Innovative Pedagogical Tools

Baseline courses

Summary report **Intellectual Output 7**

August 17, 2022 Geo3En IO7

1 Introduction

The idea of baseline courses is to develop tools and methodology that will enable students from different thematic backgrounds to gain the same level of competencies in geothermal engineering. The tools and methods should ensure that students acquire basic knowledge in all fields of geothermal engineering in order to be able to follow classes in unrelated fields.

The courses can be divided into four groups:

1. Rock deformation, fluid rock interaction, geological concept of reservoir
2. Geology engineering, borehole types, heat transfer in deep geological structures and the surface heat output
3. Electric power system overview – electricity production, transmission and distribution, power plant operation and energy conversion from primary sources to useful forms of energy
4. Management and financing, environmental impact, societal acceptance

One or more introductory lectures should introduce students to the content of these four main topics (geology, reservoir engineering and exploitation, electrical engineering, management and financing). These are key lectures because they must be simple enough for students to follow, but on the other hand they must cover all the areas that will be discussed. It is crucial that Master's students receive information about the reasons why these courses are part of the study programme. There are two innovative accomplishments in this approach:

1. In a multidisciplinary approach involving teachers and students of different backgrounds, the students must be able to answer general questions: why we do this, how are we going to achieve this are what are going to be the outputs. In particular, energy technology students need to know the reasons for learning about geological principles, and vice versa. And of course, the knowledge they will acquire must be sufficient to understand and apply the basic principles of geothermal engineering. The innovative methods of teaching and learning should be able to satisfy this requirement.
2. The consortium includes different universities covering different areas of research and education. In their research and teaching work, they cover a wide range of areas and topics providing their students with diverse competencies. Some of these competencies will also be represented in the Geo3EN program, some will be modified and adapted to geothermal engineering, and some, which go too wide, or are not required, will not be covered. An innovative approach, in this case, requires institutions to adapt to the new curriculum, select topics relevant to geothermal engineers from their portfolio, fully replicate them, or, much more likely, adapt their curricula to meet the requirements of the Geo3EN idea. For example, in turbine engineering the focus should be on turbines found in geothermal power plants, turbines for organic fluids, geothermal steam in dry steam power plants, or saturated geothermal water in flash systems. The requirements for such turbines are different than for turbines in conventional thermal power plants. Or, another example, in power engineering the focus should be on smart grids because geothermal fluid is used in a cascade cycle depending on its thermodynamic parameters: for electricity generation, district heating, in industry, agriculture, heat pumps, etc. As geothermal power plants are of lower power, more time should be devoted to low and medium voltage distribution networks than to high voltage transmission

networks. Usually, the latter are studied in more detail because from a safety point of view, failures on high voltage networks are more dangerous than on lower voltages, so the curriculum should be adapted to the requirements of the introduction of geothermal power plants in the power system. There are many more such examples, from geological research techniques, advanced drilling techniques, to environmental impact, entrepreneurship and economic analysis.

a. With all this said, it is clear that this curriculum must be developed in close interaction of all involved institutions in order for all competencies to be represented, and so that there is no repetition among different institutions that provide similar learning outcomes.
b. The Geo3EN program provides excellence in the education of future geothermal engineers because each of the four institutions involved provides the highest level of expertise in its field.

Students will master the teaching material using innovative pedagogical methods both in teaching and learning activities. The methods, which are explained in more detail in the next section, are as follows:

1. Lectures will include theoretical background and numerical examples. They will be supported by the laboratory work, computer simulations, field trips, excursion to technical facilities, etc. In this way, students will master the theory of geothermal systems, but also its application in practice and in the field.
2. Advanced learning methods will include e-learning, feedbacks, project and problem based learning, group work, etc. As students have different prior knowledge that they have acquired in Bachelor study, working in a group is a natural way to acquire knowledge. Groups will be created in a way that will combine students from different incoming institutions and different profiles. In this way, they will learn from each other when solving problems, and teachers will encourage discussions and define topics that will further encourage team work.

More sophisticated methods such as augmented reality and 3D models are used in learning, not only to make it easier for students to understand the material, but also to master advanced technologies that will be increasingly used in technical systems and geological research in the future.

2 Innovative pedagogical methods

Geothermal engineering students need to acquire a significant amount of knowledge and skills. In order to facilitate student work and education, in addition to classical methods, advanced learning methods are widely used. The innovative pedagogical methods, applied within the Geo3EN program, are discussed below.

2.1 Combination of lectures, numerical problems, laboratory work, computer simulations, field trips, technical excursions

Theoretical lectures are clearly the basic and most important way of transferring knowledge. They are performed in a blended learning approach that uses alternating distance and face-to-face learning. Based on experience, the face-to-face learning is an indispensable teaching tool, but hybridization provides additional benefits. Today's communication platforms (Teams, Zoom, Webex, etc.) provide advanced options for teacher-student interaction, content recording, sharing on social networks, etc. Care must be taken to ensure a balance between distance and face-to-face learning in order that distant learning does not exceed a certain duration of the course. Similarly, face-to-face learning should regularly alternate with distance learning in order to maintain contact with the group, to encourage a sense of belonging and to allow for the comparison of understandings; for the teacher, it is also the best way of ensuring that the students are making progress.

Power engineering cannot be taught or learned without numerical examples and calculations. Specifically, what interests us most about a geothermal power plant is its rated power, efficiency and possible electricity production. In order to calculate these quantities, many parameters of the working medium, location characteristics, power plant performance, types of equipment, etc. must be known, and they are explained during lectures. In addition, lectures are used to introduce students to basic physical laws, equations and mathematical models. On the other hand, in the exercises, mathematical models are applied in solving numerical problems. The models can be simple, which allows students to manually calculate the characteristics of the power plant using simple methods, ie. equations. In this way they get important information about the order of magnitude of the plant's energy output. Complex, and therefore more accurate, models require the use of computer simulations. Students will learn to use the software tools for many applications: reservoir 3D structural modeling, reservoir numerical simulations, integrated energy system simulation, power plant simulation, etc. by means of numerical methods that include lumped parameter, finite difference and finite element methods.

The synergy of lectures and exercises forms the basis of quality education for future geothermal energy experts. What is still lacking and what the acquired knowledge must be supplemented with are the field work, work in the laboratory and preferably in the technical facility. If the latter cannot be achieved, at least visits accompanied by professional staff should be provided.

