Retraining of Fossil Fuel Mining Area Workforce for Modern Industry REMARKER

Project Results

Output 1: Re-training Course for Electrical Drives

Contents

Description

Electrical drives play a critical role in electromechanical energy conversions. They are seen everywhere in our daily life, from the cooling fans, washing machines to computers. They are the fundamental building blocks in manufacturing, transportation, mineral processing, wind energy, and many other industries. For the last several decades, the advances of electronically switched semiconductors in power electronics have made AC motor drives gain more prominence over the DC machines in industries since they allow a direct connection to power grids via grid-connected power converters and have a more reliable physical structure.

For the objective of re-training, the existing electrical drive courses and materials have to be adjusted in order to meet the needs of the modern automated and robotized mechatronic industry. With the present trend of global industrial automation, the application of electric drive systems (including drive control) is expected to grow rapidly in the next decade. In the automotive sector, the utilization of power electronics and their control to drive electric motors can significantly control environmental pollution. In addition, intensive environmentally clean photovoltaic and wind energy resources also show a bright future.

The main aim of Output 1 is to develop the structure and specification of retraining module supporting pieces of training in the field of electrical drives. The module 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 Electrical Drives

In this section curriculum in the field of Electrical Drives 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 electrical drives is combined with basics of power electronics

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	EEV5040
Course title in Estonian	Tööstusautomaatika ja elektriajamid
Course title in English	Industrial Automation and Drives
ECTS credits	6.0
Assessment form	Examination
Teaching semester	autumn
Lecturer	Anton Rassõlkin; Tarmo Korõtko
Course aims	1. To introduce industrial and building automation technologies, automation, devices programming languages and data communication interfaces and protocols.

	2. To introduce the development, contemporary problems and motor control principles of today's industry. 3. To develop necessary analysis abilities to plan industrial automation, as well as development and implementation skills of industrial automation solutions. 4. To introduce ac machine dynamics modelling and vector models and practical realization of vector control application in industry.
Learning outcomes in the course	The student: - is acquainted with production technologies and industrial technical systems of different industries, including hardware and software resources of industrial automation (pneumatic systems, drives, controllers, SCADA, servers), industrial data communication and standards; - is acquainted with standardized programming languages (IEC 61311-3, IEC 61499, DIN 66312) for industrial controllers and robots; - is acquainted with contemporary problems of electrical drives and dynamics of ac electrical drives, principles of vector control and direct torque control; - knows how to program industrial automation devices, data communication and condition monitoring systems, including implementation of controllers for the control of production processes; - has experience in motor dynamics modelling, including vector control of ac electrical machines and transformation of vector coordinates.
Brief description of the course	Overview of production technologies. Industrial controllers, SCADA systems, data communication systems. Programming languages IEC 61311-3, IEC 61499, DIN 66312. P, PI, PID controllers, Principles of ac electrical machines vector control. Modelling of ac electrical machine dynamics, vector models. Realization of vector control. Transformation of vector coordinates and devices used for that.
Study literature	1. Lecture conspectus 2. Study literature(for distance learning): 3. F. Lamb, Industrial automation: hands-on, New York: bMcGraw-Hill Education, 2013. 4. V. Vodovozov, Electrical Drive: Performance, Design and Control, LAP Lambert Academic Publishing, 2014.
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/EEV5040
Content of lectures	1) Introduction to automation. 2) Introduction to sensor devices; Different types of sensors; Sensing elements; Sensor signals; Signal stability and conditioning.

	3) Introduction to actuator devices; Different types of actuators; Actuating elements; Control signals. 4) Introduction to PLC-s; Classification of PLC-s; PLC components; PLC programming languages and standards. 5) PLC programming concepts; PLC regulators; PLC special functionalities. 6) Classification of HMI's; HMI components; HMI design. 7) Advanced SCADA systems; Industrial communication networks and protocols; Building automation networks and protocols. 8) Current and future trends in automation systems; Best practices for automation project management. 9) Introduction to electrical drives. 10) Modern concepts of electrical drives. 11) Vector models of AC electrical machines. Transforming vector variables. 12) AC motor parameters estimation. 13) Vector control principles of AC induction and synchronous motors. 14) Sensorless control of electrical drives. Model predictive control of electrical drives. 15) Advanced control strategies of electrical drives (incl. fuzzy logic control, synthetic load). 16) Trends and future development of electrical drive.

1.2 Silesian University of Technology (SUT)

1.2.1 Bachelor studies

Course code	Es1-32-VI
Course title in English	Electric Drives
ECTS credits	4.0
Assessment form	Examination, test
Teaching semester	Spring
Lecturer	Michał Jelen, Ph.D.
Course aims	Student has obtained the knowledge on: principles and systems of electromechanical energy conversion in drive systems, methods and systems of speed control, measurements of drive systems.
Learning outcomes in the course	Student is able to: - define basics of operation of electrical drives and principles of modelling of drive systems; - know basic power electronic converters used in drive systems and control systems of them; - analyze and make calculations of basic drive systems; - design and choose the elements of basic drive system; - perform measurements of electrical and mechanical quantities of drive system, is able to use the appropriate methods and measuring tools, can make a research report and present the results in numerical and graphical form; - aware of the importance of proper design and operation of electrical drive systems and energy conversion efficiency to the environment.
Study literature	1) Kazmierkowski M. P., Tunia H.: Automatic Control of Converter-Fed Drives. Elsevier, 1994.

