UNIVERSIDAD PONTIFICIA ICAI ICADE COMILLAS MADRID

COURSE SYLLABUS
2017-2018

GENERAL INFORMATION

Course information	
Name	HVDC and FACTS
Code	DIE-OPT-611
Degree	Official Master's Degree in Industrial Engineering (MII)
Year	2st
Semester	Fall
ECTS credits	3 ECTS
Type	Optional
Department	Electrical Engineering
Area	Power Systems
Coordinator	Luis Rouco Rodríguez

Instructor	
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Instructor	
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DETAILED INFORMATION

Contextualization of the course

Contribution to the professional profile of the degree

This course is aimed at addressing the application of power electronics to power systems. Two approaches are presented: FACTS and HVDC transmission.

AC power systems are governed by Kirchoff laws. Power flows are hardly controllable. Flexible AC Transmission Systems (FACTS) can be achieved incorporating to the system power electronic devices. FACTS devices are power electronic devices aimed at making AC transmission systems more flexible. In other words, helping to override, at some extend, the limitations of AC power systems. The course will present the principles, and topologies of FACTS devices.

Transmission by high voltage direct current (High Voltage Direct Current transmission or simply HVDC transmission) is needed for high power applications over very long distances or when underground/undersea cables are used instead overhead lines. The course will show the principles of the two existing technologies: line commutated converters and voltage source converters.

The course will pay attention not only to the device perspective but the contribution to the steady-state (power flow) and dynamic performance (stability) of the power system will be detailed.

Prerequisites

A general background of power systems is required.

CONTENTS

Contents

Part I: Introduction to Power Systems

Chapter 1. Introduction

1.1 Power flows in AC systems. Series and shunt compensation
1.2 DC transmission versus AC transmission

Chapter 2. An overview on power semiconductor switches

2.1 Line-commutated devices vs self-commutated devices: Thyristors and IGBTs.
2.2 Limitations of Si-based semiconductors.
2.3 New alternatives

Chapter 3. Line-commutated FACTS (the first generation)

3.1 Thyristor Controlled Reactor (TCR).
3.2 Thyristor Switched Capacitor (TSC).
3.3 Static Var Compensator (SVC).
3.4 Thyristor Controlled Series Capacitor (TCSC).

Chapter 4. Self-commutated FACTS (the second generation)

4.1 Voltage Source Converters: voltage and current control, power-flow control and beyond.
4.2 STATic -synchronous- COMpensator (STATCOM).
4.3 STATCOM vs SVC.
4.4 Static Series Synchronous Compensator (SSSC).
4.5 Series + shunt compensator: the Unified Power Flow Controller (UPFC).

Chapter 5. Power flows with FACTS devices

5.1 Shunt device control in the power flow solution.
5.2 Series device control in the power flow solution.
5.3 Hybrid device control in the power flow solution.

Chapter 6. Stability enhancement with FACTS devices

6.1 Large-disturbance stability of a synchronous machine connected to an infinite bus.
6.2 Large-disturbance stability enhancement of a synchronous machine connected to an infinite bus by shunt and series compensation.
6.3 Small -disturbance stability of a synchronous machine connected to an infinite bus.
6.4 Small-disturbance stability enhancement of a synchronous machine connected to an infinite bus by shunt and series compensation.

Chapter 7. High Voltage DC (HVDC) transmission based on line-commutated converters

7.1 Fundamentals: description of a basic system.
7.2 Power-flow control in DC.
7.3 Reactive-power requirements.
7.4 Current harmonics.
7.5 Typical topologies: from two-level converters to multi-level modular converters (MMC).

Chapter 8. High Voltage DC (HVDC) transmission based on self-commutated converters

8.1 Fundamentals: description of a basic system.
8.2 Power-flow control in DC.
8.3 Reactive-power requirements.
8.4 Current harmonics.
8.5 Typical topologies: from two-level converters to multi-level modular converters (MMC).