Field work at geological sites and mines allows students to identify sites suitable for geothermal exploitation in terms of thermal capacity and the possibility of extracting thermal energy to the surface by identifying faults and cracks inside rocks where water can easily penetrate. Laboratory work using field material samples and studying its properties helps to classify the geothermal site, estimate energy output and the cost-effectiveness of the project. Laboratory work also refers to work in energy laboratories, which includes measurements of the operating characteristics of electrical machines (generators and transformers), turbines, components of substations and transmission lines. In the laboratory, students are taught measuring techniques, measuring instruments and measuring procedures. Students who have a background in mechanical or electrical engineering thus learn about geology and reservoir engineering in the field trips and laboratories, and the geology students about power energy systems by making electrical measurements. Technical excursions to power plants, substations and factories that produce electrical equipment are crucial not only because they in some way introduce students to future employers but also give students an idea of how to apply theoretical knowledge in practice, or what skills they need to acquire to be successful in their future work.

2.2 Advanced learning methods: e-learning, feedbacks, project and problem based learning, group work

The use of learning management systems (such as Moodle or Claroline) allows to create digital materials available to students that help in learning, understanding the material, but, more importantly, they provide additional opportunities that are not feasible in face-to-face learning. The e-learning systems are modular platforms which offer many possibilities (presentation, format of training courses, quizzes, portfolio, podcasting ...). In principle, these platforms can be used as repositories of files, software, and other teaching materials. Furthermore, the possibility of making quizzes serves to test and upgrade the knowledge in geothermal engineering. The quizzes can be of a simple type (multiple choice questions) or more complex numerical problems with random variation of input parameters.

As expected, students with background in geology and reservoir engineering need more time to comprehend and interpret materials related to surface engineering (power plant operation, energy grids, energy systems), and vice versa. Therefore, after the lecture, a discussion is organized in which the material is analyzed with a focus on the goals of the course and the study itself. In this way the teacher gets the information about students' learning and the link between the current state of his/her learning and the expected objectives (feedback). The feedback can influence positively students' motivation if properly directed by the teacher. Communication between the student and the teacher is crucial in the process of acquiring knowledge.

It has been observed that students respond much better if they work in groups composed of students of different profiles. In this way, students complement and share knowledge with each other. This is of particular importance in a multidisciplinary study, such as the study of geothermal engineering. A special way of working with a group is to assign group projects. The project is a comprehensive task where students have to demonstrate the ability to analyze the given problem from theoretical and practical aspects, devise a solution using the knowledge acquired in multiple courses and literature, implement the solution, write the documentation and instructions for use and/or for further work (if the final product is some kind of hardware and/or software), to present their work in written and oral form. The project task must be given in such a way that it can be divided into parts that cover all aspects of geothermal engineering so that each student contributes equally to the work in the group. In this way, students adapt to team work, but also take responsibility because the success of the project will be ensured only if all students equally contribute to the final product.

An example of such a project is to make a design a geothermal power plant with known conditions on site. It is a complex problem and requires equal contribution of all students. Mechanical engineering students can choose the type of power plant, operating parameters, characteristics of the working medium with an emphasis on the maximum plant efficiency. Electrical engineering students will be in charge of selecting an electric generator, transformer, substation and connection to the electrical network. But for this to be feasible one must know the heat capacity of the geothermal reservoir. This then requires the knowledge of geology and reservoir engineering students who must explore ways to extract heat from reservoir to the surface. Students should be able to ask the right questions and use the contribution of colleagues in their own work. There are a lot of unknowns in solving the problem and optimization is needed, but this way of working helps students to understand the complexity of the topic and brings them closer to areas of research that they have not encountered so far.

2.3 3D models, augmented reality

3D visualization of geological formations and power plants greatly facilitates the understanding of the geological processes, structures, rock transformations, plate tectonics, but also power plant operation and design.

The popularity of virtual reality (VR), augmented reality (AR) and mixed reality (MR) has grown remarkably over the last few years, and their development is progressing year after year. Virtual reality technology creates a completely virtual, artificial digital environment, augmented reality technology places virtual objects into real world environment and mixed reality technology combines the two technologies mentioned above to enable real-time interaction between users and virtual elements. AR and MR are mature enough as technologies so they are used in manufacturing, managing smart buildings, in the automotive and aerospace industries and in the military industry. The Smart Grid Laboratory at the University of Zagreb Faculty of electrical engineering and computing has used mixed and augmented technology and applied them in the energy sector to create an interactive and intuitive graphical interface for the management of the hydroelectric power plant located in the laboratory. The graphical interfaces are accomplished with two client applications - the Android mobile application and the Microsoft HoloLens application (Figure 1). The idea is simple – to use interactive graphical interface to start, stop and change the power of the power plant (Figure 2).

Figure 1: Demonstration of using HoloLens smart glasses

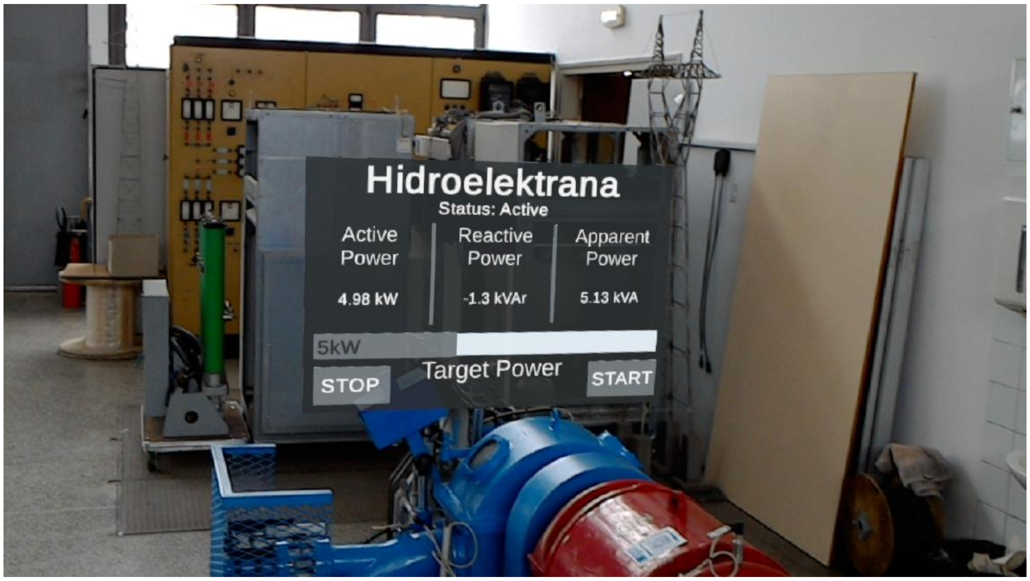

Figure 2: Hologram with control graphic interface for hydropower plant

Such techniques can be applied in geothermal engineering in many ways, not only in power plants, and in combination with 3D models they represent a powerful pedagogical tool in the creation of which students, teachers and industry participate together.