	2) Kazmierkowski M. P., Krishnan R., Blaabjerg F.: Control in power electronics : selected problems. Amsterdam : Academic Press, 2002.
Daytime study: weekly hours	4.0
lectures	2.0
Practices	1.0
exercises	1.0
Session-based study workload (in a semester):	60.0
lectures	30.0
practices	15.0
exercises	15.0
Content of lectures	1) Basics. Main components of the controlled electrical drive: motor, driven machine, gearing, control device. Fundamental dynamic equation of the drive system. 2) Transitory states. Stationary operation. Speed/torque diagram, operating quadrants, motor and braking operations. Basic characteristics of electric motors and driven machines. Effective load. 3) DC drives. Mathematical model and characteristic curves of DC motor. Block diagram, dynamical behavior. Armature (voltage) and field control. 4) Speed control of DC motor using a thyristor or transistor converter. Braking operation: regenerative braking, dissipative braking. Control-loop structures of the of the DC power-electronic drives. DC traction. 5) AC drives. Fundamental equations and characteristic curves of 3-phase induction machines. Starting, braking and speed control operations: methods and systems. Behavior of an induction machine under frequency control. Drive systems with induction motor supplied by frequency inverter. 6) Pulse-width modulation (PWM). PWM inverter with U/f control. Behavior of induction motor in field oriented frames of reference. 7) Field–oriented control of induction motor. Direct torque control of induction machine. Speed control of a wound-rotor induction motor. 8) Doubly fed induction machine. Drive systems with 3-phase synchronous motors. Fundamental equations and characteristic curves. Starting and speed control operations. Drive systems with synchronous motor supplied by frequency inverter. 9) Synchronous motor with permanent magnets. Brushless DC machine. Switched reluctance motor (SRM) drives. Principle of operation. Machine topologies. 10) Power converters in the supply systems of SRM motors. Servo drives. Requirements and systems. Induction and synchronous servo motors. Servo inverters. The levels of servo drives control: drive control and motion control.

1.2.2 Master studies

Course code	Es2-06-I
Course title in English	Dynamic of Drive Systems
ECTS credits	4.0
Assessment form	Examination

Teaching semester	Spring
Lecturer	Jarosław Michalak, Ph.D.
Course aims	Student has obtained the knowledge on: mathematical description and modeling of drives systems, control methods and control systems for power electronics drive systems, identification methods of machine parameters, using simulation programs for modeling the drive systems.
Learning outcomes in the course	Student is able to: - know models and mathematic equations describing the DC and AC drive system elements: control system, power electronic converter, motor and load. Student knows simulation programs for modeling the drive systems; - know control systems and control methods for complex drive systems; - collect and use knowledge in mechanics, electrotechnics, power electronics and automatics to form goals and tasks during designing the control system for the drives; - assess the suitability of analytical methods and models to solve problems related to simulation and control of complex drive systems; - design complex drive systems and its control taking into account the assumed criteria; - plan, prepare and carry out laboratory experiment and draw up a tests report; - generalize knowledge and apply it to solve new problems.
Study literature	1) Kazmierkowski M. P., Tunia H.: Automatic Control of Converter-Fed Drives. Elsevier, 1994. 2) Kazmierkowski M. P., Krishnan R., Blaabjerg F.: Control in power electronics : selected problems. Amsterdam : Academic Press, 2002. 3) Vas P.: Sensorless Vector and Direct Torque Control. Oxford University Press, 1998. 4) Nyugen Phung Quang, Jorg Andreas Dittrich: Vector Control of Three-Phase AC Machines. Springer-Verlag Berlin Heidenberg 2015. 5) Krause P. C., Wasylczuk O., Sudhoff S. D.: Analysis of Electric Machinery and Drive Systems. Wiley-IEEE Press, 2 edition, 2002.
Daytime study: weekly hours	 4.0
lectures	2.0
Practices	2.0
exercises	0.0
Session-based study workload (in a semester):	 60.0
lectures	30.0
practices	30.0
exercises	0.0
Content of lectures	1) Electric drive system as electromechanical system. Mechanical joints in drives systems: stiff joints and elastic joints. Mechanical equations describing the drive systems, operation in steady state and during transients. Operation of drive systems during electromechanical transients. 2) Control systems in electrical drives. Criteria and methods for rating the control quality. Dynamic properties correction in controlled drive

	systems. Methods (criteria) for designing the control system and controller tuning. Serial and parallel connection of controllers in control system. Typical cascade control system for drive with inner control loops. Role of limits in control systems. 3) Mathematical models and dynamic properties of the separately excited DC motor - nonlinear and linear model and linear of motor, block diagrams, transfer functions, dynamic response. Start up and dynamics of the DC motor. Separately excited DC motor supplied power electronic converters - diagrams, characteristics, properties. The mathematical model of power electronic converter. Model of drive system consist of the DC motor and converter for continuous and discontinuous conduction. Structures of control systems drives with the separately excited DC motor. 4) The use of space vectors for the analysis of electromechanical systems. Model of induction machine. Per unit equations describing asynchronous induction motor in a coordinate system rotating at any speed. Coordinate systems: stationary □,□, associated with the rotor d,q and synchronous x, y. Model of induction machine in field-oriented synchronous coordinate system x, y, 0 and its implications for methods of frequency control of induction motor. The identification methods of parameters of the drive. Simulators and observers for estimation fluxes and speed in induction motors. 5) Voltage source inverters with pulse width modulation (PWM) – pulse width modulation methods. Principles of frequency control of induction motors: minimal power losses control, constant flux control. Methods for ensuring constant flux in scalar and vector control of induction motor. Drive systems with scalar (voltage-frequency) control. Flux-oriented control (vector control) of induction motors: rotor and stator field-oriented control (FOC) and the direct torque control (DTC) methods. 6) Synchronous motor drive systems. Mathematical model of the synchronous motor. External and internal frequency control methods of synchronous motors. Field-oriented control of a synchronous motor. Permanent magnet synchronous motors (PMSM) - construction, basic properties, mathematical model. Control systems, drive properties, applications. Drives with DC brushless motor - features and control systems. 7) The influence of drive systems on power network. The power factor coefficient and high current harmonics generation caused by power electronic converter based drives. Methods of reduction of the reactive power consumption and current harmonic in power electronic converter based drives. Active front-end converters. Passive active power filters. 8) Using the computer simulation programs for investigation the dynamics and operation of drive systems.

