Retraining of Fossil Fuel Mining Area Workforce for Modern Industry REMARKER

Project Results

Output 3: Re-training Course for Power Electronics

Contents

Description

As part of mechatronics systems, the power semiconductor devices at the heart of modern power electronics are under continuous development. The improved technology in semiconductor processing, device fabrication, and packaging produces high-density, high-performance, high-reliability, and high-yielding microelectronic chips, together with new semiconductor material discovery, made a possible significant reduction in energy consumption, driving these systems to an incredibly economical price. Without a doubt, these achievements force the control strategy techniques to evolve rapidly to the newly created drive conditions and adapt to the overall systems performance requirements.

In recent years, soft switching converters became the center of interest compared with more conventional hard switching converters due to their significant advantages such as minimization of switching loss, improved efficiency, improved reliability due to soft stress, and reduced electromagnetic emission. The continuous growing interest in the modern industrial area relates to the intelligent power electronics modules, where the power and the control are embedded in the same package and interface directly with logic signals. The converter modules and control are mounted directly on the machine for low and medium power applications for variable frequency drives.

The main aim of Output 3 is to develop the structure and specification of retraining module supporting pieces of training in the field of power electronics. The course is aimed at different target groups: employees of manufacturing plants, mainly operators of advanced machines, such as robots, automats, cells/machines for automated assembly, teachers / trainers / consultants in the field of automation and robotics, technicians, and also students.

1 Analysis of the curriculum in the field of Power Electreonics

In this section curriculum in the field of Power Electronics at partner universities is presented. Both bachelor and master courses are taken into account. Aims, outcomes, and descriptions are collected and structured. Content of the lectures is provided for further analysis. Moreover, the dedicated literature and references is presented.

1.1 Tallinn University of technology (TalTech)

1.1.1 Bachelor studies

In TalTech basics of power electronics is combined with basics of electrical drives

Course code	ATV0080
Course title in Estonian	Toitemuundurid ja masinate juhtimine
Course title in English	Supply Converters and Control of Machines
ECTS credits	6.0
Assessment form	Examination
Teaching semester	autumn - spring
Lecturer	Anton Rassõlkin; Indrek Roasto
Course aims	To introduce the students to the essentials of electric drives. Main attention is on explaining construction and operating principles of electric drives used in the industry and infrastructures. To study energy exchange between power supply, electric drive and load machine as well as related electromechanical processes. To explain selection criteria of the drive based on the load and operating conditions with speed and torque control possibilities. To familiarize the students with the user interfaces of modern microprocessor-controlled drives.
Learning outcomes in the course	A student shall acquire: - understanding of energy exchange processes in electric drives; - knowledge of characteristics of different drive types; - skills for selecting the drive according to the application; - knowledge of the control possibilities of electric drives; - knowledge of the sensors used in the drive systems; - skills for choosing protective devices; - skills for reading and composing connection diagrams; - skills for for using different user interfaces.
Brief description of the course	Description and structure of an electric drive. A historical overview. Energy flows in an electric drive. Power and control circuits. Relations to power and micro electronics. Drive mechanics: transmissions and basic movement equations. Translations of the moments of inertia, forces, torques and speeds. Load types and calculation examples. Standardized duty types. Motor power selection. Connection diagrams and schematic elements. DC drives characteristics and equations. Rheostat control of DC drives. DC drives with power converter. Pulse control of DC drives. AC asynchronous drives electromechanical characteristics. Starting of asynchronous drives. Soft starters. Asynchronous motor models. Principle of frequency control. Energy flows in frequency controlled drives. Use of frequency converters with different loads. Synchronous and servo drives. Basics of vector control. Stepper motor drives. Drives in electric transportation. Protection and control of electric drives. Sensors in

	electric drives. User interfaces. Electromagnetic compatibility in electrical drives.
Study literature	1) Lehtla, T. Elektriajamid. Tallinn, TTÜ, 2007. 2) Vodovozov, V. 3) Elektriajamite ja jõuelektroonika e-õppelabori metoodilised materjalid. Tallinn, TTÜ, 2008.
Daytime study: weekly hours	4.0
lectures	2.0
Practices	2.0
exercises	0.0
Session-based study workload (in a semester):	64.0
lectures	32.0
practices	32.0
exercises	0.0
Course description	http://ois2.ttu.ee/uusois/subject/ATV0080
Content of lectures	1) Introduction to Power Electronics. 2) Components of The Power Electronics. 3) Converter Design. 4) DC/DC Converters. 5) AC/DC Converters. 6) DC/AC Converters. 7) Frequency Converters. 8) Control of Converters. 9) Introduction to electrical drives. Definition and main components. 10) Mechanics of electrical drive. Transmission systems and basic equations of motion. Moment of inertia, torque, speed. 11) Load types. Standard operating modes. Motor power selection. 12) DC drives and control of DC machines. 13) AC drives. 14) Control of AC machines. Variable Speed Drives (VSD). 15) Special types of AC drives. Synchronous Drives. Servo Drives. Stepper-Motor Drives. 16) Protection of electrical drives. Electromagnetic compatibility of electrical drives.