3 Baseline courses – UniLaSalle

3.1 Students with no geological background

3.1.1 Thermodynamics

This lecture covers fundamental aspects in thermodynamics, correctly define parameters characterizing a thermodynamic system, and study system evolution as a function of external exchanges. The program gives a series of concepts and definitions dealing with pressure, temperature, work and heat, first principle of thermodynamics (energy conservation), second principle of thermodynamics (system evolution). A series of applications are given (engines, cooling, heat pumps).

3.1.2 Thermics

This lecture aims at understanding the different heat transfer mechanisms: 1) conduction : Fourier law, heat propagation equation, thermal resistance, 2) natural or forced convection: Newton law, exchange coefficients calculations, thermal resistance, 3) thermal radiation (black, grey and real bodies, Planck, Wien and Stefan laws, radiative thermal exchanges between black and grey surfaces in a cavity. Applications in the field of building engineering and management are given.

3.1.3 New energy sources

The lecture aims at describing the operation, use and (micro) gridding of new renewable energy sources (solar, wind, geothermal, hydroelectric, biomass) taking into account electrothechnical, socio-economics, environmental and energetical aspects. All these sources require the use of electric equipment, electromechanics and mechanics dedicated to energy conversion from a non constant and intermittent physical form to a modular, tunable and exploitable electrical form usable by consumers. The course includes a project (TP-PROJET) aiming at studying, model, simulate and control an electric or electro mechanic conversion chain (PV system). The students will 1) learn to optimize hybrid microgrids in the framework of sustainable development and energy saving, 2) get an overview of renewable energy sources with an associated review of energy conversion chain and MPP principle (variable primary source, technology, principles, efficiency and impacts) and 3) study the different forms of electrical energy storage with a detailed description of storage main elements: chemical (batteries and accumulators), mechanical (hydraulic, electromechanics), thermal (thermal capacity, MCP, heat transfer), electromagnetic (super-condo, SMES).

3.2 Students with geological background

3.2.1 Geochemistry

This course presents a series of tools dedicated to analysis of samples gained in the field. Techniques of sample description are demonstrated and all fundamental aspects of mineral geochemistry with applications to mineral resources, soil and rock geochemistry, isotope geochemistry (stable isotope tracers: $\delta 18O$ and δD; radioactive isotope tracers Sr / Rb-Sr), hydrothermalism related processes, organic geochemistry with applications to reservoirs and fluid inclusions analysis techniques are presented.

3.2.2 General geology

Basis of cartography, igneous petrology, sedimentary petrology, microscopy (magmatic minerals). General geology (plate tectonics, geodynamics, concept of geological timescale (relative and absolute dating), geomorphology. Field work (outcrop evaluation, geological object observation, techniques of measurements, positioning in space, fieldbook management, synthesis, teamwork).

3.2.3 Basic GIS techniques

Basic GIS techniques (project construction, georeferencing, 2D spatial analysis) in ArcGIS. Excel (workbook manipulation). SQL Database building.

3.2.4 Soft skills

This lecture is dedicated to a presentation of soft skills needed in professional missions and responsibilities. In addition to the fundamental sciences which constitute the common core of the first years of the curriculum, these skills are established through teaching relating to interpersonal skills, management and teamwork, ethics, project management, professional posture and efficiency, personal development, information systems and business plan. An introduction to a "sustainable development" dimension through the acquisition of competences in line with the Sustainable Development Goals (SDGs) listed by UNESCO is given. Based on a wide range of teaching methods, the course is built around scientific experts and bibliographical references that will be provided during the lessons.

3.2.5 Sampling and subsurface data analysis

This course gives the basics in the field of ore geology, isotope chemistry, organic and mineral chemistry applied to reservoirs and fluid inclusion analysis techniques.

3.2.6 Dynamic of porous media

The lecture deals with fundamentals in hydrogeology (water cycle, notion of aquifer), reservoir geology (rock petrophysics, fracturation, concept of saturation), porous environment mechanics, geothermal energy (technological and legal aspects, presentation of the different types of geothermal exploitation).

3.2.7 Drilling and wireline

The lecture presents the drilling tools and mechanical aspects, borehole monitoring, wireline interpretation (quicklook, data analysis and interpretation, numerical data treatment techniques).

3.2.8 Identification of Geo, Bio Energies

This course aims at offering an overview in terms of exploration and exploitation of primary energy resources (methane production, algae cultures, Hydrogen, Uranium, geothermal, fossil fuels, marine renewable energies), energy storage, carbon compensation measures either biological (agroforest, algae, biomass) or geological (depleted reservoirs, abandoned salt mines, mineral sequestration in basalts). The fundamental aspects of carbon neutrality strategies and associated new employment opportunities in the energy sector are presented.

3.2.9 Quantification and production of Geo, Bio Energies

The lecture deals with a double approach: 1) evaluation of fossil resources with a dedicated effort on sedimentary fluid evaluation: a case study "Uranium in sedimentary provinces" is proposed and 2) feasibility study of combined renewable energy production project (geothermal and biogas).

3.2.10 Innovation, Carbon neutrality and Territories

The lecture is driven by decision makers, stakeholders and investors in the market of renewable energies at local, regional and European scale. Emphasis is given on the challenges and perspectives of energy mixes and carbon reservoirs. A case study dealing with local wood production and associated energy production taking into account production efficiency, economic sustainability and carbon neutrality is proposed. Results are to be presented during a symposium for local entrepreneur and governing entities at the end of the course.

3.2.11 Integrated approaches for Geo, Bio Energies

The lecture presents an overview of natural energy storage solutions. Technologies dealing with Carbon Capture Utilization and Storage, Bio reservoirs, Energy strategic storage are extensively presented with inputs from industrials leaders in these fields.