1.3 University of West Bohemia (UWB)

1.3.1 Bachelor studies

In UWB basics of electrical drives consist of two courses “Electrical Drives”, “Electrical Drives and Power Electronics”.

Electrical Drive

Course code	KEV/ELP
Course title in English	Electric Drives
ECTS credits	4.0
Assessment form	Combined, test, examination, individual presentation at semester
Teaching semester	Spring
Guarantor	Ing. Jiří Cibulka, Ph.D.
Lecturer	Ing. Jiří Cibulka, Ph.D., Prof. Ing. Zdeněk Peroutka, Ph.D.
Tutorial lecturer	Ing. Jiří Fořt, Ph.D., Ing. Štěpán Janouš, Ph.D., Doc. Ing. Martin Pittermann, Ph.D.)
Course aims	Knowledge enhancing of modern electric drives (motors fed by semiconductor converters controlled with microprocessor) used inindustry, energetics and traction applications.
Learning outcomes in the course	Knowledge – knowledge resulting from the course: - to be able to explain a basic principle of regulation of DC motors, induction motors and synchronous motors. Skills – skills resulting from the course: - to be capable of both to analyze typical transient states appearing during the regulation of DC motors, induction motors andsynchronous motors and to explain the cause of their occurrence
Study literature	1) Pavelka, Jiří; Javůrek, Jiří; Čeřovský, Zdeněk. Elektrické pohony. Praha : Vydavatelství ČVUT, 2001.ISBN 80-01-02314-1. 2) Piskač, Luděk. Elektrické pohony : principy a funkce. 2., upr. vyd. Plzeň : Západočeská univerzita,2008. 3) Zeman, Karel. Studijní texty na počítačové síti.
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) Power circuit of drives with DC motor supplied from AC power grid and from DC overhead line. Steady states and selected transient states. 2) Regulation algorithms of DC drives with torque control in the field of traction applications and with speed control and rotation angel control in the field of industry applications and energetics. 3) Mathematical models of power circuits and regulation algorithms of DC drives. Synthesis of regulation algorithm parameters.Computer simulation. 4) Power circuit of drives with either induction or synchronous motors fed from AC power grid and from an overhead line. Steady states and selected transient states. 5) Scalar control of drives with induction motor. Regulation algorithms without a speed sensor and strategy of the current limitation.

	Regulation algorithms with feedback from a speed sensor used in industry and traction applications. 6) Principal diagrams of a vector control and a direct torque control of induction motors, description of an operation in steady states and selected transient states. 7) Regulated drives with a synchronous motor. Theoretical judgement of speed regulation possibilities. Relation between change of the stator frequency and a load angle, issue of pulling out of synchronism. 8) Regulation algorithms of drives with a synchronous motor used in industry and traction applications. Principle of a vector control, issue of a flux weakening in case of the permanent magnet synchronous machine. 9) The Brushless DC motor. The principle of an operation in comparison with a vector controlled synchronous machine and the conventional DC motor. The principal diagram of regulation algorithms, description of an operation in a driving and braking mode. 10) and 11) Drives with switched reluctance and synchronous reluctance motors, linear motors and stepping motors – basic principle of their operation. 12) Basic principle of a real time microprocessor drive's control, discrete digital equivalent of the continuous PI controller. 13) Power rating of drives and converters, methods of determination of their nominal powers.

Electrical Drives and Power Electronics

Course code	KEV/PVEL
Course title in English	Electrical Drives and Power Electronics
ECTS credits	5.0
Assessment form	Test, examination
Teaching semester	Spring
Guarantor	Prof. Ing. Václav Kůs, CSc.
Lecturer	Prof. Ing. Václav Kůs, CSc., Doc. Ing. Martin Pittermann, Ph.D.
Tutorial lecturer	Ing. Vojtěch Blahník, Ph.D., Doc. Ing. Pavel Drábek, Ph.D., Ing. Jiří Fořt, Ph.D., Ing. Jan Molnár, Ph.D., Doc. Ing. Martin Pittermann, Ph.D., Ing. Miloš Straka, Ing. Luboš Streit, Ph.D., Ing. Jan Štěpánek, Ph.D., Ing. Martin Zavřel
Course aims	To introduce students with the fundamentals of power electronics and the basics of electric drives. Introduce students to differences from common electronic circuits. To explain basic possibilities of regulation of electric rotary machines and basic principles of their control. Introduce the basics of electromagnetic compatibility of power semiconductor systems.
Learning outcomes in the course	Knowledge - knowledge resulting from the course: - to describe basic types of power semiconductor convertors; - to evaluate requirements for semiconductor converters, motors and their regulation as a whole; - explain the operation of the drive and the drive in different quadrants; - to distinguish the basic control structures of electric drives; - explain the basics of electromagnetic compatibility with regard to power electronics and electric drives;

