&D department of RTE, the French TSO, to study system dynamics analysis. His doctoral research activities on 100 % power electronic based system continue within two European Project: MIGRATE and OSMOSE.

Control of power converters in low inertia systems: A practical approach, Drs. Agustí Egea and Javier Renedo

Power converter penetration in the power system has increased substantially in the last 20 years bringing new challenges from the grid operation, control and stability perspectives. Low inertia systems are seen as one of the most likely scenarios that the future power system will operate. Under these conditions, power converter will play an important role in keeping the grid operation stable and reliable. Multiple power converter control strategies have been suggested for low inertia systems but the major part of them are under research and electrical equipment manufacturers and power system operators have little runtime experience.

This lab session will comment on the challenges that power converters are facing when connected to a low inertia system, comment on the converter control research trends and show the implementation and impact of some of the proposed control topologies in a lab-based session. The attendees will be guided through a MATLAB/Simulink model where at the same time that they explore the proposed control topologies and evaluate their performance, theoretical background will be given. The simulation models will be based on open source models and they might be reused in the future for the attendees.

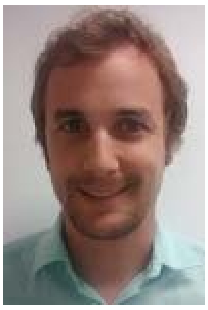
Agustí Egea-Àlvarez is Strathclyde Chancellor's fellow (Lecturer) at the electronic & electrical engineering department and member of the PEDEC (Power Electronics, Drives and Energy Conversion) group. He obtained his BSc, MSc and PhD from the Technical University of Catalonia in Barcelona in 2008, 2010 and 2014 respectively. In 2015 he was a Marie Curie fellow in the China Electric Power Research Institute (CEPRI). In 2016 he joined Siemens Gamesa as converter control engineer working on grid forming controllers and alternative HVDC schemes for offshore wind farms. He is a member of IEEE, IET and has been involved in several CIGRE working groups.

Javier Renedo obtained his MSc and PhD degrees from Universidad Pontificia Comillas de Madrid in 2010 and 2019. At present, he is a researcher at the Instituto de Investigación Tecnológica (IIT) of Universidad Pontificia Comillas de Madrid. Before joining IIT, he was engineer at the department of generation and power grids of BOSLAN Ingeniería y Consultoría (September 2011 - September 2012). His main areas of interest are power system stability, VSC-HVDC multi-terminal systems, and applications of power electronics to electrical energy systems. He is a member of IEEE and Cigré.

Island power systems, Dr. Lukas Sigrist

Islands are facing considerable challenges in meeting their energy needs in a sustainable, affordable and reliable way. This is mainly due to the isolated nature and small size of island power systems and the cost of the fuel for power generation. According to local resource availability, renewable energy sources (RES) offer an interesting solution to decrease the dependency on fossil fuels and increase island sustainability. Other actions such as including energy storage devices can further increment RES penetration.

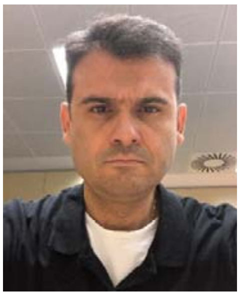
Intermittent behavior of RES affects both the stability of isolated island power systems as well as their economic operation. Actually, reserve requirements serve as the nexus between operation and stability. Reserve requirements currently contemplate the size of the disturbance but they do not take into account the dynamics of the power system. This presentation will first provide a techno-economic analysis of island power system under high RES penetration. Impact on reserves and frequency stability will be shown. Second, the presentation will present a methodology to estimate the maximum penetration of RES in island power systems taking into account lessons learnt from the previous analysis. Finally, the fundamental design of energy storage devices will be addressed.