1.1.2 Master studies

In TalTech advanced studies in the field of electrical drives is combined with industrial automation

Course code	EEV5050
Course title in Estonian	Jõuelektroonika erikursus
Course title in English	Advanced Course of Power Electronics
ECTS credits	6.0
Assessment form	Examination
Teaching semester	spring
Lecturer	Indrek Roasto
Course aims	1. To provide an overview of new semiconductor components, special converter topologies and control methods of the modern power electronics.

	2. To give basic design skills of the power electronic converters and their control systems. 3. To teach modelling and simulation methods of power electronic converters. 4. To develop practical skills for building power electronic converters.
Learning outcomes in the course	A student shall have: - a general overview of modern power electronic converter topologies, their properties and applications. - knowledge about components of power electronic converters and ability to calculate their parameters. - skills to use power electronic specific computer software for simulation and modelling. - knowledge of control principles and compensators used in power electronic converters. - knowledge about typical faults in converters and ability to find them. - practical skills to design and build a power electronic converter.
Brief description of the course	Development trends of the modern power electronics. Novel semiconductor components (SiC and GaAs devices). Power electronic converters for renewable energy applications. Modelling (Matlab, Mathcad) and simulation (PSIM, PLECS) of converters. Control principles and stability criteria of converters. Analysis of interferences and faults of power electronics. Design, simulation and construction of a real power electronic converter.
Study literature	1. M. H. Rashid, „Power Electronics: Circuits, Devices, and Applications“ 2. R.W. Erickson, „Fundamentals of Power Electronics“ 3. S. Maniktala Switching Power Supplies A to Z
Daytime study: weekly hours	4.0
lectures	2.0
Practices	2.0
exercises	0.0
Session-based study workload (in a semester):	64.0
lectures	32.0
practices	32.0
exercises	0.0
Course description	http://ois2.ttu.ee/uusois/subject/EEV5050
Content of lectures	1) Components of power electronics. 2) Trends in power electronics. 3) Loses in converters and thermal design. 4) Modulation methods. 5) Control system design. 6) Introduction to system stability and Control. 7) Bode plots. 8) LTI systems. 9) Advanced converter topologies. 10) PFC converters. 11) Multi-level converters.

1.2 Silesian University of Technology (SUT)

1.2.1 Bachelor studies

In the SUT course for power electronics consists of two courses: Power Electronics and Power Electronics Elements and Systems.

Power Electronics

Course title in English	Power Electronics
ECTS credits	6.0
Assessment form	Test
Teaching semester	spring
Lecturer	dr inż. Marcin Zygmanowskil
Course aims	Student has obtained the knowledge on: switching power converters and dissipative ones, switching devices (diodes, transistors, etc.), mathematical models of power electronic converters (DC-DC, AC-DC, AC-AC and AC-DC), control systems, power quality and distributed systems.
Learning outcomes in the course	Student is able to: - define basic properties of power electronic devices (diodes, transistors, etc.); - set up models of power electronic converters (analytical and numerical); - select a power electronic converter to given controlled process; - identify positive and negative influence of power converter on the grid.
Study literature	1) N. Mohan: Power Electronics: A first course, Wiley 2011. 2) D. W. Hart: Power Electronics, McGraw-Hill, 2011. 3) N. Mohan, T. M. Undeland, W. P. Robbins: Power Electronics: Converters, Applications, and Design, Wiley 2002.
Daytime study: weekly hours	5.0
lectures	2.0
Practices	2.0
exercises	1.0
Session-based study workload (in a semester):	75.0
lectures	30.0
practices	30.0
exercises	15.0
Content of lectures	1) Introduction to Power Electronics. 2) switching devices (diodes, transistors, etc). 3) DC-DC buck converter. 4) DC-DC buck converter design. 5) DC-DC boost converter. 6) DC-DC forward converter. 7) DC-DC flyback converter. 8) Resonant D-class inverter with R-L load. 9) Modulation in DC-AC converters. 10) Multilevel converters. 11) Serial resonant DC-DC converters. 12) Diode rectifiers with RL filter.

	13) Six-pulse thyristor rectifier. 14) AC-AC converters. 15) Magnetic component design. 16) Thermal issues.

Power Electronics Elements and Systems

Course title in English	Power Electronics Elements and Systems
ECTS credits	4.0
Assessment form	Test
Teaching semester	spring
Lecturer	prof. Mariusz Stepien
Course aims	Student has obtained the knowledge on: switching power converters and dissipative ones, switching devices (diodes, transistors, etc.), mathematical models of power electronic converters (DC-DC, AC-DC, AC-AC and AC-DC), control systems, power quality and distributed systems.
Learning outcomes in the course	Student is able to: - define basic properties of power electronic devices (diodes, transistors, etc.); - know the method of measurements of power electronics devices and power electronic converters; - planning and investigate measurements of power electronic devices according to safety rules; - do the written rapport related to laboratory investigation, student is able to explain and discus results; - realized laboratory task working individually and in the team.
Study literature	1) N. Mohan: Power Electronics: A first course, Wiley 2011. 2) D. W. Hart: Power Electronics, McGraw-Hill, 2011. 3) N. Mohan, T. M. Undeland, W. P. Robbins: Power Electronics: Converters, Applications, and Design, Wiley 2002.
Daytime study: weekly hours	3.0
lectures	2.0
Practices	1.0
exercises	0.0
Session-based study workload (in a semester):	45.0
lectures	30.0
practices	15.0
exercises	0.0
Content of lectures	1) Increasing knowledge related to properties of power electronics devices (diodes, SCR, transistors) – systematics, parameters, technical data, computer models, power losses, implementation. 2) Control issues and minimization of transistors power losses. Problematics aspects of heat generation and cooling of power transistors. Problematics of choice of cooling system. 3) Selected problems of current commutation in rectifier. Resonant inverters of Class C, D, DE, E, F i EF - properties, practical realization and industry implementation.