Chapter 9. Power flows with HVDC links

9.1 LCC-HVDC control in the power flow solution.
9.2 VSC-HVDC control in the power flow solution.

Chapter 10. Stability enhancement with HVDC links

10.7 Large-disturbance stability enhancement by a parallel LCC-HVDC link
10.8 Small-disturbance stability enhancement by a parallel LCC-HVDC link
10.9 Large-disturbance stability enhancement by a parallel VSC-HVDC link
10.10 Small-disturbance stability enhancement by a parallel VSC-HVDC link

Laboratory

Laboratory session # 1. Power flows with FACTS devices

Application of shunt devices for voltage control: synchronous condensers, shunt capacitors, statcoms
Application of series devices for power flow control: phase angle regulators and series voltages sources

Laboratory session # 2. Stability simulation with FACTS devices and power flows with HVDC links

Stability simulation with FACTS devices: static var compensators
Power flows with HVDC links: LCC and VSC converter based links

Competences and Learning Outcomes

Competences

General Competences / Basic Competences

CB1. To have acquired and demonstrated advanced knowledge in a context of scientific and technological research (or in a highly specialized area), detailed and informed understanding of the theoretical and practical aspects in one or more fields of study, and the related work methodology

Specific Competences

CE1. Understand the applications of FACTS devices and HVDC transmission.

CE2. To be familiar with the power electronic converters used in FACTS devices and HVDC transmission

CE3. To be familiar with the power flow solutions when FACTS devices and HVDC links are incorporated to the power system

CE4. To be familiar with contribution to power system stability of FACTS devices and HVDC links

Learning outcomes

By the end of the course students should be able to:

LO1. Understand the applications of FACTS and HVDC

LO2. Understand the use of line commutated converters in FACTS devices

LO3. Understand the use of self commutated converters in FACTS devices

LO4. Understand the impact of shunt and series FACTS devices on power flows and to run simulations with them

LO5. Understand the impact of shunt and series FACTS devices on stability and to run simulations with them

LO6. Understand the use of line commutated converters in HVDC transmission

LO7. Understand the use of self commutated converters in HVDC transmission

LO8. Understand the impact of HVDC transmission on power flows and to run simulations with them

LO9. Understand the impact of HVDC transmission on stability and to run simulations with them

TEACHING METHODOLOGY

General methodological aspects	
This course will provide the students with basic concepts and tools they will require in the following courses. To obtain a good understanding of the different concepts, it is necessary to combine theory and practice. As the students will have to assimilate a wide range of knowledge in a short period of time, their commitment will be essential as well.	
In-class activities	**Competences**
Lectures (hours): Presentation of the theoretical concepts by the instructors with proven experience in developing decision support tools for the power sector. These lectures will include dynamic presentations, case studies, and the participation and interaction with students.	CB1, CE1, CE2, CE3, CE4
Laboratory sessions (4 hours): Under the instructor's supervision, students will apply the concepts and techniques covered in the lectures. The sessions will take place in a computer laboratory.	CB1, CE3, CE4
Tutoring for groups or individual students will be organized upon request.	–
Out-of-class activities	**Competences**
Personal study of the material (100 hours): This is an individual activity by the students, in which they will read, analyze and question the readings provided as background material, and that will be discussed with other students and lecturers in the classroom.	CB1, CE1, CE2, CE3, CE4

ASSESSMENT AND GRADING CRITERIA

Assessment activities	Grading criteria	Weight
Exams	▪ Understanding of the theoretical concepts. ▪ Application of these concepts to problem-solving.	90%
Reports of laboratory sessions	▪ Application of theoretical concepts to real problem-solving. ▪ Interpretation and critical analysis of numerical results. ▪ Written communication skills.	10%

GRADING AND COURSE RULES

The student has two periods of final evaluation during one academic year. The first one (regular assessment) will be carried out throughout the course. In case that this was not passed obtaining 5 or more points, the student has another opportunity of final evaluation (Retake) at the end of the academic year. The dates of retake evaluation period will be announced in the web page.

Grading

Regular assessment

Theory will account for 90% of the grade, of which:

- Intermediate exam: 20%
- Final exam: 60%

The exams are a combination of a multi-option test and problems.
Laboratory session reports will account for the remaining 10%.

Retake

A single retake final exam that will account for 90% of the grade.
Laboratory session reports (handed out in the regular assessment) will account for the remaining 10%.

Course rules

Class attendance is mandatory according to Article 93 of the General Regulations (*Reglamento General*) of Comillas Pontifical University and Article 6 of the Academic Rules (*Normas Académicas*) of the ICAI School of Engineering. Not complying with this requirement may have the following consequences:

- Students who fail to attend more than 15% of the lectures may be denied the right to take the final exam during the regular assessment period.
- Regarding laboratory, absence to more than 15% of the sessions can result in losing the right to take the final exam of the regular assessment period and the retake. Missed sessions must be made up for credit.