3.2.12 Entrepreneurship

This series of lectures aims at mastering innovation concepts and methodology ranging from activity creation, collective intelligence and design thinking at international level. It is aimed to promote engineers able to coordinate innovative projects, able to integrate within transdisciplinary collective intelligence processes. Several modules cover a variety of thematics: 1) personal development and entrepreneurial stance, 2) territorial ecosystems, 3) research dedicated to innovation, 4) value creation and economical models, 5) entrepreneur opportunities, innovation, marketing and data analysis, 6) financing, business plan and business game, 7) risk analysis, 8) negotiations and leading markets.

4 Baseline courses – TU Darmstadt

4.1 Students with no geological background

4.1.1 Introduction to business administration

The course is an introduction to business administration for students not familiar with the subject. From the origins of the subject to its current differentiation into its areas of specialization, the course offers insights into the broad spectrum of business administration. Main topics to be covered are general basics of business administration (legal forms and definitions), some marketing concepts, basic features of production management (process optimization and quality management), organization and personnel management, basics of financing and investment appraisal as well as basic knowledge in accounting and controlling.

4.1.2 Energy finance

With the agreed energy turnaround, the nuclear phase-out and the even faster shift towards renewable forms of energy in the future, the associated financing issues have once again gained considerable political importance. On the one hand, the event will discuss financing issues for the renewable energy sector. This industry segment can be used to look at the entire corporate life cycle with its specific financing problems, starting with early-stage risk financing by institutional financiers (venture capital), through the growth and establishment phase, which also includes IPOs, to consolidation with corporate takeovers (M&A) and outsourced project financing. On the other hand, it is also about the costs of the energy transition from the perspective of today's dominant conventional electricity suppliers. This raises the question of the changes in capital costs due to the nuclear phase-out and the costs incurred when existing power plants have to be dismantled or removed. In addition, the sale of the electricity grids and the use of the financial resources that are freed up are of importance here.

4.2 Students with geological background

4.2.1 Characterization of deep geothermal systems from various geological contexts

This course will decipher the question on how to integrate the geological knowledge of an area to quantify the geothermal potential, following geological concepts, integration of geological data from various sources, geophysics, fieldwork, and borehole data, to achieve the multi-scale and multi-disciplinary approach of the system.

4.2.2 Structural modelling

Content will here focus on geomodelling, its fundamentals, how to build explicit structural model, followed by practical courses to the students to discover geomodelling software and to construct a 3D model areas of interest URG reservoirs from MEET and or DGE Rollout projects datasets.

4.2.3 Geostatistical methods

This course will include an introduction to geostatistics, with data analysis and data quality estimation. The notions of variograms, how to calculate and model them, the principles, how to interpret it and how to use it later in the properties modelling workflow. The rest of the baseline course will focus on the different possible methods to model rock properties in geological models, e.g., kriging methods, stochastic simulation methods, etc.

5 Baseline courses – University of Zagreb

5.1 Introduction to power engineering

The introductory lecture is about the importance of energy (electricity) supply, about production and consumption of energy (electricity), about the electric power system and electrical energy, about the peculiarities of the electric power system and the overall energy demand and supply. The electric power system consisting of power plants, substations, transmission lines, control systems and consumer devices is briefly described to the students. The basic idea of electricity production by electromechanical conversion in synchronous generators is described next. The concept of a turbine in different types of power plants is presented to explain that the turbine and the generator are the basic components of a power plant, regardless of the energy source (fossil fuel, hydropower, wind energy, geothermal energy). Sources of energy, amounts of energy obtained from different sources, the difference between power and energy, the price of electrical energy and the energy mix in different European countries are described in a graphic and simple way in order to make students aware of the basic quantities and terms so that they can more easily follow dedicated lectures.

5.2 Power plant operation

In power plants internal energy (of an energy source) is converted into electricity. Types of internal energy are gravitational potential energy, chemical energy, nuclear energy of fission and fusion, kinetic energy, mass–energy equivalence and internal caloric energy. Gravitational potential energy is used in hydro power plants, chemical energy in thermal power plants, nuclear fission energy in nuclear power plants, kinetic energy of moving air in wind power plants and internal caloric energy in geothermal power plants. In thermal power plants the energy source (geothermal, solar, nuclear, chemical) is converted first in heat energy (in the steam generator), then in the turbine in mechanical work, and finally in electric energy in the electric generator. Thermal power plant consists of four main components: boiler, turbine, condenser and pump. In the boiler heat is transferred into the system to produce steam, work is produced in the turbine, heat is transferred out of the system in the condenser by the cooling water and in the pump, work is performed to increase water pressure to obtain working parameters in the boiler. Thermal power plant is basically a closed thermodynamic system, where each component is an open system. For each system basic physical principles of mass and energy conservation, and conversion oh heat into work, to fluids that enable energy uptake, storage, transmission and conversion of initial forms of energy into useful electrical energy and mechanical work are presented and discussed.

Ideal gas processes serve as an introduction to real fluid processes. The basic equations are given for defining the relationship between state variables and for heat transfer, technical work and mechanical work of a closed system. They are applied to isothermal, isobaric, isochoric and isentropic processes. The Carnot cycle consisting of two isothermal and isentropic processes is used to explain heat engines, conversion of heat into work and thermal efficiency. The Brayton cycle, used in gas-turbine engines, is the next example of thermodynamic cycle with pure gases. The introduction of entropy and the second law of thermodynamics makes it possible to divide processes into reversible (if the entropy of adiabatic system remains constant) and irreversible (if the entropy of adiabatic system increases) processes.

The Rankine cycle (Figure 3) is the basic cycle in steam turbine power plants. It uses steam-water mixture as working fluid. Water enters the pump as saturated liquid and is compressed to the operating pressure of the boiler, then enters the boiler (steam generator) as a compressed liquid and leaves as a superheated vapor. The boiler is a large heat exchanger where the heat originating from combustion gases, nuclear reactors, or other sources is transferred to the water essentially at constant pressure. The superheated vapor enters the turbine, where it expands and produces work by rotating the shaft connected to an electric generator. At the exit from the turbine steam is usually a saturated liquid–vapor mixture with a high quality. Steam is condensed at constant pressure in the condenser by rejecting heat to a cooling medium such as a lake, a river, or a sea. Steam leaves the condenser as saturated liquid and enters the pump, completing the cycle. Processes are explained, and numerical examples are solved, both with isentropic expansion in the turbine as well as irreversible adiabatic expansion. At the end, procedures for increasing the efficiency in steam and gas turbine power plants are covered. In addition, numerical examples are presented so that students understand what values of efficiency, work, heat, pressure, temperature, enthalpy, etc. are expected in thermal power plants.