	4) IC power electronics converters. Measurements of voltage/current/power – transformers, hall sensor, Rogowski coils, oscilloscope measurements, calorimetric methods. 5) Idea/rules of power and control circuit design. Selected problems of electromagnetic compatibility.

1.2.2 Master studies

Course title in English	Power Electronics Converters
ECTS credits	6.0
Assessment form	Examination
Teaching semester	spring
Lecturer	prof. Zbigniew Kaczmarczyk, Dr. Marcin Kasprzak, Dr. Marcin Zygmanowski
Course aims	The aim of the subject is the extension of the basic knowledge of power electronic converters.
Learning outcomes in the course	Student is able to: - explain principle of operation of overcurrent and overvoltage protection, especially active protection and snubber circuits, choice/design procedure of protection circuits; - explain the principle of the operation of power electronic converters in detail together with operation of the controls; - compare properties of hard and soft switching power electronic converters with providing qualitative evaluation between these topologies; - explain electromagnetic compatibility issues in power electronics; - think and act in creative way, and should understand the need for further self-study.
Study literature	1) Mohan N, Undeland T, Robbins W.P.: Power Electronics; Converters, Applications and Design. Wiley and Sons, 2003. 2) Mohan N, Power Electronics: A First Course. Wiley and Sons, 2011.
Daytime study: weekly hours	 3.0
lectures	2.0
Practices	2.0
exercises	1.0
Session-based study workload (in a semester):	 75.0
lectures	30.0
practices	30.0
exercises	15.0
Content of lectures	1) Forward and flyback converters. Diode rectifier operating with close loop control. Transistor based PWM rectifiers. 2) Influence of power device switching on the converter operation and AC line. Control strategies of power electronic inverters. Voltage- and current-mode control. 3) Single Pulse Width Modulation (PWM) and Pulse Density Modulation (PDM). 4) Single and three-phase power electronic inverters. Multilevel converters. Single and three-phase thyristor based inverters.

	5) Voltage and current source AC-DC-AC converters. Resonant converters. Minimization of switching power losses. 6) Comparison between parallel and series resonant transistor or thyristor based converters. Class E inverter. 7) Control and protection circuits. Active and passive protection devices for current and voltage limitation. Other protection devices. 8) Methods and circuits for protecting power devices. Snubber circuits. Connecting of power devices in series and parallely. 9) Control circuits and IGBT and MOSFET drivers, Principle of inverters construction and design. 10) Electromagnetic compatibility in power electronic circuits. Standards, datasheets and application notes. Power converters applications.

1.3 University of West Bohemia (UWB)

1.3.1 Bachelor studies

Course code	KEV/VEL
Course title in English	Power Electronics
ECTS credits	4.0
Assessment form	Examination, test, individual presentation at a semester
Teaching semester	Autumn
Guarantor	Doc. Ing. Pavel Drábek, Ph.D.
Lecturer	Doc. Ing. Pavel Drábek, Ph.D., Ing. Jiří Fořt, Ph.D., Ing. Jana Jiřičková, Ph.D., Ing.Jan Molnár, Ph.D.
Tutorial lecturer	Ing. Bedřich Bednář, Ph.D., Ing. Vojtěch Blahník, Ph.D., Ing. Jiří Fořt, Ph.D., Ing.Martin Jára, Ph.D., Ing. Jana Jiřičková, Ph.D., Doc. Ing. Tomáš Komrska, Ph.D.
Course aims	Deepening knowledge of power electronics, focusing on control of individual types of power converters (rectifiers, DC/DCconverters, inverters and frequency converters), more complex topology of power converters (multiquadrant, three-phase, etc.).
Learning outcomes in the course	Knowledge – knowledge resulting from the course: - describe the different types of power electronic converters; - analyze power electronic circuits; - explain the operation of the power converter; - explain the voltage and current waveforms of the different converters for various controls and various types of loads. Skills – skills resulting from the course: - assess the usability of power electronic converters for practical use; - perform measurement of power converters; - connect the power converters to the circuit.
Study literature	1) Vondrášek, František. Výkonová elektronika. Sv. II, Měniče s vnější komutací. 2. vyd. Plzeň :Západočeská univerzita, 2001. ISBN 80-7082-695-9. 2) Vondrášek, František. Výkonová elektronika. Sv. 1, Přehled výkonových polovodičových součástek.1.vyd. Plzeň : Západočeská univerzita, 2001. ISBN 80-7082-136-1.

	3) Vondrášek, František; Glasberger, Tomáš,; Fořt, Jiří,; Jára, Martin. Výkonová elektronika. Svazek 3.
Daytime study: weekly hours	4.0
lectures	2.0
Practices	2.0
exercises	0.0
Session-based study workload (in a semester):	52.0
lectures	26.0
practices	26.0
exercises	0.0
Content of lectures	1) The basic devices of the power electronics, the real characteristics of the power semiconductor components, the special power components (SiC, GaN, etc.). 2) DC/DC converters and their control (hysteresis, PWM, etc.), output current ripple, two-quadrant topology (current and voltage reversal), four-quadrant topology. 3) Voltage inverters, single-phase inverter with rectangular control, three-phase inverter with rectangular control. 4) Voltage Inverters, three-phase Inverter with Pulse Width Modulation, single-phase Inverter with Pulse Width Modulation. 5) Rectifiers with external commutation, single-phase full-wave and half-wave bridge rectifier, three-phase full-wave and half-wave bridge rectifier. 6) Rectifiers with external commutation, real commutation of the rectifier, control properties of rectifiers. 7) Voltage-source active rectifier, single-phase and three-phase topology, principle of operation. 8) Indirect frequency inverters with voltage DC link, motor / generator mode (different variants of input rectifier in generator mode), capacitor pre-charging, influence on power grid, etc. 9) Current inverters, topology, principle of operation, commutation of current converters, reactive and active power. 10) Frequency converters, indirect frequency converters with current DC link, Direct frequency converters with self commutation -matrix converters, single-phase and three-phase topology, principle of operation. 11) AC power switches and voltage converters (softstarters), principle of operation, control range, voltage and current waveforms. 12) Resonant converters, basic topology, principle of operation, method of their control. 13) Application of power converters in industrial.

1.3.2 Master studies

Course code	KEV/VEL2
Course title in English	Power electronics 2
ECTS credits	5.0
Assessment form	Combined examination
Teaching semester	Autumn
Guarantor	Doc. Ing. Tomáš Glasberger, Ph.D.

Lecturer	Doc. Ing. Tomáš Glasberger, Ph.D., Ing. Martin Jára, Ph.D., Doc. Ing. Martin Pittermann,Ph.D.
Tutorial lecturer	Doc. Ing. Tomáš Glasberger, Ph.D., Ing. Zdeněk Kehl, Ing. Pavel Krýsl (100%), Ing. JanMichalík, Ph.D.
Course aims	The aim of the subject is to deepen the knowledge in the area of power semiconductor converters. Students will get knowledgefrom advanced topologies of the power semiconductor converters, particularly from serial or parallel connection point of view,advanced control methods of voltage source inverters, multilevel converters, current source converters and resonant converters.Students will be able to design components of input and output filters of the converters. Furthermore, they will get detailedknowledge in the area of analysis and design of semiconductor converters and will be able to use advanced control algorithms forcontrol of converters in complex ac and dc drives respectively.
Learning outcomes in the course	Knowledge – knowledge resulting from the course: - to describe scheme and function of voltage and current source converters in detail; - to describe scheme and function of parallel connected converters, particulary rectifiers and buck converters; - to describe advanced converters control methods; - to describe design of basic component of filters for power semiconductor converters. Skills – skills resulting from the course: - to use known converter topologies for proposal of new power circuit; - to use advanced control algorithms; - to design simulation model including control algorithms; - to evaluate experimental or simulation results properly.
Study literature	1) Vondrášek František. Výkonová elektronika. Svazek 3, Měniče s vlastní komutací a bez komutace.Část 1, Pulsní měniče. Plzeň, 2012. ISBN 978-80-261-0143-7. 2) Vondrášek František. Výkonová elektronika. Svazek 3, Měniče s vlastní komutací a bez komutace.Část 2, Měniče kmitočtu a střídavého napětí. Plzeň, 2017. ISBN 978-80-261-0688-3.
Daytime study: weekly hours	5.0
lectures	3.0
practices	2.0
exercises	0.0
Session-based study workload (in a semester):	65.0
lectures	45.0
practices	20.0
exercises	0.0
Content of lectures	1) Buck converters - multiquadrant, parallel and serial connections. 2) Buck converters - design of input filter. 3) Voltage source inverters and active rectifiers - advanced control algorithms.

	4) Voltage source inverters and active rectifiers - design of input and output filte, synchronisation algorithms. 5) Multilevel converters - NPC, FLC,, advanced control algorithms, voltage balancing problematics. 6) Multilevel converters - CHB, NPP, advanced control algorithms, voltage balancing problematics. 7) Current source inverters. 8) Current source active rectifier. 9) Direct frequency converters, cycloconverters. 10) Serial and parallel connection of rectifiers. 12) Resonant converters. 13) Resonant converters.