	- describe torque characteristics of machines for different operating conditions; - explain the voltage and current of the individual inverters for various forms of control and various types of loads; - assess the applicability of power electronic converters for practical use; - to assess the possibilities of using electric drives for basic applications; - recognize scalar and vector control inverters; - to explain basic principles of electric drive control. Skills - skills resulting from the course: - to design the basic parameters of the inverter for practical use; - to determine the basic parameters of the rotating machine with regard to the practical application; - to analyze basic power electronic circuits; - to analyze basic circuits with electric drives; - perform basic measurement of inverters; - perform basic connection with semiconductor converters; - make basic connection of inverters and electric machines together; - to measure the basic characteristics of electric drives.
Study literature	1) Kůs, Václav. Elektrické pohony a výkonová elektronika. Druhé vydání. 2016. ISBN 978-80-261-0639-5. 2) Pavel Kobrle; Jiří Pavelka. Elektrické pohony a jejich řízení, 3. přepracované vydání. Praha, 2016.ISBN 978-80-01-06007-0. 3) Vondrášek, František; Glasberger, Tomáš,; Fořt, Jiří,; Jára, Martin. Výkonová elektronika. Svazek 3,Měniče s vlastní komutací a bez komutace.. 3., rozšířené vydání. 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	39.0
practices	26.0
exercises	0.0
Content of lectures	1) Types of converters. Basic elements of power electronics. Commutation. Types of loads. 2) Uncontrolled rectifier - circuit, current and voltage waveforms. Controlled rectifier - circuit, current and voltage waveforms. 3) Operating principle of controlled rectifier, load influence on characteristics and behavior of voltage and current. Control characteristic of rectifier, calculation of Udav. Control principles of rectifiers. Reversing rectifiers. 4) Step-down and step-up converters. Resistivity chopper. 5) Inverter - principle, voltage and current inverter and their comparison. Influence of reverse diode in inverter circuit. 6) Control of output voltage of inverters. AC frequency converters - direct, indirect. AC convertor voltage. More quadrant converter.

	7) Power part of electric drive. Partition. Kinematics of el. drive. Formula motion. Motor as a system. Operating principle of rotational electric motors - DC, asynchronous, synchronous motors. 8) Fundamental values and relations of DC motor. Control of DC motor. DC motor power supply. Reversible converter group. 9) Fundamental values and relations of asynchronous motor. Natural characteristic. Steady state behavior Phasor diagram, mathematical model AM. 10) Drive control with asynchronous motor. Start and stops of induction motor. Single phase motors. 11) Electric drives with synchronous motors. Basic control structure of electric drive. Control of current and speed of DC motor. 12) Control structures of drives with asynchronous motors. Scalar control. Vector control. 13) Negative effects of converters to distribution network. Minimization of voltage and current harmonics. Influence of converters to distribution network and motor. Energy balance of electric drive.

1.3.2 Master studies

In UWB advanced of electrical drives consist of two courses “Automatic Control of Electrical Drives”, “Drives and Power Electronics”.

Automatic Control of Electrical Drives

Course code	KEV/ARPO
Course title in English	Automatic Control of Electrical Drives
ECTS credits	6.0
Assessment form	Project, examination
Teaching semester	Autumn
Guarantor	Ing. Jakub Talla, Ph.D.
Lecturer	Prof. Ing. Zdeněk Peroutka, Ph.D., Doc. Ing. Martin Pittermann, Ph.D., Doc. Ing. Václav Šmídl,Ph.D., Ing. Jakub Talla, Ph.D.
Tutorial lecturer	Ing. Štěpán Janouš, Ph.D., Doc. Ing. Martin Pittermann, Ph.D., Doc. Ing. Václav Šmídl,Ph.D., Ing. Jakub Talla, Ph.D.
Course aims	The aim of this course is to provide the students with skills from advanced control of electric drives and power electronics converters. The students will learn how to design the digital control algorithm of drives resistant to noise and parameter/model mismatch, control with optimal efficiency etc.
Learning outcomes in the course	Knowledge - knowledge resulting from the course: - describe mathematically components of electric drives and motors; - design simulation models of power converters and electric drives; - able to analyze the model of electric drives by transfer functions and frequency characteristics; - able to analyze electric drives by state space representation. Skills - skills resulting from the course: - design the control algorithm of electric drives with induction motor; - design the control algorithm of electric drives with synchronous motor; - design the control algorithm of electric drives with BLDC motor;

	- design the control algorithm of electric drives with synchronous and switched reluctance motor; - design the outer control loop of electric drive; - analyze a signal spectra and design basic digital filters.
Study literature	1) Zeman, Karel; Peroutka, Zdeněk; Janda, Martin. Automatická regulace pohonů s asynchronnímimotory. 1. vyd. Plzeň : Západočeská univerzita, 2004. ISBN 80-7043-350-7. 2) Toliyat, Hamid A.; Campbell, Steven. DSP-Based electromechanical motion control. Boca Raton :CRC Press, 2004. ISBN 0-8493-1918-8.
Daytime study: weekly hours	6.0
lectures	4.0
practices	2.0
exercises	0.0
Session-based study workload (in a semester):	113.0
lectures	52.0
practices	26.0
exercises	0.0
team project	25.0
presentation	10.0
Content of lectures	1) Digital control of electric drives based on frequency analyses and PID control. 2) Digital signal processing in electric drives. 3) Finite control set model predictive control. 4) State space control of drives. 5) Identification of drive parameters and states. 6) Linear Kalman filter and extended Kalman filter. 7) Control and identification algorithms of electric drives with induction motors. 8) Control and identification algorithms of electric drives with synchronous motors. 9) Control and identification algorithms of electric drives with BLDC, synchronous and switched reluctance motors. 10) High power electric drives and other special drives. 11) The master control loop of the drives 1. 12) The master control loop of the drives 2. 13) Artificial intelligence and other new trends in electric drives control.

Drives and Power Electronics

Course code	KEV/PVE2
Course title in English	Drives and Power Electronics 2
ECTS credits	5.0
Assessment form	Test, examination
Teaching semester	Autumn
Guarantor	Prof. Ing. Zdeněk Peroutka, Ph.D.
Lecturer	Ing. Jiří Cibulka, Ph.D., Doc. Ing. Tomáš Glasberger, Ph.D., Ing. Martin Jára, Ph.D., Prof. Ing. Zdeněk Peroutka, Ph.D., Ing. Jakub Talla, Ph.D.
Tutorial lecturer	Ing. Bedřich Bednář, Ph.D., Ing. Vojtěch Blahník, Ph.D., Ing. Jiří Cibulka, Ph.D.,Ing. Jiří Fořt, Ph.D., Ing. Antonín Glac, Doc. Ing. Tomáš

	Glasberger, Ph.D., Ing.Martin Janda, Ph.D., Ing. Štěpán Janouš, Ph.D., Ing. Zdeněk Kehl, Doc. Ing. TomášKomrska, Ph.D., Ing. Jiří Očenášek, Prof. Ing. Zdeněk Peroutka, Ph.D., Doc. Ing.Martin Pittermann, Ph.D., Ing. Luboš Streit, Ph.D.
Course aims	The aim of this course is to provide the students with advanced knowledge of the power electronics converters and ac motor drives. The space vector theory and transformations between different refence frames take first part of the course. Second part of the course is dedicated to the detail description of the functionality and control of inverters, active rectifiers, ac/ac converters and multilevel converters. The course also provides the students with the knowledge of resonant converters and soft-switching technology. Third part of the course introduces mathematical models of ac machines and drives which are suitable under both steady-state and transient conditions. The last part presents the advanced control of fundamental types of electrical drives with induction motor and synchronous motors.
Learning outcomes in the course	Knowledge - knowledge resulting from the course: - describe in detail the functionality of inverters, active rectifiers, ac/ac converters and multilevel converters and explain their control; - describe the control of induction machine drives; - describe the control of synchronous machine drives; - utilize advanced control strategies of power electronics converters and ac motor drives; - design simulation models of power electronics converters and electric drives. Skills - skills resulting from the course: - describe and design control of inverters, active rectifiers, ac/ac converters and multilevel converters; - design the control of induction machine drives; - design the control of synchronous machine drives; - utilize simulation models and simulate the behaviour of power electronics converters and electric drives under both steady-state and transient conditions.
Study literature	1) Zeman K., Peroutka Z., Janda M. Automatická regulace pohonů s asynchronními motory. ZČU Plzeň,2004. 2) Trzynadlowski, Andrzej M. Control of induction motors. San Diego : Academic Press, 2001. ISBN 0-12-701510-8. 3) Vas, P. Sensorless Vector and Direct Torque Control.. Oxford University Press, New York,, 1998. 4) Vondrášek, František; Glasberger, Tomáš,; Fořt, Jiří,; Jára, Martin. Výkonová elektronika. Svazek 3,Měniče s vlastní komutací a bez komutace.. 3., rozšířené vydání. 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	39.0

practices	26.0
exercises	0.0
Content of lectures	1) Space vector theory and transforms. 2) Voltage-source inverters and their control - mainly carrier-based PWM and space-vector PWM. 3) Voltage-source active rectifiers and their control - mainly control strategies in different reference frames. 4) AC/AC converters - indirect and direct (matrix) converters. 5) Resonant converters - soft-switching theory, fundamental power circuit configuraitons of resonant converters. 6) Multilevel converters - part I - T-converter, NPC, ANPC. 7) Multilevel converters - part II - FLC, cascaded converters and special topologies. 8) General ac machine theory, induction machine models (including models necessary for IM drive control). 9) Control of induction motor drives - part I - mainly FOC. 10) Control of induction motor drives - part II - mainly DSC, DTC. 11) Models of synchronous machines - model of general synchronous motor and description of the model for particular types of synchronous motors. 12) Control of synchronous motor drives - mainly FOC and optimal drive control. 13) Advanced control of power electronics converters and ac motor drives.

1.4 University of Applied Science Mittelhessen (THM)

1.4.1 Bachelor studies

Course title in English	Control of electrical Drives / Electronical drive engineering
ECTS credits	7.0
Assessment form	Examination
Teaching semester	spring
Lecturer	Prof. Dr. Probst
Learning outcomes in the course	Professional Skills: The students can... - Draw the structure of converter-fed DC and three-phase drives; - Name control methods of electronic drives depending on the machine type and desired speed setting range and represent them with characteristic curves. Methodical Skills: The students can... - DC- and AC-drives; - Draw signal flow diagrams and describe them with transfer functions; - Design and calculate associated control loops on the basis of the signal flow diagrams; - Select and dimension suitable sensors. Social Skills: The students can...

	- Explain exercise tasks to each other and jointly create simulation models of the drives and evaluate simulation results; - Present and discuss the results of 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	Control of electrical Drives: DC and AC drives, current sensors, encoders for speed and position.
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	2.0
exercises	1.0
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) Design of converter-fed DC and three-phase drives. 2) Building blocks of an electronically controlled drive. 3) Converters of modern drive technology. 4) Typical drive and load characteristics. 5) Electromagnetic, mechanical and thermal time constants. 6) Stability considerations. 7) Structure and design of the control loops. 8) Signal flow diagram of a GS machine. 9) Anchor and field control. 10) Typical control structures. 11) Two-axis theory of DS machines. 12) Pole wheel-oriented control of permanently excited synchronous machines.

1.4.2 Master studies

Course title in English	Multi Body Simulation
ECTS credits	5.0
Assessment form	Exam with practical part
Teaching semester	autumn
Lecturer	Invited lecturers
Learning outcomes in the course	Qualification goals and intended learning outcomes: The students…

	- master methods and strategies for the discrete and numerical analysis of motion engineering problems and can integrate these into the development and design of technical systems and products; - can numerically calculate and detail drive engineering analyses on design and machine elements; - can prepare basic decision papers on the acquisition, operation and maintenance of multi-body analysis systems; - are able to carry out the development, design and construction process with the help of multi-body dynamics and to hand over results to the interface partners. Professional Skills: The students… - are able to work on and solve a transmission/drive technology problem using the specialist competence acquired during the course of study. Methodical Skills: The students… - are able to carry out a gearbox/drive technology problem numerically and analytically as a multi-body analysis; - possess knowledge, methods and techniques from the sub-fields of machine systems, technical mechanics and machine dynamics and apply them to a concrete application. Social Skills: The students… - can present the results of the project in a seminar and discuss them in an open-minded way, even if they are confronted with different solutions and other sources. Self-competence: The students… - can reflect on the analysis result and their contribution made through theoretical knowledge; - can organise and manage themselves; - can act independently and in a goal-oriented manner.
Brief description of the course	Introduction to computer-aided MBS analysis, definition of multi-body systems and investigation of drive and transmission systems, simulation and calculation accompanying design, written exam with practical part of the task. Computer aided Multi-Body Systems engineering for machine and drive systems, investigation of gears and transmission systems based on commercial MKS-System, requirement management for technical process and development systems for transmission systems, simulation and calculation of transmission and gear systems, Exam with graphical test
Daytime study: weekly hours	 4.0
lectures	0.0
practices	2.0

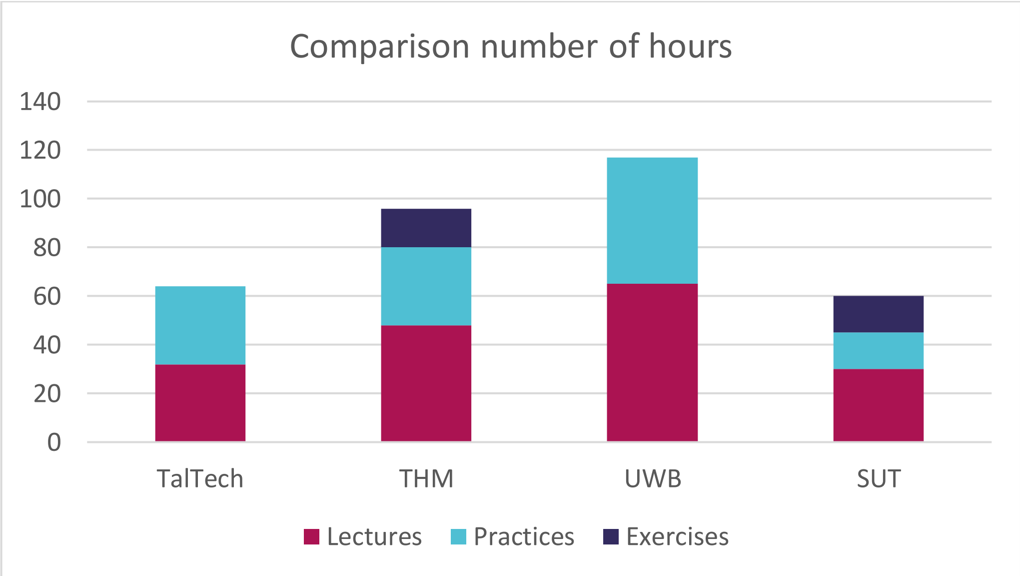
exercises	2.0
Session-based study workload (in a semester):	150.0
lectures	0.0
practices	30.0
exercises	30.0
self-learning	90.0
Content of lectures	1) Multibody systems -mechanisms and gears (definition, poles (velocity, acceleration), degree of freedom, running degree, Grübler equation), joints and joint structures. 2) Concepts of plane kinematics. 3) Coordinate systems and transformation basics. 4) Equations of motion of dynamics. 5) Constraints and joint systems. 6) Spatial systems. 7) Examples for the standardised description of multi-body systems.

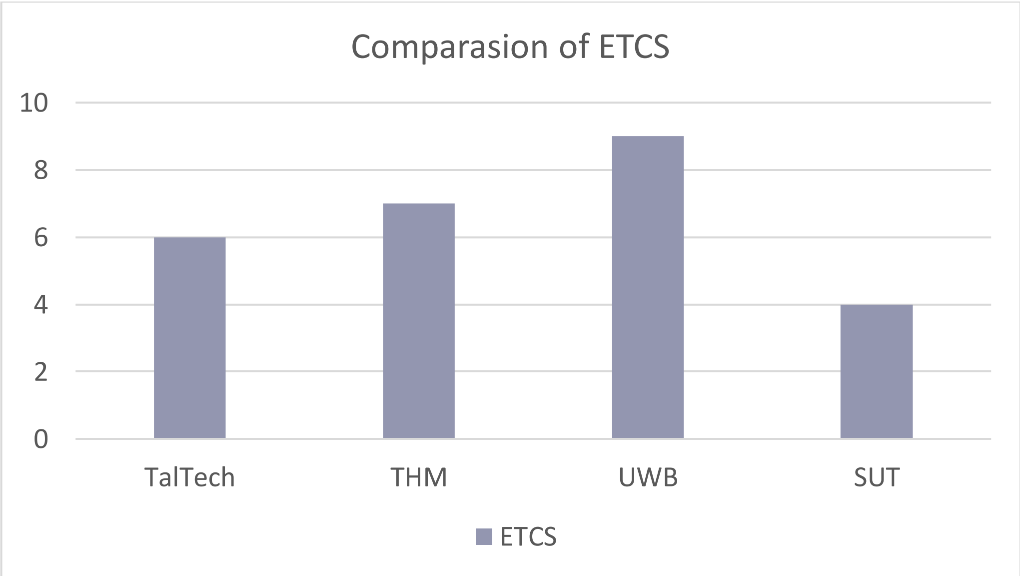
2 Comparison of electrical drives curricula

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	117	60
lectures	32	48	65	30
practices	32	32	52	15
exercises	0	16	0	15
ETCS credits	6	7	9	4