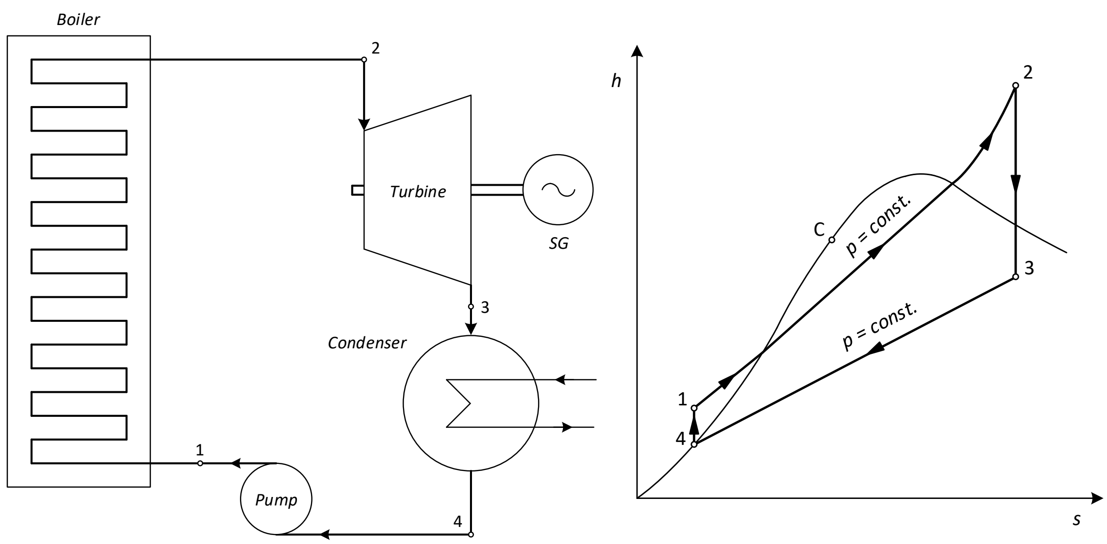

Figure 3: Steam turbine power plant and the Rankine cycle

5.3 Fluid machinery

A fluid machine is a device which converts the energy stored by a fluid into mechanical energy (turbines) or vice versa (pumps, compressors). The energy stored by a fluid mass appears in the form of potential energy, kinetic energy and intermolecular (internal) energy. The mechanical energy is usually transmitted by a rotating shaft (turbo machinery). The turbine type depends on the driving fluid. Steam turbines are used at power plants to generate electricity using high temperature and high pressure steam. Gas turbines use high temperature and high pressure combustion gases. Wind turbines use kinetic energy of wind and hydrokinetic turbines use kinetic energy of water: Pelton impulse turbines, Francis and Kaplan reaction turbines. Direction of flow could be axial, radial, or mixed flow, while the interaction of fluid and rotor blades is either of impulse type (uses dynamic head only – velocity) or reaction type (uses both dynamic (velocity) and static heads (pressure).

The power of the turbine is given by the Euler equation:

$$P = \dot{m}u\left(c_1 \cos\alpha_1 + c_2 \cos\alpha_2\right), \qquad (1)$$

where $\dot{m}$ is the fluid mass flow rate, u velocity of the turbine blade, c_1, c_2, fluid absolute velocities at turbine inlet and outlet, α_1 and α_2 absolute velocity angles (Figure 4).

The emphasis of this course is on turbines in geothermal power plants: steam turbines and turbines for organic fluids. The working principle of steam turbines is explained. Turbines are divided into stages: impulse and reaction stages. In the impulse stage the whole pressure drop is in the nozzle (whole enthalpy drop is changed into kinetic energy in the nozzle) and in the reaction stage the pressure drop is both in stationary blades and in rotary blades (enthalpy drop changed into kinetic energy both in stationary blades and in the moving blades in rotor). The turbine construction, regulation, compounding, monitoring instrumentation, sealing system, classification based on:

- flow direction (axial, radial),
- number of stages (single and multi-stage),
- rotational speed (regular, low, or high speed),
- inlet steam pressure (high pressure ($p>6{,}5$MPa), intermediate pressure ($2{,}5\text{MPa}<p<6{,}5\text{MPa}$), low pressure ($p<2{,}5$MPa),
- way of energy utilization (condensing, extraction, back-pressure turbine)

are discussed as well.

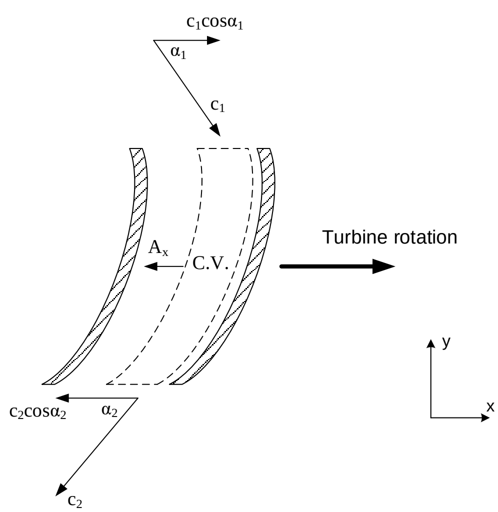

Figure 4: Variables used in Euler turbine equation

In binary geothermal power plants, the working fluid is organic fluid and turbine types are a bit different. Three types are used:

- axial, possibly multistage with low rotational speed, low peripheral speed, low mechanical stress and no reduction gear,
- radial, inflow, usually single stage with high rotational speed, reduction gear and high work extraction per stage,

- radial, outflow, multistage where fluid passage area naturally increases along the expansion process with low work extraction per stage (centrifugal force potential acts against work extraction), high number of stages, low rotational speed and no reduction gear.

5.4 Geothermal power plants

There are three main types of geothermal power plants: dry steam power plants, flash steam power plants and binary cycle power plants (Figure 5). Their operation, components, temperature-entropy diagrams, efficiency, operating parameters are discussed in detail.

In dry steam power plants saturated steam is extracted from the well and after expansion in the valve directed to the centrifugal separator that separates impurities from the incoming steam. The pressure is decreasing in the expansion valve and in the separator; the lower the pressure the lower the saturation temperature – which means that steam is getting superheated, but due to pressure decrease part of useful energy-work (work depends on pressure!) is lost. Steam then expands in the turbine, some of the steam condenses and the remainder is condensed in the condenser. The cycle is similar to the Rankine cycle but it is an open cycle as the liquid is re-injected back into the well.

In flash steam power plants the geothermal fluid is in the liquid state (saturated liquid!) which is expanded through an expansion valve resulting in a two-phase flow. This mixture of liquid and vapor is directed to a separator with pressure decreasing once again. The steam-liquid mixture in the separator is kept at a constant temperature and pressure, so that the liquid and the vapor are separated from each other. The produced vapor is directed to the steam turbine to generate electricity while the remaining liquid is re-injected to a re-injection well like in the dry steam power plant. Regarding the temperature and efficiency the fluid in the flash steam plant is at a lower temperature and thus efficiency is lower than in the dry steam power plant.

If the temperature of the geothermal fluid is too low to be used in a flash steam plant, then the internal energy of the geothermal water is used to heat up an organic fluid in the binary cycle power plant in a special type of heat exchanger. A secondary fluid such as hydrocarbon or fluorocarbon is used instead of water to run the organic Rankine cycle (ORC) turbine. (Because geothermal fluid-water is at low temperature at subcooled conditions.) In ORC, the geothermal fluid is circulated in a vaporizer and sent back to the re-injection well. The secondary fluid is heated and vaporized in the vaporizer by the heat exchange between the geothermal fluid and the secondary fluid. The generated vapor from the secondary fluid is directed to the turbine for electricity production in the electric generator. The advantage of the organic fluid is that it becomes superheated after expansion in the turbine which results in better thermodynamic turbine performance.

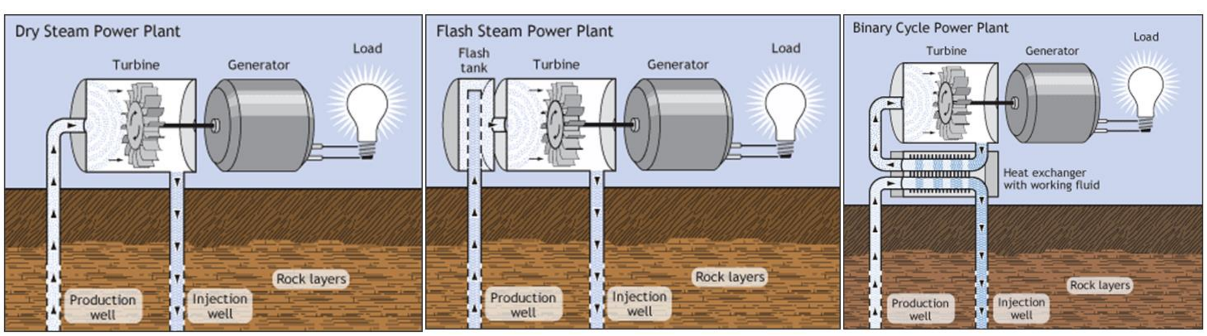

Figure 5: Geothermal power plant types

5.5 Electric machines and transformers

An electric machine is a device that converts electrical energy to mechanical (motor) or/and mechanical energy to electrical (generator). Generators convert mechanical energy from a prime mover to electrical energy through the action of the magnetic field. Transformers convert AC electrical energy at one voltage level to AC electrical energy at another voltage level at the same frequency. The output voltage of the generator in a power plant is of the order of 10-30 kV. This voltage is too low for the transmission grid because it would cause excessive losses. That is why a unit transformer is installed at the output of the generator, which raises the voltage to several hundred kilovolts. The idea of this lecture is therefore to explain to students the most basic electrical machines in geothermal power plants.

Synchronous generators are the primary source of electrical energy we consume today. In synchronous machines the rotor and magnetic field rotate with the same speed, unlike in induction or asynchronous machines where this is not the case.

Synchronous machines are AC machines that have a field circuit supplied by an external DC source. In a synchronous generator, a DC current is applied to the rotor winding producing a rotor magnetic field (excitation). The rotor is then turned by external means producing a rotating magnetic field, which induces a 3-phase voltage within the stator winding. In a synchronous motor, a 3-phase set of stator currents produces a rotating magnetic field causing the rotor magnetic field to align with it. The rotor magnetic field is produced by a DC current applied to the rotor winding.

The introductory lectures cover the construction of synchronous machines, measuring parameters, rotation speed, internal generated voltage of a synchronous generator, equivalent circuit, phasor diagram, power, torque, active and reactive power generation, characteristics of the generator when it works independently or when connected to the grid. The power-flow diagram, power losses, voltage and speed regulations are also covered.

The transformer (Figure 6) consists of one or more coils of wire wrapped around a common ferromagnetic core. These coils are not connected electrically together but are connected through the common magnetic flux confined to the core. Assuming that the transformer has at least two windings, one of them (primary) is connected to a source of AC power; the other (secondary) is connected to the loads.

The main types of transformers are explained: unit transformers connected to the output of a generator and used to step its voltage up to the transmission level, substation transformers used at a substation to step the voltage from the transmission level down to the distribution level, distribution transformers for converting the distribution voltage down to the final level, voltage or current transformers for electrical measurements. The operation of the transformer is analyzed using the equivalent circuit in order to account for the copper losses, eddy current losses, hysteresis losses and leakage flux. Voltage regulation, efficiency, phasor diagram and 3-phase transformer connections are also covered.

Figure 6: ISP students at the Končar D&ST company in front of a power transformer (Croatia)

5.6 Transmission and distribution of electric energy

Transmission and distribution networks carry electricity from power plants to electrical substations and individual consumers. Transmission networks include transformer stations, energy transformers, compensators and transmission lines. It is electric power grid of high voltage: 110 kV, 220 kV, 400 kV with power levels 60-160 MVA, 300-600 MVA and >1100 MVA. Different types of conductors (HTLS – High Temperature Low Sag conductor and ACSR – Aluminum conductor steel-reinforced conductor) and poles (tension and supporting lines) are explained.

Electrical substations are facilities which connect generator to transmission network, different levels of transmission systems and transmission to distribution networks. ISP students visited substation Žerjavinec in Croatia. It is a 400/220/110 kV substation (Figure 7). Substations consist of the following components: transformers, disconnectors, earthing switches, supporting isolators, current/voltage transformers, circuit breakers, surge arresters, busbars, lighting and other protection systems. A short description of each component is provided and explained on the example of a real facility. In addition, a typical layout of the substation based on the voltage level is presented.

Power system equilibrium, power flows, frequency control, transmission losses, AC vs. DC transmission, investments costs, etc. are also described. Introduction to smart grid concepts (wide area monitoring systems, flexible AC transmission systems, phase shift transformers, dynamic thermal rating, dynamic voltage regulation) is given as well.

Distribution systems at 35(30), 10(20) and 0.4 kV and distributed generation are introduced because many geothermal power plants with low power are connected to the distribution, and not the transmission network. Distribution lines, radial operation, distribution cables and new concepts in distribution systems (electric vehicles, demand response, multi-energy, ancillary services, reserve provision, distributed storage) are briefly described.

Figure 7: ISP students at electrical substation Žerjavinec (Croatia)

5.7 Heat exchangers and heat pumps

Heat exchangers are devices that facilitate the exchange of heat between two fluids that are at different temperatures while keeping them from mixing with each other (hydraulically separated). They are important components in power plants because they are used for many applications (heating/cooling/evaporation) in boilers/steam generators, condensers, evaporators, combustion chambers, regenerators, etc. They are classified on the basis of fluid type (gas to gas, gas to liquid, liquid to liquid), flow pattern (single pass, multi pass), shape and geometry (shell and tube, double pipe, plate type), direction of flow (parallel flow, counter flow, cross flow, hybrid flow). In binary cycle power plants a main heat exchanger is an air cooled device that serves as a condenser for the organic fluid where heat is rejected directly to ambient air.

A mathematical model of the heat exchanger is explained that includes the parameters: the overall heat transfer coefficient, fouling factor, logarithmic mean temperature difference, heat exchanger efficiency. This is done for both the parallel flow and counter flow heat exchangers.

Probably the most common way to use geothermal energy is for heating applications in heat pumps. Heat pumps use reversed heat cycles to transfer heat from a low-temperature reservoir to a high-temperature reservoir. The main components are evaporator, compressor, condenser and expansion valve. The working fluid (refrigerant) has low temperature and low enthalpy of evaporation. The efficiency of a reversed cycle is expressed in terms of the coefficient of performance which is greater than 1. Heat pumps are made as horizontal and vertical, compression and absorption type. The operation of the heat pump is described in detail, and several numerical examples are also solved.

5.8 High voltage technology

In this course, an introductory overview of high voltage technologies is given. The topics covered in more or less details are the following:

- generation of high voltages, HV AC test transformers, cascade of transformers, measurement of HV in HV lab and HV substation,
- voltage divider and spark gap, voltage measuring transformers, applicability of HV in industry and transmission of electrical energy, analytical methods for electrical field problem solving,
- ionization and deionization of gases, the origins and effects of the AC and impulse corona, materials in the electrical field, dielectric losses and polarization, electromagnetic field in the proximity of the HV transmission lines and substations,
- solid dielectrics, partial discharges, electrical, thermal and electromechanical breakdown of solid dielectrics, liquid dielectrics, electrical breakdown theory,
- generation of high DC voltages, electrostatic generator, generation of impulse voltages, Tesla's coil (Tesla transformer),
- temporary overvoltages, switching overvoltages, physical basis of lightning flashes,
- theory of electro-geometric model of lightning strike, basics of lightning location systems, gas insulated switchgear, surge protection, basics of traveling waves,
- overvoltage classification according to IEC 60071-1, traveling waves in overvoltage protection, wave equation, reflections and refractures of traveling wave, Petersen's rule, multiple reflections, lattice diagram,
- temporary overvoltages simulation, Ferranti effect, ferroresonance, emergence and switching-off of faults, switchings of unloaded transmission lines, cables and transformers,
- origin and development mechanism of lightning strike, application of lightning location system in power system, lightning protection of overhead transmission lines, overvoltage protection of the switchgear, transformers and generators,
- theory and calculation of magnetic field – practical examples, measurement of magnetic induction in HV laboratory.

In short, students will learn about significance and use of high voltage, high voltage alternating current (HVAC) and direct current (HVDC), HV transmission lines, overvoltages in power system, types of insulation systems, power transformer failure modes, insulation coordination, overvoltage protective devices, surge arresters, high voltage testing, etc.

Faculty of electrical engineering and computing, University of Zagreb, has a certified High voltage laboratory where students can attend live tests of high-voltage equipment (Figure 8).

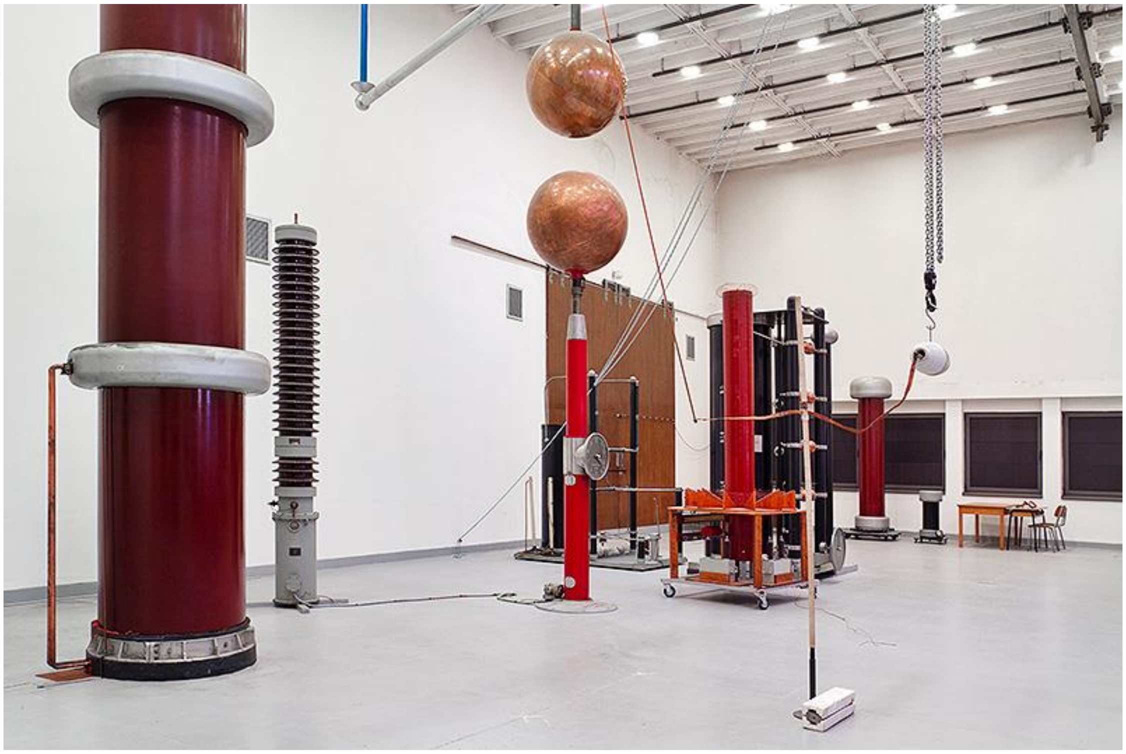

Figure 8. High voltage laboratory at FER University of Zagreb

6 Baseline courses – University of Reykjavik

6.1 Geothermal Reservoir Engineering/Modelling

Introductory geothermal reservoir engineering, through lectures and several practical projects and assignments, with the aim of providing the student with basic knowledge on the different aspects of the discipline as well as some experience in tackling practical problems.