1.4 University of Applied Science Mittelhessen (THM)

1.4.1 Bachelor studies

Course title in English	Power Electronics
ECTS credits	7.0
Assessment form	Examination
Teaching semester	4th – 6th semester (autumn/1 semster)
Lecturer	Prof. Dr. Probst
Learning outcomes in the course	Professional Skills: The students can… - name the basic components of power electronics; - name, explain and visualise basic circuits for rectifiers, DC changers and inverters; - design control circuits. Methodical Skills: The students can… - building components; explain the structure and function of power semiconductors; - Rectifier, DC/DC converter, DC/AC converter; calculate the steady-state output variables of rectifiers and inverters; - select suitable power components; - design and configure the control of the respective circuit topology; - apply and understand control characteristics; - calculate losses; - design the required heat sinks for stationary operation. Social Skills: The students can… - explain exercises to each other and prepare time curves of the most important input and output variables together; - present and discuss the results of the laboratory experiments; Self-competence: The students can… - independently follow up and deepen the contents of the script developed in the lecture; - prepare summaries, e.g. collections of formulas, and prepare for the laboratory experiments in a targeted manner;

	- use the available applets to reflect on learning progress and adapt learning behavior or strategies if necessary.
Brief description of the course	Power Electronics: Power electronic devices, Rectifier, DC/DC Converter, DC/AC Converter.
Study literature	1) Probst, U.: Leistungselektronik für Bachelors; 4. Auflage Carl Hanser Verlag 2020. 2) Virtual Laboratory: https://homepages.thm.de/~hg13555/Datenbank/lei/index.php/
Daytime study: weekly hours	6.0
lectures	3.0
Practices	1.0
Practical experiments	2.0
Session-based study workload (in a semester):	210.0
lectures	48.0
practices	32.0
exercises	16.0
self-learning	114.0
Content of lectures	1) Power components. Diode, Thyristor, bip Trans., MOS-FET, IGBT. 2) Rectifier circuits. Line-commutated converters M1, M2, M3, B6. Circuit analysis. 3) DC/DC converter. Buck converter. Boost converter. Two-quadrant controller. Four-quadrant controller. 4) DC/AC converter. Single-phase voltage impressing half-bridge and full-bridge inverter. Three-phase voltage impressing two-point inverter. 5) Heating and Cooling. Calculation of the power loss. Cooling system design.

1.4.2 Master studies

Course title in English	Circuit simulation using the example of power electronics
ECTS credits	5.0
Assessment form	Examination
Teaching semester	autumn
Lecturer	Prof. Dr. Probst
Learning outcomes in the course	Knowledge: Application of basic circuits for state of the art topologies. New devices and modulation techniques. Convert important circuits into simulation models using SIMPLORER, perform investigations. Skills: Understand the operation of important modern circuit topologies. Explain structure and operation of conduction semiconductors; principles and advantages of unloaded switching. New Power Devices Competencies: Being able to select and use the most suitable circuit for the respective task in a well-founded manner. Be able to interpret calculation and measurement results regarding their technical significance.

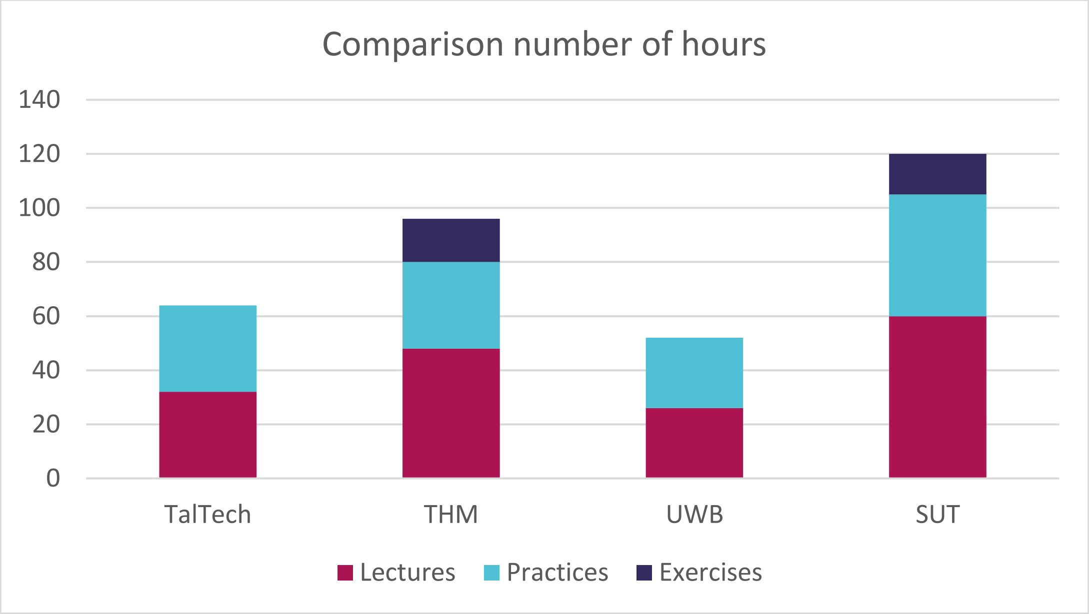
Brief description of the course	Power Electronics: Power electronic devices, Rectifier, DC/DC Converter, DC/AC Converter.
Study literature	1) Probst, U.: Leistungselektronik für Bachelors. 2) NN: Applikationshandbuch Leistungshalbleiter, Semikron GmbH. 3) Mohand, Undeland et. al.: Power Electronics; Wiley & Sons.
Daytime study: weekly hours	4.0
lectures	4.0
Practices	0.0
Practical experiments	0.0
Session-based study workload (in a semester):	64.0
lectures	64.0
practices	0.0
practical experiments	0.0
self-learning	86.0
Content of lectures	1) Modulation methods (space vector et. al.). 2) Power factor correction. 3) New converter types (multipoint converters, active front end converters). 4) Unloaded switching, resonant switching. 5) Primary switched mode power supplies. 6) SiC devices.