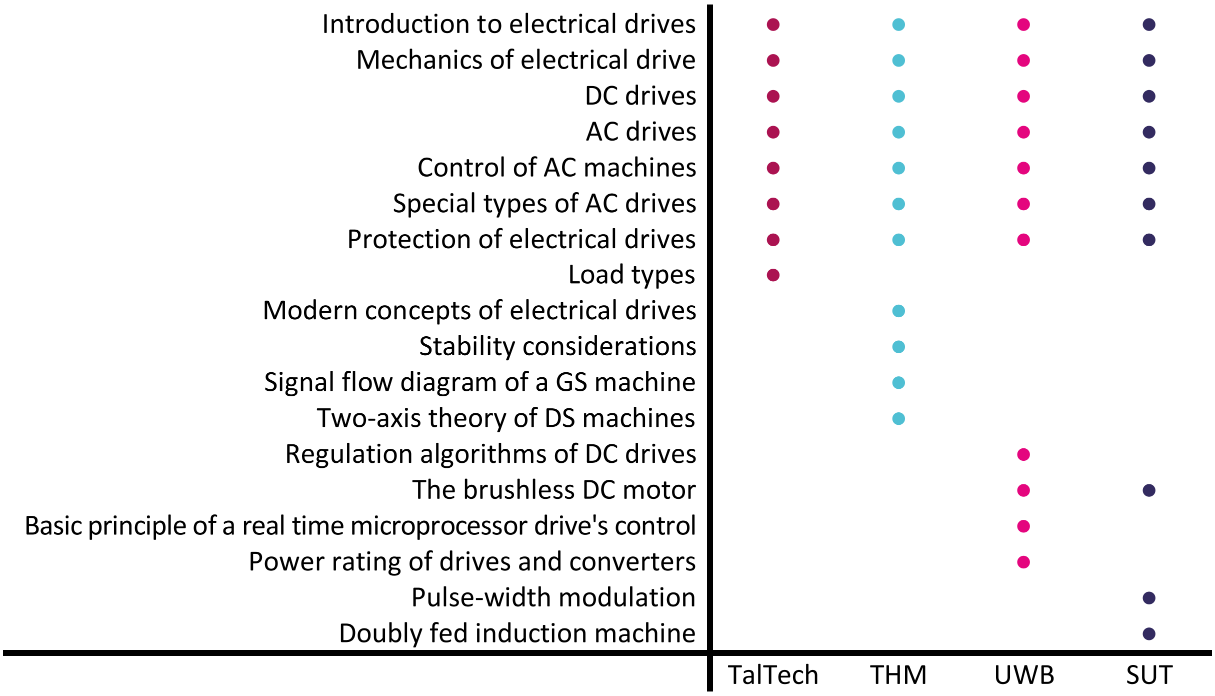




As seen from the graphs the bigger value of the study hours in the UWB, the smaller the SUT. Only THM and SUT have study hours for exercises. The number of lecture hours in TalTech and SUT is similar, however, UWB is bigger two times. Study hours for practices are similar between universities. This depends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

The ETCS is almost identical between universities, the average value is 6,5.

Topics



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

1. The common topics between universities are introduction to electrical drives; mechanics of electrical drive; DC drives; AC drives; control of AC machines; special types of AC drives; protection of electrical drives.

2. In TalTech additional tech load types.

3. In THM additional teach modern concepts of electrical drives; stability considerations; signal flow diagram of a GS machine; two-axis theory of DS machines.

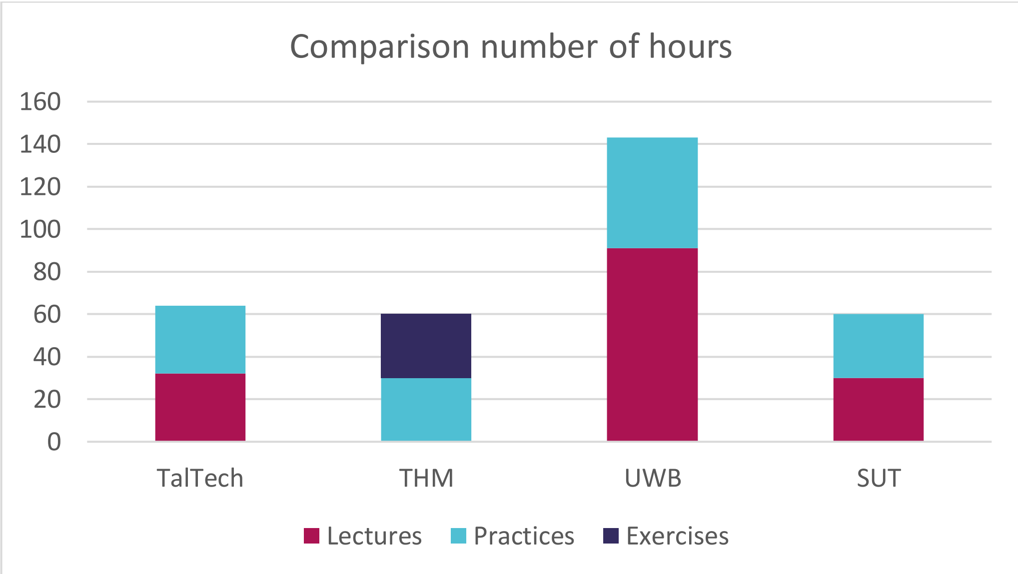
4. In UWB additional teach regulation algorithms of DC drives; basic principle of a real time microprocessor drive's control; power rating of drives and converters.

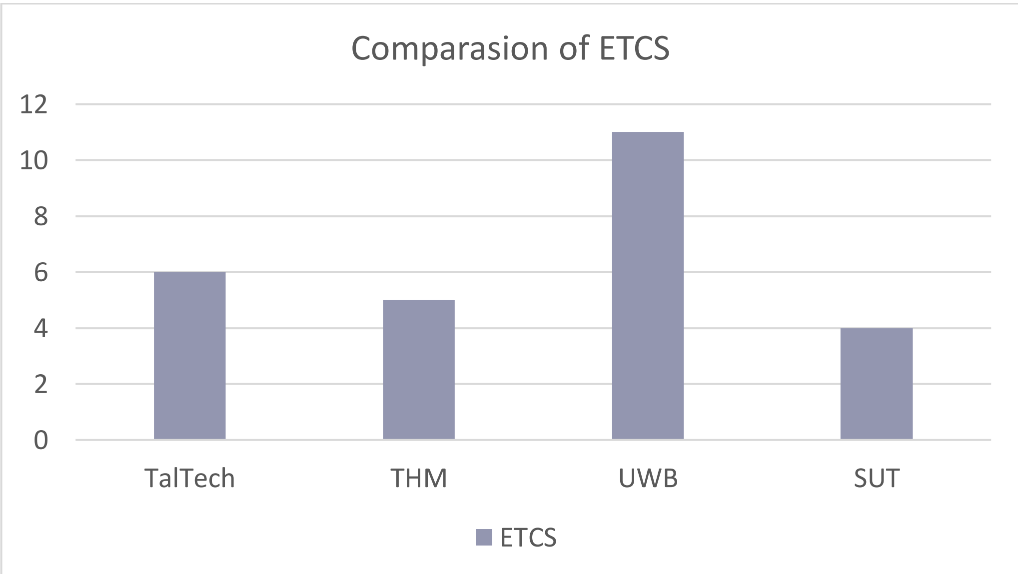
5. In SUT additional teach pulse-width modulation; doubly fed induction machine.

6. The common topic in UWB and SUT is the brushless DC motor.

2.2 Master studies

	TalTech	THM	UWB	SUT
Workload:	64	60	143	60
lectures	32	0	91	30
practices	32	30	52	30
exercises	0	30	0	0
ETCS credits	6	5	11	4





As seen from the graphs the bigger value of the study hours in the UWB, the smaller the SUT. The number of study hours in TalTech and SUT is similar, however, UWB is bigger two times. This depends on UWB having two courses for electrical drives for bachelor's studies. In THM haven't course for master's studies for electrical drives.

The ETCS bigger in UWB, the average value is 7.

Topics

	TalTech	THM	UWB	SUT
Introduction to electrical drives	●		●	●
Vector models of AC electrical machines. Transforming vector variables	●		●	●
Motor parameters estimation	●		●	●
Vector control principles of motors	●		●	●
Model predictive control of electrical drives	●		●	●
Advanced control strategies of electrical drives	●		●	●
Trends and future development of electrical drive	●		●	●
Modern concepts of electrical drives.	●			
Sensorless control of electrical drives	●			
Digital signal processing in electric drives			●	
Structure and design of the control loops			●	
Linear Kalman filter and extended Kalman filter			●	
High power electric drives and other special drives			●	
Models of synchronous machines			●	●
Voltage source inverters with pulse width modulation (PWM)				●
Using the computer simulation programs for investigation the dynamics and operation of drive systems.				●
Multibody systems -mechanisms and gears, joints and joint structures		●		
Examples for the standardised description of multi-body systems		●		

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

1. The common topics between universities are introduction to electrical drives; vector models of AC electrical machines. Transforming vector variables; motor parameters estimation; vector control principles of motors; model predictive control of electrical drives; advanced control strategies of electrical drives; trends and future development of electrical drive.

2. In TalTech additional tech modern concepts of electrical drives; sensorless control of electrical drives.

3. In THM master students have additional exercises and practices about mechanical parts and systems.

4. In UWB additional teach digital signal processing in electric drives; structure and design of the control loops; linear Kalman filter and extended Kalman filter; high power electric drives and other special drives.

5. In SUT additional teach voltage source inverters with pulse width modulation (PWM); using the computer simulation programs for investigation the dynamics and operation of drive systems.

6. The common topic in UWB and SUT is models of synchronous machines.

3 Curricula for re-training course for electrical drives

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 electrical drives
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; - is acquainted with production technologies and industrial technical systems of different industries, including hardware and software resources of industrial automation (pneumatic systems, drives, controllers, SCADA, servers), industrial data communication and standards; - is acquainted with standardized programming languages (IEC 61311-3, IEC 61499, DIN 66312) for industrial controllers and robots; - is acquainted with contemporary problems of electrical drives and dynamics of ac electrical drives, principles of vector control and direct torque control.
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):	32.0
lectures	32.0
practices	0.0
exercises	0.0
Content of lectures	1) Introduction to electrical drives. 2) Mechanics of electrical drive. 3) DC Drives. Brushless DC motor. regulation algorithms. 4) AC drives. Control of AC machines. 6) Special types of AC drives. 7) Protection of electrical drives. 7) Advanced control strategies of electrical drives. 8) Trends and future development of electrical drive.

4 Conclusion

Based on the outputs provided, it can be concluded that there are several common topics shared among universities in the field of electrical drives. These common topics include the introduction to electrical drives, mechanics of electrical drives, DC drives, AC drives, control of AC machines, special types of AC drives, and protection of electrical drives. These foundational areas provide students with a comprehensive understanding of electrical drives across different institutions.

However, each university also offers additional teachings that focus on specific aspects within the field of electrical drives. TalTech introduces modern concepts of electrical drives and sensorless control of electrical drives, providing students with knowledge of the latest advancements in the field. THM offers master students additional exercises and practices related to mechanical parts and systems, emphasizing the practical application and integration of mechanical components in electrical drive systems.

UWB expands the curriculum by teaching digital signal processing in electric drives, the structure and design of control loops, and the application of Kalman filters in drive systems. Additionally, UWB focuses on high power electric drives and other special drives, catering to the specific requirements of these specialized systems. SUT provides teachings on voltage source inverters with pulse width modulation (PWM) and computer simulation programs for investigating the dynamics and operation of drive systems, enabling students to gain practical experience and insights into drive system performance.

Furthermore, there are common topics between UWB and SUT, such as the brushless DC motor in the first set of outputs and models of synchronous machines in the second set of outputs. These shared topics indicate the importance and widespread application of these technologies in the field of electrical drives.

In summary, while there are foundational topics covered by multiple universities, each institution enhances the curriculum by offering additional teachings that focus on specific areas within electrical drives. This approach ensures that students acquire a well-rounded education encompassing both fundamental principles and specialized knowledge, preparing them for various challenges and advancements in the field of electrical drives.