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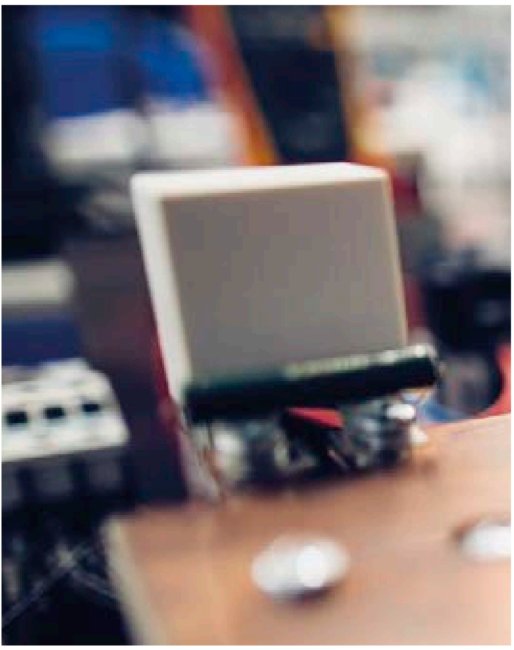
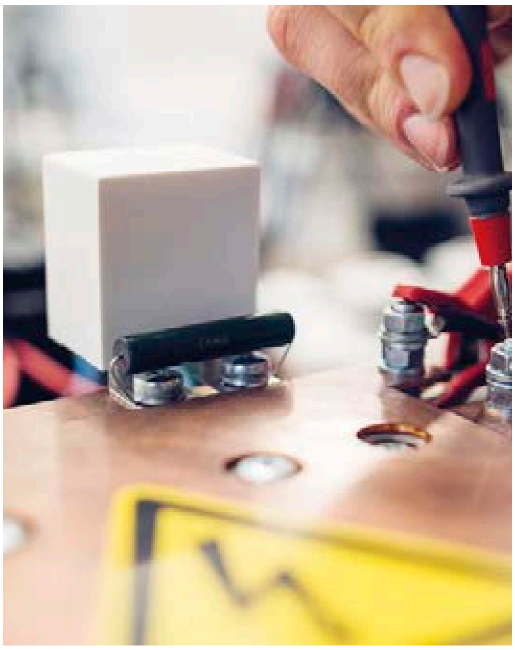
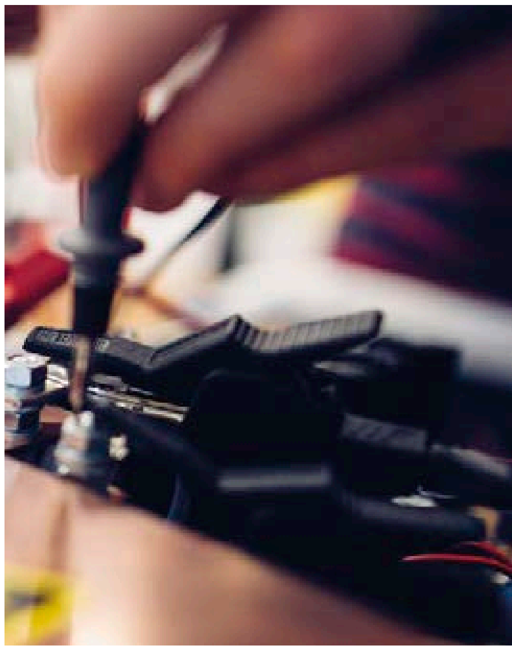
Energie-Forschungszentrum
Niedersachsen

Annual Report 2014/2015

Energy Research Centre of Lower Saxony (EFZN)







