ANX-PR/CL/001-01

LEARNING GUIDE

SUBJECT

93001314 - Simulation And Optimization Software For Photovoltaic Systems

DEGREE PROGRAMME

09BP - Master Universitario En Energia Solar Fotovoltaica

ACADEMIC YEAR & SEMESTER

2023/24 - Semester 1

Index

Learning guide

1. Description

1.1. Subject details

Name of the subject	93001314 - Simulation And Optimization Software For Photovoltaic Systems
No of credits	3 ECTS
Type	Optional
Academic year ot the programme	First year
Semester of tuition	Semester 1
Tuition period	September-January
Tuition languages	English
Degree programme	09BP - Master Universitario en Energia Solar Fotovoltaica
Centre	09 - Escuela Tecnica Superior De Ingenieros De Telecomunicacion
Academic year	2023-24

2. Faculty

2.1. Faculty members with subject teaching role

Name and surname	Office/Room	Email	Tutoring hours *
Cesar Dominguez Dominguez (Subject coordinator)		cesar.dominguez@upm.es	- -
Pablo Garcia-Linares Fontes		p.garcia-linares@upm.es	Sin horario.
Ruben Nuñez Judez		ruben.nunez@upm.es	Sin horario.

* The tutoring schedule is indicative and subject to possible changes. Please check tutoring times with the faculty member in charge.

2.3. External faculty

Name and surname	Email	Institution
Estefanía Caamaño Martín	estefania.cmartin@upm.es	E.T.S. DE INGENIEROS DE TELECOMUNICACION

3. Skills and learning outcomes *

3.1. Skills to be learned

CB10 - Que los estudiantes posean las habilidades de aprendizaje que les permitan continuar estudiando de un modo que habrá de ser en gran medida autodirigido o autónomo.

CB6 - Poseer y comprender conocimientos que aporten una base u oportunidad de ser originales en el desarrollo y/o aplicación de ideas, a menudo en un contexto de investigación

CB7 - Que los estudiantes sepan aplicar los conocimientos adquiridos y su capacidad de resolución de problemas en entornos nuevos o poco conocidos dentro de contextos más amplios (o multidisciplinares) relacionados con su área de estudio

CB8 - Que los estudiantes sean capaces de integrar conocimientos y enfrentarse a la complejidad de formular juicios a partir de una información que, siendo incompleta o limitada, incluya reflexiones sobre las responsabilidades sociales y éticas vinculadas a la aplicación de sus conocimientos y juicios

CB9 - Que los estudiantes sepan comunicar sus conclusiones y los conocimientos y razones últimas que las sustentan a públicos especializados y no especializados de un modo claro y sin ambigüedades

CE2 - Conocimiento, anÃ¡lisis y propuestas de nuevos conceptos, mÃ©todos o dispositivos para la conversiÃ³n fotovoltaica.

CE5 - DiseÃ±o, anÃ¡lisis, caracterizaciÃ³n, planificaciÃ³n e instalaciÃ³n de componentes y sistemas fotovoltaicos de propÃ³sito general, autÃ³nomos o conectados a la red.

CE7 - Analizar, diseÃ±ar e implementar sistemas fotovoltaicos de complejidad media-alta

CG5 - GestiÃ³n de la informaciÃ³n: buscar y gestionar recursos bibliogrÃ¡ficos adecuados con eficiencia, aprender a continuar los estudios de manera ampliamente autÃ³noma como base para la futura actividad de investigaciÃ³n e innovaciÃ³n

CG8 - Aplicar metodologÃas, procedimientos, herramientas y normas del estado del arte para la creaciÃ³n de nuevos componentes tecnolÃ³gicos; Construir nuevas hipÃ³tesis y modelos, evaluarlos y aplicarlos a la resoluciÃ³n de problemas

CG9 - Comunicar juicios, y conocimientos a audiencias especializadas y no especializadas, de una manera razonada, clara y sin ambigÃ¿edades

CT3 - Uso de la lengua inglesa: comprender los contenidos de clases magistrales, conferencias y seminarios en lengua inglesa; redactar en inglÃ©s informes y artÃculos cientÃfico-tÃ©cnicos usando herramientas informÃ¡ticas; realizar exposiciones pÃºblicas en inglÃ©s de trabajos, resultados y conclusiones de investigaciÃ³n, por ejemplo, en las asignaturas del MÃ¡ster o en congresos de carÃ¡cter mayoritariamente internacional o en estancias en centros extranjeros, todo ello con la ayuda de medios informÃ¡ticos audiovisuales

3.2. Learning outcomes

RA34 - Formación general sobre las aplicaciones, el uso práctico de los sistemas fotovoltaicos y una perspectiva sobre la tecnología fotovoltaica

RA37 - Conocer las herramientas específicas de ingeniería para diseñar y evaluar sistemas fotovoltaicos

RA14 - RA4 - Capacidad para analizar los resultados

RA35 - Conocer los aspectos prácticos de la instalación

RA13 - RA3 - Conocer las herramientas de simulación más utilizadas para células y sistemas FV

RA15 - RA5 - Relacionar los principios básicos con los aspectos prácticos

RA36 - Aplicar los servicios y herramientas disponibles en el mercado al diseño de sistemas fotovoltaicos

* The Learning Guides should reflect the Skills and Learning Outcomes in the same way as indicated in the Degree Verification Memory. For this reason, they have not been translated into English and appear in Spanish.