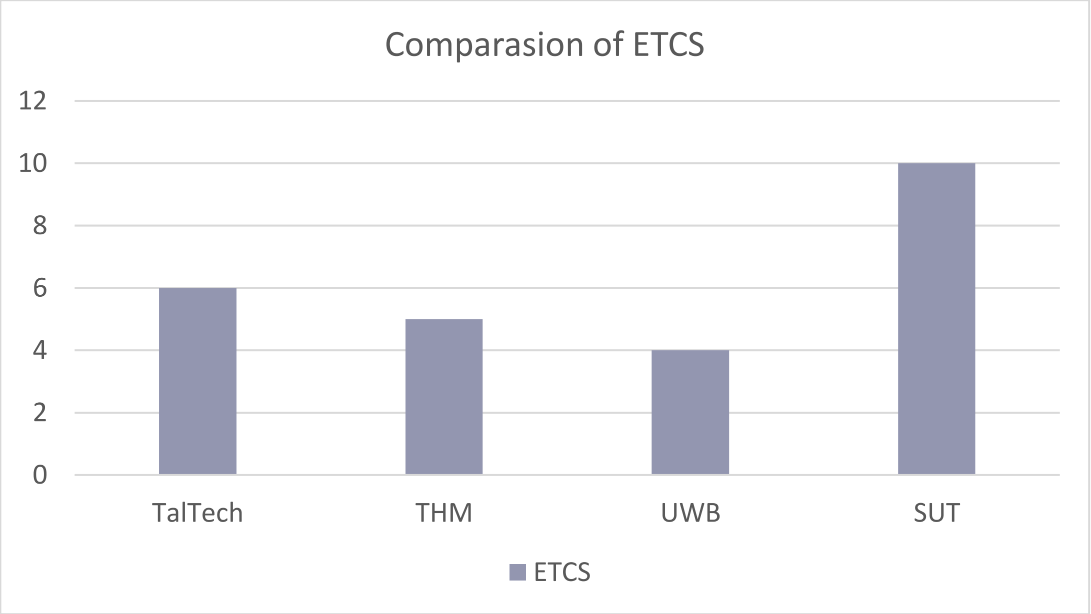
2 Comparison of power electronics curricula

2.1 Bachelor studies

Comparison of the courses consists of two parts: the first part shows the difference between the workload of the courses (in the hours in a semester); the second part presents similar topics in electrical drives courses between universities and topics are special in each program.

	TalTech	THM	UWB	SUT
Number of hours in semester	64	96	52	120
lectures	32	48	26	60
practices	32	32	26	45
exercises	0	16	0	15
ETCS credits	6	5	4	10





As seen from the graphs the bigger value of the study hours in the SUT, the smaller the UWB. Only THM and SUT have study hours for exercises. Study hours in TalTech and UWB are similar. Study hours for practices are similar between universities. This depends on UWB having two courses for electrical drives for bachelor's studies.

The ETCS is almost identical between universities, the average value is 6,25.

Topics

	TalTech	THM	UWB	SUT
Introduction to power electronics	●	●	●	●
Components of the power electronics	●	●	●	●
Converter design	●	●	●	●
DC/DC converters	●	●	●	●
AC/DC converters	●	●	●	●
Special types of AC drives	●	●	●	●
Protection of electrical drives	●	●	●	●
Current inverters				
Frequency converter	●		●	
Resonant converters			●	
Application of power converters in industrial			●	
AC switches and voltage converters			●	
Control of converters	●			
DC/AC converters	●	●		●
Thermal issues		●		●
Multilevel converters				●
Diode rectifiers with RL filter				●
Six-pulse thyristor rectifier				●
AC/AC converters				●

Based on the comparison of topics between universities, possibly to make the next conclusion:

1. The common topics between universities are introduction to power electronics; components of the power electronics; converter design; DC/DC converters; AC/DC converters; special types of AC drives; protection of electrical drives.

2. In TalTech additional tech control of converters.

3. In UWB additional teach resonant converters; application of power converters in industrial; AC switches and voltage converters.

4. In SUT additional teach multilevel converters; diode rectifiers with RL filter; six-pulse thyristor rectifier; AC/AC converters.

