Warsaw University of Technology

COURSE OFFERED IN THE DOCTORAL SCHOOL

Code of the course	4606-ES-00000BI-0089	Name of the course	Polish	**Harmoniczne w Energoelektronice i Systemach Elektroenergetycznych**	
			English	**Harmonics in Power Electronics and Power Systems**	
Type of the course	SEED Visiting Professors (ViP – Task 4)				
Course coordinator	Marek Jasinski WUT (Kocewiak Lukasz Orsted)				
Implementing unit	DOD+WE	Scientific discipline / disciplines*	Automation, electronics, and electrical engineering		
Level of education	PhD Students	Semester	Winter		
Language of the course	English				
Type of assessment:	Test/project	Number of hours in a semester	30	ECTS credits	2
Minimum number of participants	5	Maximum number of participants	25	Available for students (BSc, MSc)	Yes/~~No~~

Type of classes		Lecture	Auditory classes	Project classes	Laboratory	Seminar
Number of hours	in a week					
	in a semester					20

* does not apply to the Researcher's Workshop

1. Prerequisites

The seminar is for all Doctoral Studies, Doctoral Schools, and MSc students.

2. Course objectives

1. The participant after the course is expected to:
2. – know how to perform harmonic propagation studies in modern power systems,
3. – know how to calculate harmonic distortion indices,
4. – know how to evaluate harmonics in power systems and compare against applicable standards,
5. – how to select preventive and corrective optimal harmonic mitigation measures,
6. – how to design a passive filter to mitigate excessive harmonic distortion,
7. – how to design a measurement system for power quality monitoring,
8. – how provide power system design recommendation to assure electromagnetic compatibility,
9. – how to model power system and power electronic components for harmonic analysis.

3. Course content (separate for each type of classes)

Lecture / Seminar

This course provides a broad overview of power system harmonic problems, and methods of analyzing, measuring and effectively mitigating them. Several extended simulation and data processing tools, including DIgSILENT PowerFactory, Matlab/Simulink or LabVIEW are used to assess and study the harmonic distortion at different points of power networks. The results of analytical investigation and simulations are validated against measurements applying sophisticated data processing techniques. Furthermore, deep understanding of hardware considerations regarding harmonic measurements in harsh industrial environment is given, using specialized equipment, for instance GPS-synchronized measuring instruments.

The course covers the following topics:
– Power quality definitions. Generation mechanism of power system harmonics. Harmonic indices.
– Voltage vs. current distortion as well as parallel vs. series resonance in modern power systems.
– Sources and effects of harmonic distortion.
– Harmonic measuring instruments and measuring procedures in LV, MV and HV networks.
– Mathematical tools and theories for analyzing distorted waveforms. Signal processing and uncertainty analysis.
– Modelling of classical power system components. Harmonic analysis.
– Modelling of grid-connected converters for harmonic analysis purposes and their application in modern power systems including e.g. offshore wind power plants.
– Harmonic load-flow, frequency scan and time domain simulations. Linear and nonlinear analysis techniques.

– Steady-state harmonics vs. harmonic stability. Small-signal representation, sequence and frequency coupling. – Software tools for harmonic analysis. – Precautionary (preventive) and corrective (remedial) harmonic mitigation techniques. Passive and active harmonic filters. Filter design. – International guidelines and standards on power quality. Grid code requirements and compliance verification.
Laboratory / Workshop

4. Learning outcomes			
	Learning outcomes description	Reference to the learning outcomes of the WUT DS	Learning outcomes verification methods*
Knowledge			
K01	The world's achievements in science and the arts and the resulting implications of this for practice	SD_W2	Active participation
K02			
K03			
Skills			
S01	analyse and creatively synthesise scientifically and creative achievements to identify and solve research problems as well as those related to innovative and creative activities; contribute new elements to these achievements	SD_U1	presentation evaluation
S02			
S03			
Social competences			
SC01	conduct independent research which contributes to existing scientific and creative achievements; assume professional and public challenges taking into consideration: • their ethical dimension • responsibility for their results and develop models of good practice in such situations	SD_K5	presentation evaluation

*Allowed learning outcomes verification methods: exam; oral exam; written test; oral test; project evaluation; report evaluation; presentation evaluation; active participation during classes; homework; tests

5. Assessment criteria
The participants will be evaluated based on the following factors: – 100% attendance – report from 1 of 3 assignments (to be selected, project or laboratory report) related to the course content.

6. Literature

[1] E. Guest, T. W. Rasmussen and K. H. Jensen, "Probabilistic Harmonic Modeling of Wind Power Plants," in 16th International Workshop on Large-Scale Integration of Wind Power into Power Systems as well as on Transmission Networks for Offshore Wind Power Plants, Berlin, Germany, 23–27 October 2017.

[2] C. F. Jensen, Z. Emin and Ł. H. Kocewiak, "Amplification of harmonic background distortion in wind power plants with long high voltage connections," in CIGRÉ Biennial Session, Paris, France, 21-26 August 2016.

[3] Ł. H. Kocewiak, J. Hjerild, T. Sørensen, C. L. Bak, I. Arana and J. Holbøll, "GPS synchronization and EMC of harmonic and transient measurement equipment in offshore wind farms," Energy Procedia, vol. 24, pp. 212-228, 2012.

[4] R. Jones, R. Vernon Fulcher and H. Stiesdal, "Control methods for the synchronization and phase shift of the pulse width modulation (PWM) strategy of power converters". Patent US9293921B2, 22 03 2016.

[5] E. Guest, K. H. Jensen and T. W. Rasmussen, "Sequence Domain Harmonic Modeling of Type-IV Wind Turbines," IEEE Transactions on Power Electronics, vol. 33, no. 6, pp. 4934 - 4943, 02 August 2017.

[6] L. S. Christensen, J. G. Nielsen and T. Lund, "Using Prevailing Angle of Harmonics to Distinguish between Background Noise and Emission from a Turbine," in 16th International Workshop on Large-Scale Integration of Wind Power into Power Systems as well as on Transmission Networks for Offshore Wind Power Plants, Berlin, Germany, 23–27 October 2017.

[7] M. Lehmann, M. Pieschel, Ł. H. Kocewiak, M. Juamperez, S. Sahukari, K. Kabel, "Active Filtering with Large-Scale STATCOM for the Integration of Offshore Wind Power," in Proc. The 17th International Workshop on Large-Scale Integration of Wind Power into Power Systems as well as Transmission Networks for Offshore Wind Farms, Energynautics GmbH, 17-19 October 2018, Stockholm, Sweden.

[8] Ł. H. Kocewiak, I. Arana, B. Gustavsen, "Impact of Cable Impedance Modelling Assumptions on Harmonic Losses in Offshore Wind Power Plants," CIGRE Biennial Session, CIGRÉ, 26-31 August 2018, Paris, France, C4-309.

[9] Ł. H. Kocewiak, B. Laudal Øhlenschlæger Kramer, O. Holmstrøm, K. Høj Jensen, L. Shuai, "Resonance Damping in Array Cable Systems by Wind Turbine Active Filtering in Large Offshore Wind Power Plants," IET Renewable Power Generation, Institution of Engineering and Technology, 6 July 2017, Volume 11, Issue 7, Page(s) 1069-1077.

[10] IEC 61000-3-6:2008, "Electromagnetic compatibility (EMC) – Part 3-6: Limits – Assessment of emission limits for the connection of distorting installations to MV, HV and EHV power systems".

[11] IEC-61000-4-7:2002, "Electromagnetic Compatibility (EMC) – Part 4-7: Testing and Measurement Techniques – General Guide on Harmonics and Interharmonics Measurements and Instrumentation for Power Supply Systems and Equipment Connected Thereto".

7. PhD student's workload necessary to achieve the learning outcomes**		
No.	Description	Number of hours
1	Hours of scheduled instruction given by the academic teacher in the classroom	20
2	Hours of consultations with the academic teacher, exams, tests, etc.	10
3	Amount of time devoted to the preparation for classes, preparation of presentations, reports, projects, homework	15
4	Amount of time devoted to the preparation for exams, tests, assessments	15
	Total number of hours	**60**
	ECTS credits	**2**

** 1 ECTS = 25-30 hours of the PhD students work (2 ECTS = 60 hours; 4 ECTS = 110 hours, etc.)