4. Brief description of the subject and syllabus

4.1. Brief description of the subject

The aim of this course is to develop the student's competencies for the modeling, analysis, design and optimization of photovoltaic (PV) systems and their components using the most standard software tools used in industry (PVsyst) and the academia (PVLIB Python). The course presents typical PV module performance models as a function of the operating conditions, as well as procedures for accessing, modeling and translating solar resource and weather data in order to predict the power generated by a complete PV system at a given location.

The methodological approach is based on a series of short lectures on the modeling and analysis of PV systems and their components, complemented by tutorial and hands-on laboratory sessions on the software tools to be used: PVLIB Python (open source) and PVSyst (the industry-standard commercial tool). The students will use these tools to simulate PV systems and components using realistic case studies. Students will be asked to develop a series of individual tasks or small PV system projects throughout the course to put into practice the concepts seen in class and acquire sufficient mastery of the tools. Learning the tools of this course will be especially useful in the rest of the subjects of the PV Systems itinerary, which make use of them for some of the lab sessions or projects.

PVLIB Python tutorials: Implementation of a PV system modeling chain using open source libraries.

1 Python and PVLIB toolchain setup

2 Accessing irradiance and weather data

3 Modeling solar resource and in-plane irradiance

4 Estimating module temperature

5 The single diode model

6 Predicting module output power from operating conditions

7 Modeling a PV generator by combining module strings and AC inverters

PVSyst tutorial: modeling PV systems using commercial software

1 Modeling grid-connected PV systems with PVSyst

* Please note that **no previous background on Python language is expected or required**, as the course will provide an initial crash course on Python programming and the development environments to be used during the course, such as Spyder or Jupyter Notebooks.

4.2. Syllabus

1. Introduction to scientific Python and the PVLIB toolchain

2. Meteorological and solar resource data sources

   2.1. Accessing weather databases and evaluating data quality

   2.2. Generation of synthetic series

3. Solar resource modeling

   3.1. Estimating solar position and angle of incidence

   3.2. Estimating missing irradiance components

   3.3. Plane-of-array irradiance: transposition to the generator plane

   3.4. Modeling solar tracking and back-tracking

4. Electrical and thermal modeling of photovoltaic panels

   4.1. 5-parameters single diode model. Identification of parameters for a commercial PV module.

   4.2. Modeling the effect of irradiance and temperature

   4.3. Empirical models of I-V parameter variation

   4.4. Cell temperature estimation

   4.5. Estimating model accuracy

5. Modeling a grid-connected PV system including losses

   5.1. Partial shading

   5.2. Modeling optical (incidence angle modifier) and spectral losses

   5.3. Effect of soiling

   5.4. DC and AC electrical losses

   5.5. Modeling inverter performance

6. Introduction to PVsyst for sizing and simulation of grid-connected PV systems

5. Schedule

5.1. Subject schedule*

Week	Classroom activities	Laboratory activities	Distant / On-line	Assessment activities
1	**Course presentation** Duration: 01:00 Lecture	**Crash course on Python for engineering** Duration: 01:00 Laboratory assignments		
2		**Crash course on Python for engineering** Duration: 01:00 Laboratory assignments **PVLIB tutorial 1: Setting up a PVLIB Python toolchain** Duration: 01:00 Laboratory assignments		
3	**Lecture. Meteorological and solar resource data sources** Duration: 01:00 Lecture	**PVLIB tutorial 2: Accessing irradiance and weather data** Duration: 01:00 Laboratory assignments		**Exercise 1: processing and plotting numerical data arrays and time series.** Individual work Continuous assessment Presential Duration: 00:00
4	**Lecture. Meteorological and solar resource data sources** Duration: 01:00 Lecture	**PVLIB tutorial 2: Accessing irradiance and weather data** Duration: 01:00 Laboratory assignments		
5	**Lecfure. Solar resource modeling and plane-of-array irradiance** Duration: 01:00 Lecture	**PVLIB tutorial 3: Modeling solar resource and in-plane irradiance** Duration: 01:00 Laboratory assignments		
6	**Lecfure. Solar resource modeling and plane-of-array irradiance** Duration: 01:00 Lecture	**PVLIB tutorial 3: Modeling solar resource and in-plane irradiance** Duration: 01:00 Laboratory assignments		
7		**Practical session: Modeling solar resource and in-plane irradiance** Duration: 02:00 Laboratory assignments		**Exercise 2: accessing, analyzing and transposing solar resource time series** Individual work Continuous assessment Presential Duration: 00:00
8	**Lecture. Electrical and thermal modeling of photovoltaic modules** Duration: 01:00 Lecture	**PVLIB tutorial 3: Modeling performance of PV modules using single diode model** Duration: 01:00 Laboratory assignments		
9	**Lecture. Estimating cell temperature** Duration: 01:00 Lecture	**PVLIB tutorial 4: Estimating module temperature from ambient conditions** Duration: 01:00 Laboratory assignments		