Lukas Sigrist received his MSc degree in Electrical and Electronics Engineering from École Polytechnique Fédérale de Lausanne (EPFL) in 2007 and his PhD degree from Universidad Pontificia Comillas in 2010. At present he is a researcher at the Instituto de Investigación Tecnológica (IIT) of Universidad Pontificia Comillas de Madrid. He is also deputy director for institutional affairs. His areas of interest are modeling, analysis and control of electric power systems. Dr. Sigrist is member of the IEEE and Treasurer of the Spanish Chapter of the Power and Energy Society of IEEE.

Practical experiences on the application of energy storage systems in island systems, Mr. Alberto Barrado

This presentation will show practical experiences on the application of energy storage systems carried out by Endesa in the Spanish Canary islands. Three systems will be described: an ultracapacitor, a flywheel and a battery installed respectively in La Palma, La Gomera and El Hierro. The main application of such energy storage systems has been the enhacement of frequency stability and control.



Alberto Barrado received his MSc from Universidad Pontificia Comillas in 1999. He joined Endesa in 2000. He has held several positions in the engineering division of Endesa: (responsible of power lines, protection, system studies). He is now attached to technical services – electrical engineering unit of Global Thermal Generation of Enel. He has been involved in a number of projects on the installation of energy storage systems in the Spanish island systems.

Black start of wind generators, Prof. José Luis Rodríguez-Amenedo

System restoration after a complete blackout is one of the most important tasks for power system planners and operators. Restoration plans and procedures defines the sequence and cranking path needed to restore power to critical loads and generation facilities from black-start resources, which have been based traditionally on conventional synchronous generators. The increasing integration of renewable energy sources (RES) in electrical networks is displacing some of the oldest conventional power plants and therefore its capability to provide the power system restoration service. In case of a black start, variable speed generators in a wind farm, such as Doubly Fed Induction Generators (DFIG) and Full-Converter Permanent Magnet Synchronous Generators (FC-PMSG), should operate synchronously providing controlled voltage and frequency in the point of common coupling with the main grid.

The first part of the presentation will cover: a) Modeling and control of a wind turbine based on DFIG for stand-alone application including direct voltage and frequency control (DVFC), as well as wind turbine power control (WTPC), b) Idem for the case of FC-PMSGs. The second part of the presentation will be focused in the parallel operation of several WTs based on a novel reactive power synchronization (RPS) method. This algorithm shares one of the most promising features of power/frequency droops and Virtual Synchronous Machines (VSM): avoiding the use of a PLL and providing a synchronizing torque. Moreover, with the proposed system, the active power regulation scheme remains unchanged. The proposed control system includes internal current regulation loops that avoid over-currents in the Voltage Source Converter (VSC), solving one of the main drawbacks of VSM control systems. This proposal has been validated by experimental results of a grid-connected VSC. Finally, the third part of the presentation will cover an application of decentralized control of full-converter wind generators operating synchronously in an isolated AC grid of an offshore wind farm connected to a Diode Rectifier based HVDC. This decentralized solution allows providing black-start capability only through the WTs without additional systems, like central batteries or umbilical cables.

José Luis Rodríguez Amenedo received the MSc degree in industrial engineering from Polytechnic University of Madrid in 1994 and the PhD degree from Carlos III University of Madrid in 2000. From 1999 to 2000 he was with IBERDROLA INGENIERIA Y CONTRUCCIÓN as technology wind turbine manager and from 2001 to 2003 with IBERDROLA RENEWABLES as wind energy manager. In 2003 he joined Electrical Department of Carlos III University as Associate Professor. In the 2008-2011 period he requested an academic leave of absence for founding the technological companies ENERGY TO QUALITY and WIND TO POWER SYSTEM. He is the author of one of reference textbooks on wind energy written in Spanish “Sistemas Eólicos de Producción de Energía Eléctrica” (2003). He has supervised 4 PhD theses and is the author of 9 patents (of which 7 are active in the industry). He regularly collaborates on research projects with companies such as REE, IBERDROLA and ABB. The research areas in which he currently works are: a) integration of renewable energies in the power system, b) operation and control of HVDC transmission systems, c) control of power electronic converters and d) storage systems.