Students who commit an irregularity in any graded activity will receive a mark of zero in the activity and disciplinary procedure will follow (cf. Article 168 of the General Regulations (*Reglamento General*) of Comillas Pontifical University).

WORK PLAN AND SCHEDULE[1]

In and out-of-class activities	Date/Periodicity	Deadline
Intermediate exam	Week	
Final exam		
Lab sessions	Weeks 9, 12 and 15	
Review and self-study of the concepts covered in the lectures	After each lesson	–
Lab preparation	Before every session	–
Assignments		Between one and three weeks after the publication of the assignments (3)

STUDENT WORK-TIME SUMMARY			
IN-CLASS HOURS			
Lectures	Problem-solving	Lab sessions	Assessment
29	4	4	3
OUT-OF-CLASS HOURS			
Self-study	Problem-solving	Lab session report	
29	7	4	
		ECTS credits:	**3 (60 hours)**

BIBLIOGRAPHY

Basic bibliography

- P. Kundur, Power System Stability and Control. Mc Graw Hill, 1993.
- N.G. Hingorani and L. Gyugui. Understanding FACTS. Concepts and technology of flexible AC transmission sytems, IEEE Press. 1999

Complementary bibliography

- P. García Gonzalez and A. García Cerrada. Transporte flexible de la energía eléctrica en corriente alterna. Anales de Mecánica y Electricidad, Nov-Dic. 2004. pp 59-66.
- A. Yazdani and R. Iravani. Voltage-Sourced Converters in Power Systems. Wiley-IEEE Press, 2010.
- N.R.Chaudhuri, B. Chaudhuri, R. Majumder and A. Yazdani. Multi-terminal Direct-Current Grids: modelling, analysis and Control. Wiley-IEEE Press, 2014.

[1] A detailed work plan of the subject can be found in the course summary sheet (see following page). Nevertheless, this schedule is tentative and may vary to accommodate the rhythm of the class.

COURSE SYLLABUS
2015-2016

	IN-CLASS ACTIVITIES				OUT-OF-CLASS ACTIVITIES				LEARNING OUTCOMES
Week	h	LECTURE & PROBLEM SOLVING	LAB	ASSESMENT	h	SELF-STUDY	LAB PREPARATION AND REPORTING	OTHER ACTIVITIES	Learning Outcomes
1	1	Introduction			1	Review and self-study			LO1
1	1	An overview on power semiconductor switches			1	Review and self-study			LO1
2	2	Line-commutated FACTS (the first generation)			2	Review and self-study			LO2
3	2	Self-commutated FACTS (the second generation)			2	Review and self-study			LO3
4	1	Power flows with FACTS devices			1	Review, self-study and problem-solving			LO4
4	1	High Voltage DC (HVDC) transmission based on line-commutated converters			1	Review and self-study			LO2
5	1	Power flows with FACTS devices			1	Review, self-study and problem-solving			LO4
5	1	High Voltage DC (HVDC) transmission based on line-			1	Review and self-study			LO6
6	1	Power flows with FACTS devices			1	Review, self-study and problem-solving			LO4
6	1	High Voltage DC (HVDC) transmission based on line-			1	Review and self-study			LO6
7	1			Intermediate exam: Materials presented and discussed so far	1	Review, self-study and problem-solving			
7	1	Stability enhacement with FACTS devices			1	Review, self-study and problem-solving			LO5
8	2		Power flows with FACTS devices: Computer laboratory session		2		Report laboratory session		LO4
9	1	Stability enhacement with FACTS devices			1	Review, self-study and problem-solving			LO5
9	1	High Voltage DC (HVDC) transmission based on self-			1	Review and self-study			LO7
10	1	Stability enhacement with FACTS devices			1	Review, self-study and problem-solving			LO5
10	1	High Voltage DC (HVDC) transmission based on self-			1	Review and self-study			LO7
11	1	Power flows with HVDC links			2	Review, self-study and problem-solving			LO8
11	1	Power flows with HVDC links			1	Review, self-study and problem-solving			LO8
12	1	Power flows with HVDC links			1	Review, self-study and problem-solving			LO8
12	1	Stability enhacement with HVDC links			1	Review, self-study and problem-solving			LO9
13	2	Stability enhacement with HVDC links			1	Review, self-study and problem-solving			LO9
14	2		Power flows with FACTS devices: Computer laboratory session		2		Report laboratory session		LO6,LO7
15	2			Final exam	2	8			