10	**Lecture. Modeling a grid-connected PV system including optical, DC and AC losses** Duration: 01:00 Lecture	**PVLIB tutorial 5: Modeling a complete PV generator by combining module strings and AC inverters** Duration: 01:00 Laboratory assignments		
11		**Tutorial session on PVLIB Python projects** Duration: 02:00 Laboratory assignments		**Individual project 1: modeling a PV system with PVLIB Python** Individual work Continuous assessment Presential Duration: 00:00
12		**PVSyst tutorial: Sizing and simulation of a grid-connected PV system** Duration: 02:00 Laboratory assignments		
13		**PVSyst tutorial: Sizing and simulation of a grid-connected PV system** Duration: 02:00 Laboratory assignments		
14		**PVSyst tutorial: Sizing and simulation of a grid-connected PV system** Duration: 02:00 Laboratory assignments		
15				**Individual project 2: Modeling a grid-connected PV system with PVsyst** Individual work Continuous assessment Presential Duration: 00:00
16				
17				**Final quiz exam** Written test Final examination Presential Duration: 01:00

Depending on the programme study plan, total values will be calculated according to the ECTS credit unit as 26/27 hours of student face-to-face contact and independent study time.

* The schedule is based on an a priori planning of the subject; it might be modified during the academic year, especially considering the COVID19 evolution.

6. Activities and assessment criteria

6.1. Assessment activities

6.1.1. Assessment

Week	Description	Modality	Type	Duration	Weight	Minimum grade	Evaluated skills
3	Exercise 1: processing and plotting numerical data arrays and time series.	Individual work	Face-to-face	00:00	5%	/ 10	CG8 CG9
7	Exercise 2: accessing, analyzing and transposing solar resource time series	Individual work	Face-to-face	00:00	10%	/ 10	CB6 CB9 CB10 CG5 CG9 CT3
11	Individual project 1: modeling a PV system with PVLIB Python	Individual work	Face-to-face	00:00	40%	/ 10	CB6 CB7 CB8 CB9 CB10 CG3 CG5 CG8 CG9 CT3 CE2 CE5 CE7
15	Individual project 2: Modeling a grid-connected PV system with PVsyst	Individual work	Face-to-face	00:00	20%	/ 10	CB7 CB8 CB9 CB10 CG3 CG5 CG8 CG9 CT3 CE5 CE7

6.1.2. Global examination

Week	Description	Modality	Type	Duration	Weight	Minimum grade	Evaluated skills
17	Final quiz exam	Written test	Face-to-face	01:00	25%	/ 10	CB6 CB7 CB8 CB9 CB10 CG3 CG5 CG8 CG9 CT3 CE2 CE5 CE7

6.1.3. Referred (re-sit) examination

Description	Modality	Type	Duration	Weight	Minimum grade	Evaluated skills
Portfolio of individual projects: the student may rework and present (again or for the first time) every individual project for a new assessment before the date of the extraordinary exam	Individual work	Face-to-face	00:00	75%	/ 10	CB6 CB7 CB8 CB9 CB10 CG3 CG5 CG8 CG9 CT3 CE2 CE5 CE7
Final quiz exam	Written test	Face-to-face	01:00	25%	/ 10	CB6 CB7 CB8 CB9 CB10 CG3 CG5 CG8

						CG9 CT3 CE2 CE5 CE7

6.2. Assessment criteria

The most important part of the student's work and assessment will be based on the individual project assignments, plus a final quiz test to evaluate the student's understanding of the modeling concepts seen during the course.

7. Teaching resources

7.1. Teaching resources for the subject

Name	Type	Notes
Handbook of photovoltaic science and engineering	Bibliography	A. Luque, S. Hedgedus (eds.). Wiley, 2nd ed., 2011.
PVLIB Python documentation	Web resource	https://pvlib-python.readthedocs.io/
PVsyst documentation	Web resource	https://www.pvsyst.com/help/index.html
Scype Lecture Notes	Web resource	https://scipy-lectures.github.io/ Tutorials on the scientific Python ecosystem
Electricidad solar fotovoltaica. Volumen II: Radiación solar y dispositivos fotovoltaicos	Bibliography	E. Lorenzo. Progensa, 2006.
Electricidad solar fotovoltaica. Volumen III: Ingeniería fotovoltaica	Bibliography	E. Lorenzo. Progensa, 2014.

8. Other information

8.1. Other information about the subject

This course promotes some of the United Nations Sustainable Development Goals (SDGs), in particular:

- SDG 7: Ensure access to affordable, reliable, sustainable and modern energy for all. Target 7.2 By 2030, increase substantially the share of renewable energy in the global energy mix
- SDG 13: Take urgent action to combat climate change and its impacts. Target 13.3 Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning