Retraining of Fossil Fuel Mining Area Workforce for Modern Industry REMARKER

Project Results

Output 5: Re-training Course for Condition Monitoring of Industrial Systems

Contents

Descriprion

Mechatronics is applied in many industrial systems such as automotive, manufacturing, industrial and mobile robotics, materials processing, consumer production, defense systems, aerospace, medical, etc. Mechatronics is defined as the combination of mechanical and electronic engineering with computational power. The design of any mechatronic system is a multidisciplinary activity and is performed to attain product-related advantages, which cannot be obtained by monodisciplinary efforts. Along with the benefits of having several engineering disciplines involved in the design activity, the task's complexity increases accordingly.

The failure of any industrial systems component (mechanical or electrical) reduces reliability and can cause a complete breakdown of the whole process. Moreover, in many failure cases, the system must be stopped to avoid damage of equipment and staff, which inevitably leads to financial losses. When condition monitoring or online diagnostic measures are taken, detecting the faults at early stages and saving the machine or system from more considerable faults in time. The scope of this course includes condition monitoring, fault diagnosis, and prognosis of industrial systems, fault-tolerant industrial systems, stability and acceptable performance evaluation of the industrial systems, degradation and aging of industrial systems components, artificial Intelligent in condition monitoring of industrial systems.

The main aim of Output 5 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 Condition Monitoring of Industrial Systems

In this section curriculum in the field of Condition Monitoring of Industrial Systems 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 Master studies

Course code	EEV5100
Course title in Estonian	Elektriseadmete tõrked ja töökindlus
Course title in English	Failures and Reliability of Electrical Equipment
ECTS credits	6.0
Assessment form	Examination
Teaching semester	Spring
Lecturer	Toomas Vaimann
Course aims	1. To create the conditions and readiness for analyzing the reliability of electrical equipment. 2. To create the conditions for identifying the possibilities of maintaining the reliability of electrical equipment, formulating and implementing them. 3. To create the conditions for diagnostics and inspection of electrical equipment. 4. To create readiness for identifying and formulating: - Early stage identification of the failures; - Occurrence and propagation processes of the failures; - Possibilities to avoid the failures.
Learning outcomes in the course	he student: 1. Analyses the reliability of electrical equipment (machines, transformers, converters, protection devices, cables, lines), describing the main possible failure reasons. 2. Identifies possible failures, using the most common diagnostic methods for electrical equipment. 3. Exploits electrical equipment, taking into account the influence for the environment. 4. Describes the means and methods for enhancing the reliability of electrical equipment and avoiding failures. 5. Performs inspection of electrical equipment, taking into account the theoretical background of reliability and practical implementations.
Brief description of the course	Main factors affecting the lifecycle of electric machines. Main failures in electric machines and transformers. Aging of insulation. Main types of bearings and their problems. Reliability and failures of electronic equipment, soft starters and frequency converters. Reliability of electricity supply. Electrical equipment and environment. Diagnostics, inspection, exploitation. Maintenance of electrical equipment.
Study literature	Lecture outline
Daytime study: weekly hours	4.0

lectures	2.0
Practices	0.0
exercises	2.0
Session-based study workload (in a semester):	64.0
lectures	32.0
practices	0.0
exercises	32.0
Course description	http://ois2.ttu.ee/uusois/subject/EEV5100
Content of lectures	1) Introduction. Basic concepts of reliability. Equipment maintenance. Fault characterization. Technical diagnostics. 2) Bearing types, lubrications, failures, and diagnostics. 3) Statistics and types of faults. 4) Diagnostics of exhaust currents. 5) Opportunities to reduce outflows. 6) Diagnostics of electrical drives. 7) Diagnostics of rotors/stators. 8) Permanent magnet materials. 9) Insulators of overhead lines. 10) Cable failures. 11) Electronic equipment failures and diagnostics. 12) Battery failures and diagnostics. 13) Transformer faults and diagnostics. 14) Expertise.

1.2 University of West Bohemia (UWB)

1.2.1 Bachelor studies

In UWB basics of condition monitoring of industrial systems consist of two courses “Measurement and Testing of Electrical Devices” and “Electrical Machines and Devices Diagnostics”.

Measurement and Testing of Electrical Devices

Course code	KET/MZEZ
Course title in English	Measurement and Testing of Electrical Devices
ECTS credits	4.0
Assessment form	Examination
Teaching semester	Autumn
Guarantor	Doc. Ing. František Steiner, Ph.D.
Lecturer	Ing. Miroslav Hromádka, Ph.D., Doc. Ing. František Steiner, Ph.D.
Tutorial lecturer	Ing. Martin Hirman, Ph.D., Ing. Miroslav Hromádka, Ph.D.
Course aims	The course goal is to make students acquainted with methods and procedures of measurement, testing and verification in electricalequipment production, assembly and repair under related law, regulations and standards. The student is also acquainted with theprinciples, requirements and procedures for the marketing of electrotechnical products.
Learning outcomes in the course	Knowledge – knowledge resulting from the course: - to explain basic standards and regulations provision; - to describe basic ways of protection against electric shock;

	- to distinguish the requirements related to the protection against electrical shock in the design, manufacture and operation of electrical equipment; - to choose suitable testing and measuring methods; - to explain principle and procedures of electrical equipment inspection. Skills – skills resulting from the course: - evaluate the functionality of the proposed control algorithm and controller setting; - to apply procedures of operation and work on electrical equipment practically; - apply appropriate testing and measurement methods.
Study literature	1) Elektrické instalace nízkého napětí - Část 4-41: Ochranná opatření pro zajištění bezpečnosti -Ochrana před úrazem elektrickým proudem. ČSN 33 2000-4-41 ed. 3. 2018. 2) Low voltage electrical installations - Part 4-41: Protection for safety - Protection against electricshock. IEC 60364-4-41:2005+AMD1:2017. 3) "Modrá příručka" k provádění pravidel EU pro výrobky 2016. 2016. 4) Obsluha a práce na elektrických zařízeních. ČSN EN 50110-1 ed.3. 2015. 5) Kříž, Michal. Příručka pro zkoušky elektrotechniků : požadavky na základní odbornou způsobilost.10., aktualiz. vyd. Praha : IN-EL, 2014. ISBN 978-80-87942-01-7. 6) The 'Blue Guide' on the implementation of EU product rules 2016 - http://ec.europa.eu/DocsRoom/documents/18027/.
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) Introduction to problems, history, trends, needs of practice. 2) Laws, regulations and standards - requirements for design, production, operation and testing. 3) Effects of electricity on humans and protection from them , first aid. 4) Classification and labeling of elements and devices - consequences for measurement, testing and revision. 5) Operating measurements of basic electrical parameters - choice of methods and equipments. 6) Protection against dangerous touch - types, principles, conditions. 7) Protection testing - choice of methods and equipments. 8) Product marketing, product assessment for dangerous substances (RoHS). 9) Assessment of conformity of low voltage electrical equipment. 10) EMC conformity assessment - electromagnetic immunity. 11) EMC conformity assessment - electromagnetic interference.

	12) Electrical equipment for testing, testing laboratory - conditions, establishment, operation, equipments. 13) Revision - purpose, conditions, preparation, implementation, revision report

Electrical Machines and Devices Diagnostics

Course code	KET/DELZ
Course title in English	Electrical Machines and Devices Diagnostics
ECTS credits	5.0
Assessment form	Examination
Teaching semester	Autumn
Guarantor	Ing. Josef Pihera, Ph.D.
Lecturer	Ing. Josef Pihera, Ph.D., Doc. Ing. Radek Polanský, Ph.D., Prof. Ing. Pavel Trnka, Ph.D.
Tutorial lecturer	Ing. Jaroslav Hornak, Ph.D., Ing. Josef Pihera, Ph.D., Prof. Ing. Pavel Trnka, Ph.D.
Course aims	During the course "Electrical Machines and devices Diagnostics" will be introduced to methods and system of diagnostics of electrical machines and devices. The particular sub-systems of electrical machines and diagnostic approaches of individual functional units of the electric machine will be presented to the students. The main space will be devoted to the understanding of the subject of diagnostics from the point of view of the strategy of machine operation and will be presented the key diagnostic methods for collecting information about the characteristics of the diagnosed machine system. In the course, the subject will also be devoted to the questions of the decision making processes when introducing a diagnostics system in the production and operation of electric machines. The questions of new and special diagnostic procedures in the diagnostics of electrical machines are realized especially in cooperation with practitioners
Learning outcomes in the course	Knowledge - knowledge resulting from the course: - describe the partial systems of electrical machines in terms of diagnostics; - explain the principle and system of diagnostics; - design a diagnostic system; - justify the strategy diagnostic approach; - compare materials in terms of parameters; - explain the processes in the insulation system. Skills - skills resulting from the course: - measure the necessary diagnostic parameters; - analyze the results of the diagnostics; - verify the condition of the electric machine.
Study literature	1) Mentlík, Mentlík. Diagnostika elektrických zařízení,. 2008. 2) Stone, G.C. Electrical insulation for rotating machines. 2004. 3) Küchler, A. High Voltage Engineering. 2018. 4) Hauschild, W. High-Voltage Test and Measuring Techniques. 2014.
Daytime study: weekly hours	5.0
lectures	3.0

Practices	2.0
exercises	0.0
Session-based study workload (in a semester):	59.0
lectures	39.0
practices	20.0
exercises	0.0
Content of lectures	1) Introduction, Diagnostics System, Types of Diagnostics, Diagnostic Theory, Diagnostic Signals and Quantities. 2) Diagnostic processes, diagnostics quality, diagnostics of systems with sudden and gradual failures. 3) Diagnostics and monitoring - Dielectric methods of diagnostics Loss factor, capacity, conductivity, insulation resistance, electrical strength. 4) Diagnostics and monitoring - Dielectric methods of diagnostics - time and frequency measurement, polarization and depolarization currents, recovered voltage. 5) Diagnosis and monitoring of partial discharges. 6) Diagnostics and monitoring of diagnostics of individual subsystems of electrical machines - chemical methods, optical methods, acoustic methods and vibrations, electrical methods. 7) Diagnostic Methods of Structural Analysis Insulation System. 8) Diagnostics of transformers insulation systems, methods used, online, off-line, diagnostics system. 9) Diagnostics of small rotating machines - insulating systems, used methods, online, off-line, diagnostics system. 10) Diagnostics of large rotating machines - isolation systems, methods used, online, off-line, diagnostics system. 11) Cable diagnostics - insulation systems, methods used, online, off-line. 12) Calibration, accreditation of testing laboratories, comparative tests, international comparison. 13) New methods of diagnostics of electric machines AC and DC systems, application examples.

1.2.2 Master studies

In UWB basics of condition monitoring of industrial systems consist of two courses “Diagnostics and Life Management in Electrical Engineering” and “Diagnostic methods in Electrical Engineering”.

Diagnostics and Life Management in Electrical Engineering

Course code	KET/DELZ
Course title in English	Diagnostics and Life Management in Electrical Engineering
ECTS credits	5.0
Assessment form	Examination
Teaching semester	Autumn
Guarantor	Ing. Josef Pihera, Ph.D.
Lecturer	Ing. Josef Pihera, Ph.D., Prof. Ing. Pavel Trnka, Ph.D., Ing. Robert Vik, Ph.D.
Tutorial lecturer	Ing. Jaroslav Hornak, Ph.D., Ing. Josef Pihera, Ph.D., Kyrylo Stohnii, Prof. Ing.Pavel Trnka, Ph.D.
Course aims	During the course "Diagnostics and Life Management in Electrical Engineering" the students will be acquainted with the methodsand

	system of diagnostics of electrical machines and equipment.It will deepen existing knowledge about individual systems and diagnostic approaches of electrotechnical diagnostics.The main area will be devoted to the development of knowledge and skills in terms of individual diagnostic methods formonitoring the state of electrical machines, equipment and particulate materials. These are in particular methods of partialdischarge, AC and DC methods of diagnostics.From the point of view of strategy of operation of machines and functional units, the key diagnostic methods for off-line andonline gathering of information on the characteristics of the diagnosis system of machines and equipment will be presented.The course will introduce new and special diagnostic procedures in the newly established HVDC networks and will introduce adiagnostics system such as Internet of Things (IoT). Appropriate sensors and sensors for online diagnostics in heavy-currentelectrotechnics will be discussed.The course will also address issues of system management, risk management, and asset management overview for the operation ofwhole power units, in which diagnosis plays a key role.
Learning outcomes in the course	Knowledge - knowledge resulting from the course: - explain the principle and importance of the diagnostic approach; - to justify a diagnostic strategy for different electrical machines and equipment; - to design appropriate diagnostic sensors for a particular type of machine; - explain the degradation processes of the machine; - apply aging models for the given application; - explain degradation of materials due to operating conditions; - explain the asset management strategy of electrical machines and devices. Skills - skills resulting from the course: - apply appropriate methods for obtaining the necessary diagnostic information; - to verify technological and degradation effects on the state of the machine; - to determine residual life time based on the application of aging model.
Study literature	1) Hauschild, W. High-Voltage Test and Measuring Techniques. 2) Stone, G.C. Electrical insulation for rotating machines. 2004. 2) Küchler, A. High-Voltage Test and Measuring Techniques.
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) Introduction, diagnostics system, types of diagnostics.

	2) Off-line Diagnostic Methods - Part 1 (Rotating Machines, Transformers, Cables). 3) Online Diagnostic Methods - Part 1 (Rotating Machines, Transformers, Cables). 4) Sensors of electrical and non-electrical magnitudes and their application for diagnostics in electrical engineering. 5) Industrial data collection in online diagnostics of electrical machines and equipment. 6) Use of remote and automatic data transmission for diagnostics of electrical machines and equipment in high voltage electrical engineering. 7) Asset management of electrical machines and equipment. 8) Different strategies for determining residual lifetime. 9) Degradation factor tests, aging models. 10) Degradation of materials due to operating conditions - influence of various operating factors to the change of chemical, mechanical and electrical properties of the materials. 11) Special diagnostic procedures and methods in HVDC applications. 12) Application examples.

Diagnostic methods in Electrical Engineering

Course code	KET/DME
Course title in English	Diagnostic methods in Electrical Engineering
ECTS credits	3.0
Assessment form	Pre-Exam credit
Teaching semester	Autumn
Guarantor	Doc. Ing. Jan Řeboun, Ph.D.
Lecturer	Doc. Ing. Jan Řeboun, Ph.D.
Tutorial lecturer	Ing. Pavel Rous, Doc. Ing. Jan Řeboun, Ph.D.
Course aims	The aim of the course is to introduce methods used for diagnostics of materials, substrates, electronic components and assemblies to students. The course is mainly focused on methods of optical, fluorescence and confocal microscopy, including methods used to increase contrast. The advanced methods of electron microscopy, scanning microscopy, ultrasound microscopy and X-ray microscopy including computed tomography will be also presented to students. Students will be introduced in the field of spectroscopy and X-ray fluorescence, enabling determination of elemental composition of materials. They will also be acquainted with the methods for the preparation of the arteriography cross-sections. Students will learn and practically try procedures for the diagnostic of typical defects of electronic devices, including evaluation of defects of electronic elements and assemblies according to the IPC standard.
Learning outcomes in the course	Knowledge - knowledge resulting from the course: - explain the basic concepts of optical microscopy; - describe the differences among the individual types of microscopes the imaging techniques; - to clarify the principles of contrast methods, confocal and fluorescence microscopy; - to clarify the principles of electron microscopy and scanning probe microscopy;

	- to clarify the principles of 2D and 3D X-ray analysis; - describe the methods and procedures used to determine the elemental composition of the samples; - describe the methods and procedures used for the preparation of metallographic cross-sections. Skills - skills resulting from the course: - assess the suitability of individual diagnostic and microscopic methods according to the sample under examination; - perform microscopic inspection of samples and find defects; - evaluate the defects found on samples according to IPC standards and make conclusions; - create a report from an optical inspection; - apply the knowledge gained and clarify it to the professional public.
Study literature	1) Debashis Mukherji. Electron Microscopy - A Versatile Tool for Material Characterization. 2017.ISBN 978-87-403-1696-4.
Daytime study: weekly hours	 3.0
lectures	1.0
practices	2.0
exercises	0.0
Session-based study workload (in a semester):	 39.0
lectures	13.0
practices	26.0
exercises	0.0
Content of lectures	1.Introduction to the subject, basic terms of microscopy, the accuracy of measurement in microscopy, evaluation of typical defects of electronic elements and assemblies according to the IPC standard. 2.Optical, fluorescence and confocal microscopy, contrast methods, AOI, image data analysis, Endoscopy. 3.Transmission and scanning electron microscopy, spectroscopy. 4.Metallography and materialography, techniques for defects investigation. 5.X-ray imaging and computed tomography. 6.Scanning Probe Microscopy, Scanning Acoustic Microscopy, Thermography.

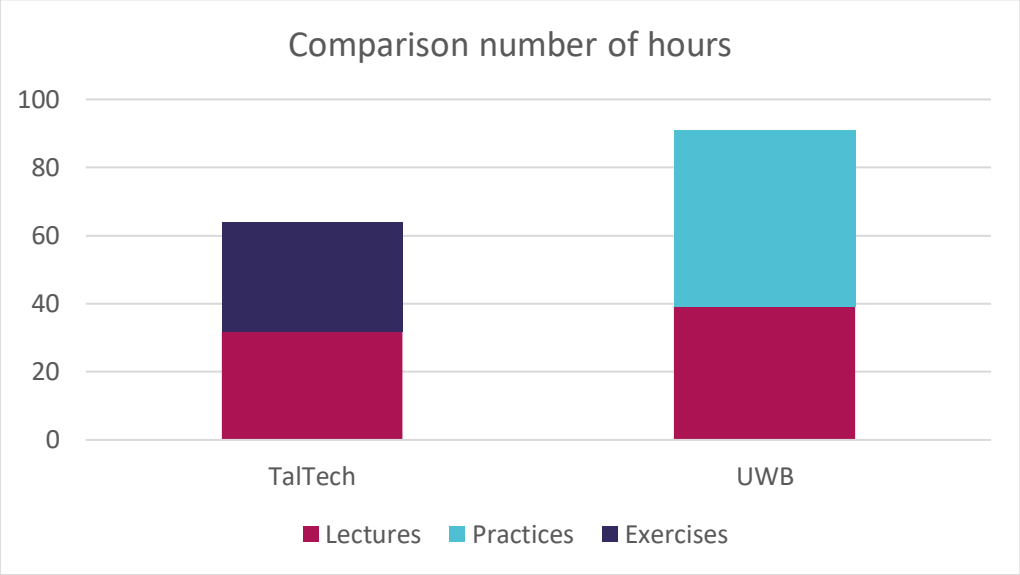
2 Comparison of condition monitoring of industrial systems

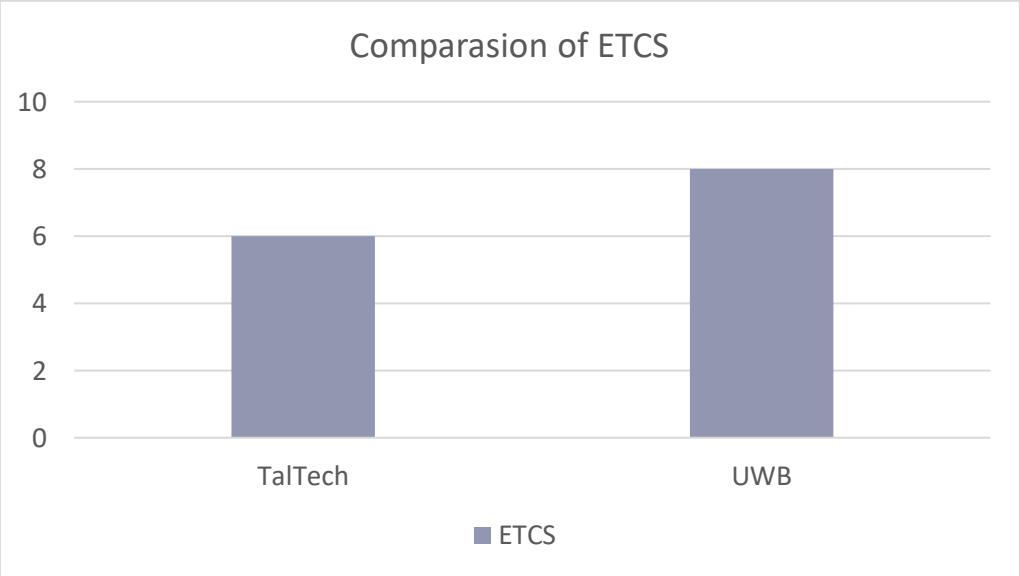
2.1 Bachelor studies

In the case that only UWB has courses for bachelors in condition monitoring of industrial systems, it makes no sense to conduct a comparison. The program of the re-training course will b based on a comparison of master's studies.