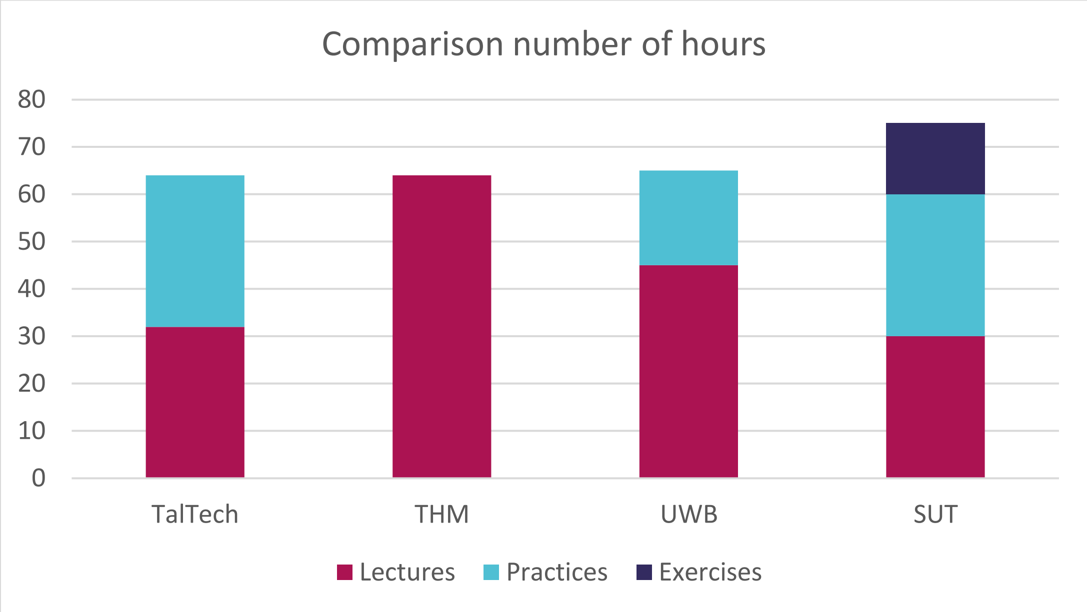
5. The common topic in TalTech and UWB is the frequency converter.

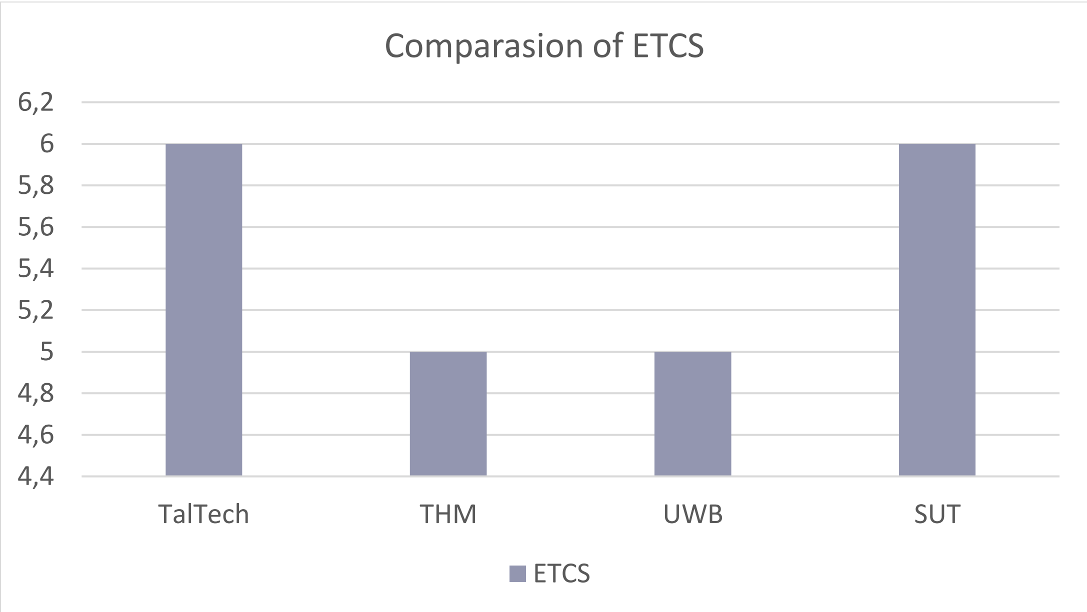
6. The common topic in TalTech, THM, and SUT is DC/AC converters.

7. The common topic in THM and SUT is thermal issues.

2.2 Master studies

	TalTech	THM	UWB	SUT
Workload:	64	64	65	75
lectures	32	64	45	30
practices	32	0	20	30
exercises	0	0	0	15
ETCS credits	6	5	5	6





As seen from the graphs the number of study hours is similar between universities. However, in THM course for master's studies in power electronics consist of only lectures. SUT has study hours for exercises. The number of lecture hours in TalTech and SUT is the same.

The ETCS in TalTech and SUT are the same. The ETCS in THM and UWB are the same. The average value is 5,5.

Topics

	TalTech	THM	UWB	SUT
Components of power electronics.	•	•	•	•
Trends in power electronics.	•	•	•	•
Loses in converters and thermal design.	•	•	•	•
Modulation methods.	•	•	•	•
Control system design.	•	•	•	•
Introduction to system stability and Control.	•	•	•	•
Advanced converter topologies.	•	•	•	•
Multi-level converters.	•	•	•	•
Bode plots.	•			
LTI systems.	•			
PFC converters.	•	•		
Unloaded switching, resonant switching.		•		
Primary switched mode power supplies.		•		
Current source inverters/active rectifier.			•	
Resonant converters.			•	•
Comparison between parallel and series resonant transistor or thyristor based converters. Class E inverter.				•
Electromagnetic compatibility in power electronic circuits. Standards, datasheets and application notes.				•

Based on the comparison of topics between universities, possibly to make the next conclusion:

1. The common topics between universities are components of power electronics; trends in power electronics; loses in converters and thermal design; modulation methods; control system design; introduction to system stability and control; advanced converter topologies; multi-level converters.