Knowledge:

- Basic theory of fluid and energy flow in geothermal reservoirs
- Utilization of geothermal systems
- The nature and response of systems to utilization
- Approaches to geothermal resource management and monitoring geothermal systems
- Analytical and numerical modelling of geothermal systems

Skills:

- Apply scientific and engineering knowledge to build conceptual models of geothermal systems
- Apply analytic models to understand the performance of geothermal systems under utilization
- Design geothermal reservoir models for numerical simulation and perform computer simulations using reservoir simulation code
- Design a monitoring system to extract key data from the system
- Interpret monitoring data for system management

Competence:

- Reservoir monitoring
- Reservoir modelling
- Reservoir management

6.2 Markets and regulations

This course provides an overview of modern energy markets, policy and market regulation, with a primary focus on the industry in the US and Canada. The primary emphasis is electricity pricing and market oversight; some lectures will include the role of liquid and gas fuel markets as well. The class is based on guest lecturers from industry and public regulatory institutions. Readings will be available on-line from journal articles and excerpts from text materials. Grading will be based on in-class participation, 2 in-class quizzes a short essay and a final examination.

6.3 Power Plant Design

Upon completion of the course, students should have the ability to:

- Structure a feasibility study
- Describe and construct the major conceptual drawings for a power project
- Evaluate technical and economic considerations for major equipment and projects
- Assess the major factors affecting technical performance of a thermal power plant
- Assess the major factors affecting financial performance of a power project
- Identify basic construction and maintenance safety practices

Knowledge:

- Thermodynamics, plant layout, operating principles of turbomachinery and major power plant equipment

Skills:

- Plant layout
- Piping design and pump selection
- Thermal plant major equipment characteristics
- Equipment sizing and selection
- Cost estimating and the procurement process
- Project financial performance
- Sustainability reviews
- Safety in design, construction and maintenance

Competence:

- Perform conceptual design for thermal power plants

6.4 Energy Technology

To introduce and give an overview of the field of energy by presenting basic concepts and laws of thermodynamics, fluid mechanics and heat transfer. Topics covered include thermodynamic systems, properties of pure substances and phase changes, ideal gas, real gas, state equations and thermodynamic variables, work, heat and the first law of thermodynamics, the second law, reversible and irreversible processes, the Carnot cycle and the Kelvin temperature scale, entropy, heat engines, Otto, Diesel, Brayton and Stirling cycles, steam cycles, refrigeration and heat pumps, heat transfer, heat conduction in one and two dimensions, steady state and transient, convection, free and forced, radiation, the laws of Stefan-Boltzmann and Planck, surface properties, shape factors, and radiation heat exchange between surfaces, heat exchangers, duty and properties.

6.5 Energy geology

An intensive module that serves as an introduction to geology for engineers, including geological modelling and conceptual modelling of geothermal systems. After the course the student can apply knowledge of how to read geological maps, understand rock classifications, interpret structural data, log core, the contribution of geological knowledge to conceptual models of earth energy systems, and the use of modelling software to describe subsurface conditions. After the course the student can assess the position of geologists in an energy development team and understand the skills and knowledge that earth science professionals contribute to an energy development or research project.

6.6 Energy financial assessment

The lecture aims at 1) understand the theoretical basis for profitability assessment and the time value of money, 2) understand the relations and the difference between company financial statement, 3) discuss and explain with the concepts and principles of accounting and financial management, 4) understand the difference between feasibility studies and business plans and the objectives of each, 5) understand Multi Criteria Decision Making and 6) understand what working capital is.

6.7 Innovation in geothermal

On the completion of the course the student shall be able to formulate technically complex ideas with respect to geothermal utilization and develop and implement them for a competitive market. Through case studies in geothermal innovation and their own ideas, the student will learn how to develop ideas through the Canvas Business Model method, build a business plan, feasibility study, carry out a financial plan and test the idea by developing and testing a prototype.

7 Summary

The baseline courses provide basic knowledge, skills and competences in geothermal engineering for students coming from different thematic backgrounds. These courses will be available in electronic form on the website of the Master's study in geothermal engineering, as well as on communication platforms such as MS Teams, or any other dedicated learning platform for study purposes. With their help, students will acquire the necessary knowledge to be able to successfully master the mandatory subjects of the Master's study. The lectures will introduce students to the content of the four main topics of the study: geology, reservoir engineering and exploitation, electrical engineering, management and financing by means of innovative approach and methods:

- combination of lectures, numerical problems, laboratory work, computer simulations, field trips, technical excursions,
- advanced learning methods: e-learning, feedbacks, project and problem based learning, group work,
- 3D models, augmented reality.

The baseline courses provided by different institutions are the following:

1. UniLaSalle
- Thermodynamics
- Thermics
- New energy sources
- Geochemistry
- General geology
- Basic GIS techniques
- Soft skills
- Sampling and subsurface data analysis
- Dynamic of porous media
- Drilling and wireline
- Identification of Geo, Bio Energies
- Quantification and production of Geo, Bio Energies
- Innovation, Carbon neutrality and Territories
- Integrated approaches for Geo, Bio Energies
- Entrepreneurship

2. TU Darmstadt
- Introduction to business administration
- Energy finance
- Characterization of deep geothermal systems from various geological contexts
- Structural modelling
- Geostatistical methods

3. University of Zagreb
- Introduction to power engineering
- Power plant operation
- Fluid machinery
- Geothermal power plants

- Electric machines and transformers
- Transmission and distribution of electric energy
- Heat exchangers and heat pumps
- High voltage technology

4. University of Reykjavik

- Geothermal Reservoir Engineering/Modelling
- Markets and regulations
- Power Plant Design
- Energy Technology
- Energy geology
- Energy financial assessment
- Innovation in geothermal