2.2 Master studies

	TalTech	UWB
Workload:	64	91
lectures	32	39
practices	0	52
exercises	32	0
ETCS credits	6	8

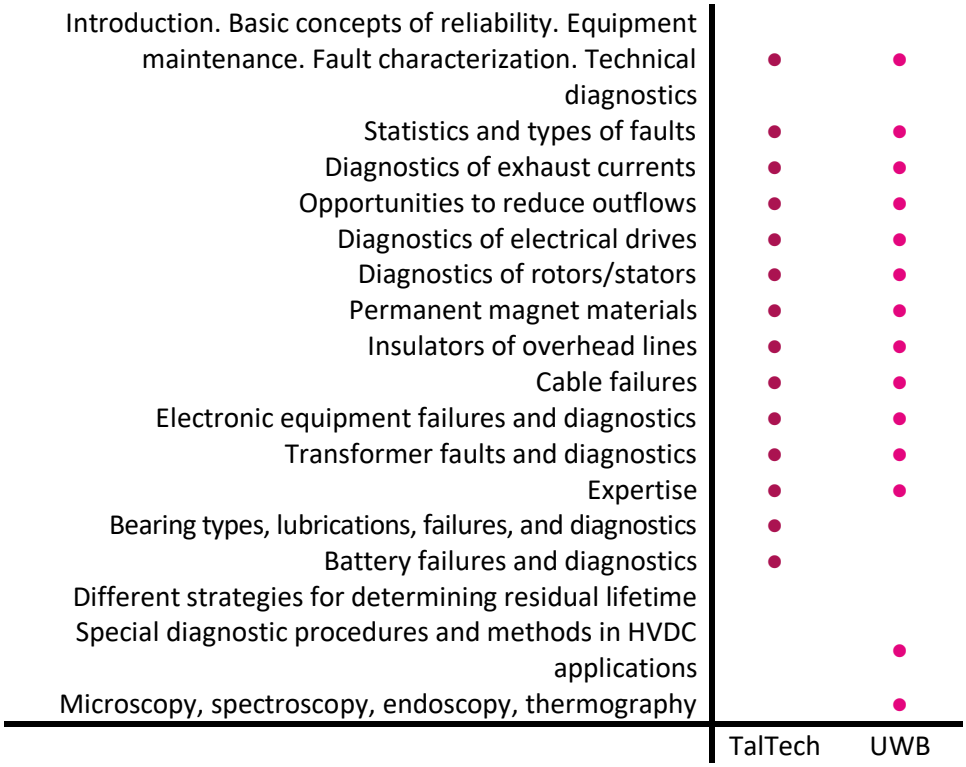




As seen from the graphs the course for condition monitoring of industrial systems in TalTech consists of lectures and exercises, in UWB course consists of lectures and practices. The number of lecture hours in both universities is almost the same.

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

Topics



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

1. The common topics between universities are introduction. Basic concepts of reliability. Equipment maintenance. Fault characterization. Technical diagnostics; statistics and types of faults; diagnostics of exhaust currents; opportunities to reduce outflows; diagnostics of electrical drives; diagnostics of rotors/stators; permanent magnet materials; insulators of overhead lines; cable failures; electronic equipment failures and diagnostics; transformer faults and diagnostics; expertise.

2. In TalTech additional tech bearing types, lubrications, failures, and diagnostics; battery failures and diagnostics.

3. In UWB additional tech special diagnostic procedures and methods in HVDC applications; microscopy, spectroscopy, endoscopy, thermography.

4. In TalTech course for condition monitoring of industrial systems is mostly based on learning faults and their natures, but in UWB this course is based on the diagnosis methods of faults.

3 Curricula for re-training course for condition monitoring of industrial systems

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 condition monitoring of industrial systems
ECTS credits	1.25
Assessment form	Examination
Teaching semester	autumn - spring
Course aims	1. To create the conditions and readiness for analyzing the reliability of electrical equipment. 2. To create the conditions for identifying the possibilities of maintaining the reliability of electrical equipment, formulating and implementing them. 3. To create the conditions for diagnostics and inspection of electrical equipment. 4. To create readiness for identifying and formulating: - Early stage identification of the failures; - Occurrence and propagation processes of the failures; - Possibilities to avoid the failures.
Learning outcomes in the course	he student: 1. Analyses the reliability of electrical equipment (machines, transformers, converters, protection devices, cables, lines), describing the main possible failure reasons. 2. Identifies possible failures, using the most common diagnostic methods for electrical equipment. 3. Exploits electrical equipment, taking into account the influence for the environment. 4. Describes the means and methods for enhancing the reliability of electrical equipment and avoiding failures. 5. Performs inspection of electrical equipment, taking into account the theoretical background of reliability and practical implementations.
Brief description of the course	Main factors affecting the lifecycle of electric machines. Main failures in electric machines and transformers. Aging of insulation. Main types of bearings and their problems. Reliability and failures of electronic equipment, soft starters and frequency converters. Reliability of electricity supply. Electrical equipment and environment. Diagnostics, inspection, exploitation. Maintenance of electrical equipment.
Session-based study workload (in a semester):	32.0
lectures	32.0
practices	0.0
exercises	0.0

Content of lectures	1) Introduction. Basic concepts of reliability. Equipment maintenance. 2) Fault characterization. Technical diagnostics. 3) Statistics and types of faults. 4) Diagnostics of exhaust currents. 5) Opportunities to reduce outflows. 6) Diagnostics of electrical drives. 7) Diagnostics of rotors/stators. 8) Permanent magnet materials. 9) Insulators of overhead lines. 10) Cable failures. 11) Electronic equipment failures and diagnostics. 12) Transformer faults and diagnostics. 13) Expertise.

4 Conclusion

In conclusion, the comparison of topics among universities provides valuable insights into the curriculum focus and offerings in the field of industrial system condition monitoring. The shared topics across all universities emphasize fundamental concepts such as introduction to the subject, basic reliability principles, equipment maintenance, fault characterization, technical diagnostics, statistics, types of faults, exhaust current diagnostics, opportunities for reducing outflows, electrical drive diagnostics, rotor/stator diagnostics, permanent magnet materials, overhead line insulators, cable failures, electronic equipment diagnostics, transformer faults, and expertise development.

Furthermore, TalTech distinguishes itself by incorporating additional topics related to various technical aspects, including different bearing types, lubrication methods, failures, and advanced diagnostics, as well as battery failure analysis and diagnostics. On the other hand, the University of West Bohemia (UWB) sets itself apart with supplementary coverage of specialized diagnostic procedures and methods tailored for High Voltage Direct Current (HVDC) applications. UWB also incorporates microscopy, spectroscopy, endoscopy, and thermography techniques into their curriculum.

An intriguing difference lies in the approach to teaching the course for condition monitoring of industrial systems. TalTech focuses primarily on imparting knowledge about different types of faults and their characteristics, whereas UWB places more emphasis on teaching diagnosis methods for faults. This nuanced difference in approach can significantly impact students' understanding and application of condition monitoring principles. Interestingly, the structure of the condition monitoring course varies between the two universities. TalTech's course integrates lectures and exercises, while UWB's curriculum combines lectures with practical exercises. Despite this difference in structure, the number of lecture hours remains quite similar in both institutions, indicating a shared commitment to delivering comprehensive theoretical knowledge.

Lastly, the comparison highlights that the European Credit Transfer and Accumulation System (ETCS) value is higher in UWB, reflecting a potentially more in-depth and rigorous approach to the subject matter. This could indicate that UWB places a greater emphasis on mastering the intricacies of industrial system condition monitoring.

In summary, the analysis of topics, approach, and structure across universities underscores the multifaceted nature of industrial system condition monitoring education. The similarities and distinctions observed shed light on the diverse pedagogical strategies employed to equip students with the necessary skills and knowledge in this critical field.