2. In TalTech additional tech bode plots; LTI systems.

3. In THM additional teach unloaded switching, resonant switching; primary switched mode power supplies.

4.In UWB additional teach current source inverters/active rectifier; resonant converters.

5. In SUT additional teach comparison between parallel and series resonant transistor or thyristor based converters. Class E inverter; electromagnetic compatibility in power electronic circuits. Standards, datasheets and application notes.

6. The common topic in TalTech and THM is the PFC converters.

7. The common topic in UWB and SUT is Resonant converters.

3 Curricula for re-training course for power electronics

Based on the comparison of the course programs of the universities participating in the project, the following course program of power electronics is proposed:

Course title in English	Re-training course for power electronics
ECTS credits	1.25
Assessment form	Examination
Teaching semester	autumn - spring
Course aims	To introduce the students to the essentials of electric drives. Main attention is on explaining construction and operating principles of electric drives used in the industry and infrastructures. To study energy exchange between power supply, electric drive and load machine as well as related electromechanical processes. To explain selection criteria of the drive based on the load and operating conditions with speed and torque control possibilities. To familiarize the students with the user interfaces of modern microprocessor-controlled drives.
Learning outcomes in the course	A student shall acquire: - understanding of energy exchange processes in electric drives; - knowledge of characteristics of different drive types; - skills for selecting the drive according to the application; - knowledge of the control possibilities of electric drives; - knowledge of the sensors used in the drive systems; - skills for choosing protective devices; - skills for reading and composing connection diagrams; - skills for for using different user interfaces.
Brief description of the course	Description and structure of an electric drive. A historical overview. Energy flows in an electric drive. Power and control circuits. Relations to power and micro electronics. Drive mechanics: transmissions and basic movement equations. Translations of the moments of inertia, forces, torques and speeds. Load types and calculation examples. Standardized duty types. Motor power selection. Connection diagrams and schematic elements. DC drives characteristics and equations. Rheostat control of DC drives. DC drives with power converter. Pulse control of DC drives. AC asynchronous drives electromechanical characteristics. Starting of asynchronous drives. Soft starters. Asynchronous motor models. Principle of frequency control. Energy flows in frequency controlled drives. Use of frequency converters with different loads. Synchronous and servo drives. Basics of vector control. Stepper motor drives. Drives in electric transportation. Protection and control of electric drives. Sensors in electric drives. User interfaces. Electromagnetic compatibility in electrical drives.
Session-based study workload (in a semester):	64.0
lectures	32.0
practices	32.0
exercises	0.0
Content of lectures	1) Introduction to Power Electronics.

	2) Components of The Power Electronics. The basic devices of the power electronics the real characteristics of the diode, thyristor, bip transistor. 3) Converter Design. Voltage inverters, rectifiers, filters. 4) DC/DC Converters. Buck converter. Boost converter. Two-quadrant controller. Four-quadrant controller. 5) AC/DC Converters. Basic topology, principle operation. 6) DC/AC Converters. Single-phase voltage impressing half-bridge and full-bridge inverter. 7) Control of Converters. 8) Loses in converters and thermal design. 9) Modulation methods. 10) Advanced converter topologies.

4 Conclusion

Based on the provided outputs, it can be concluded that there are several common topics among universities in the field of power electronics. These shared topics include the introduction to power electronics, components of power electronics, trends in power electronics, losses in converters and thermal design, modulation methods, control system design, introduction to system stability and control, advanced converter topologies, and multi-level converters. These topics form the foundation of knowledge in power electronics across different institutions.

However, each university also offers additional teachings that focus on specific aspects within the field. TalTech emphasizes the control of converters, providing students with in-depth knowledge of control techniques applied to power electronic converters. UWB expands the curriculum by teaching resonant converters, the application of power converters in industrial settings, and AC switches and voltage converters, catering to specific applications and industrial requirements. SUT offers teachings on multilevel converters, diode rectifiers with RL filters, six-pulse thyristor rectifiers, and AC/AC converters, providing students with a comprehensive understanding of various converter types and their applications.

Additionally, there are several common topics that emerge between universities. TalTech and UWB share a common topic in the frequency converter, indicating the significance of this type of converter in power electronics. TalTech, THM, and SUT share a common topic in DC/AC converters, highlighting the importance of understanding the conversion between direct current and alternating current. THM and SUT share a common topic in thermal issues, indicating the shared emphasis on addressing and managing thermal challenges in power electronic systems.

Overall, the combination of common foundational topics and specialized teachings in specific areas ensures that students receive a comprehensive education in power electronics. This diverse curriculum equips them with the necessary knowledge and skills to tackle various challenges and advancements in the field. The collaboration between universities in covering common topics also promotes a cohesive understanding and fosters exchange of ideas and expertise in the realm of power electronics.