Das EFZN ist eine wissenschaftliche Einrichtung der

TU Clausthal

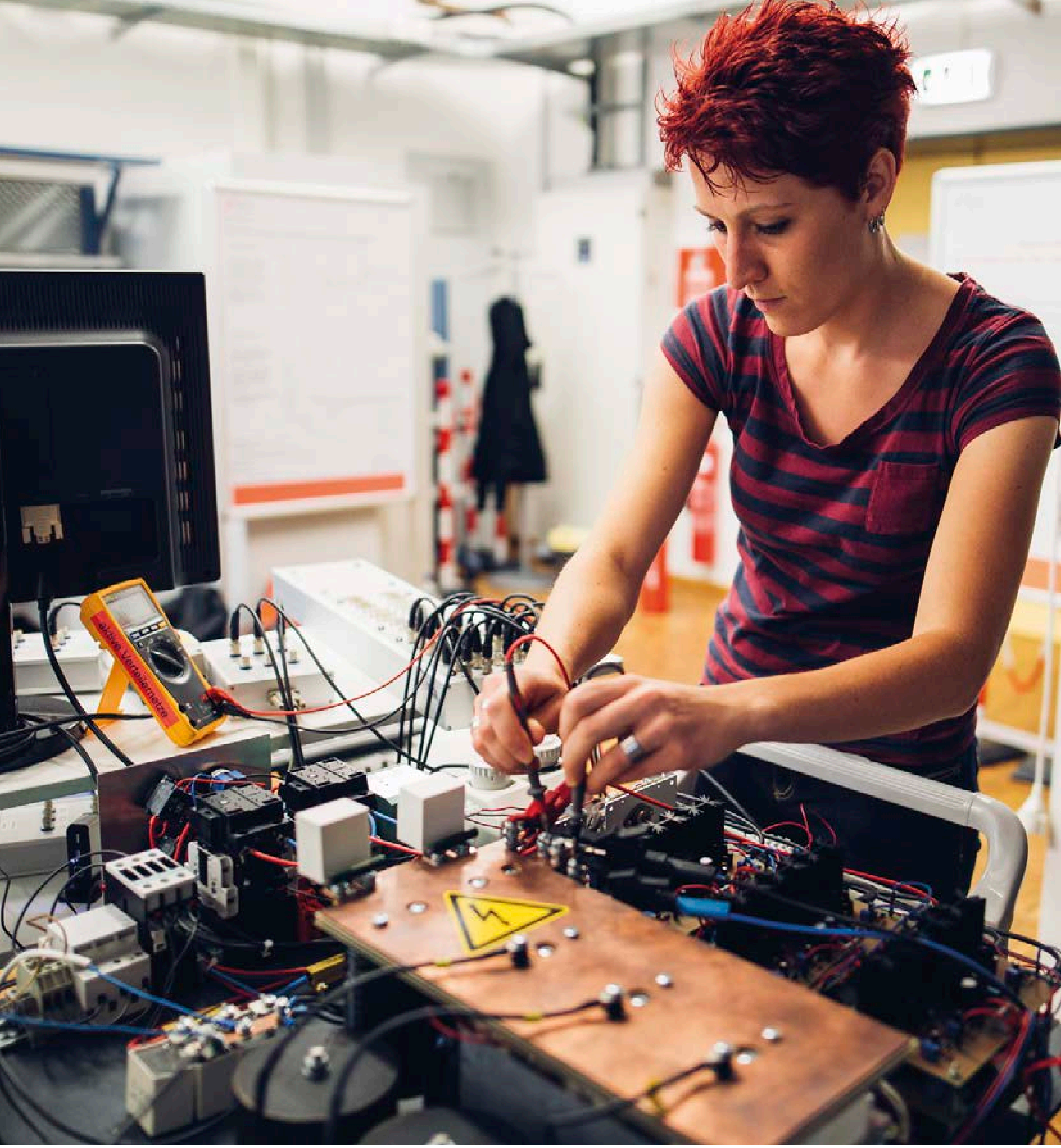
in Kooperation mit den Universitäten

Technische Universität Braunschweig

GEORG-AUGUST-UNIVERSITÄT GÖTTINGEN

Leibniz Universität Hannover

CARL VON OSSIETZKY universität OLDENBURG



Annual Report and Infrastructure

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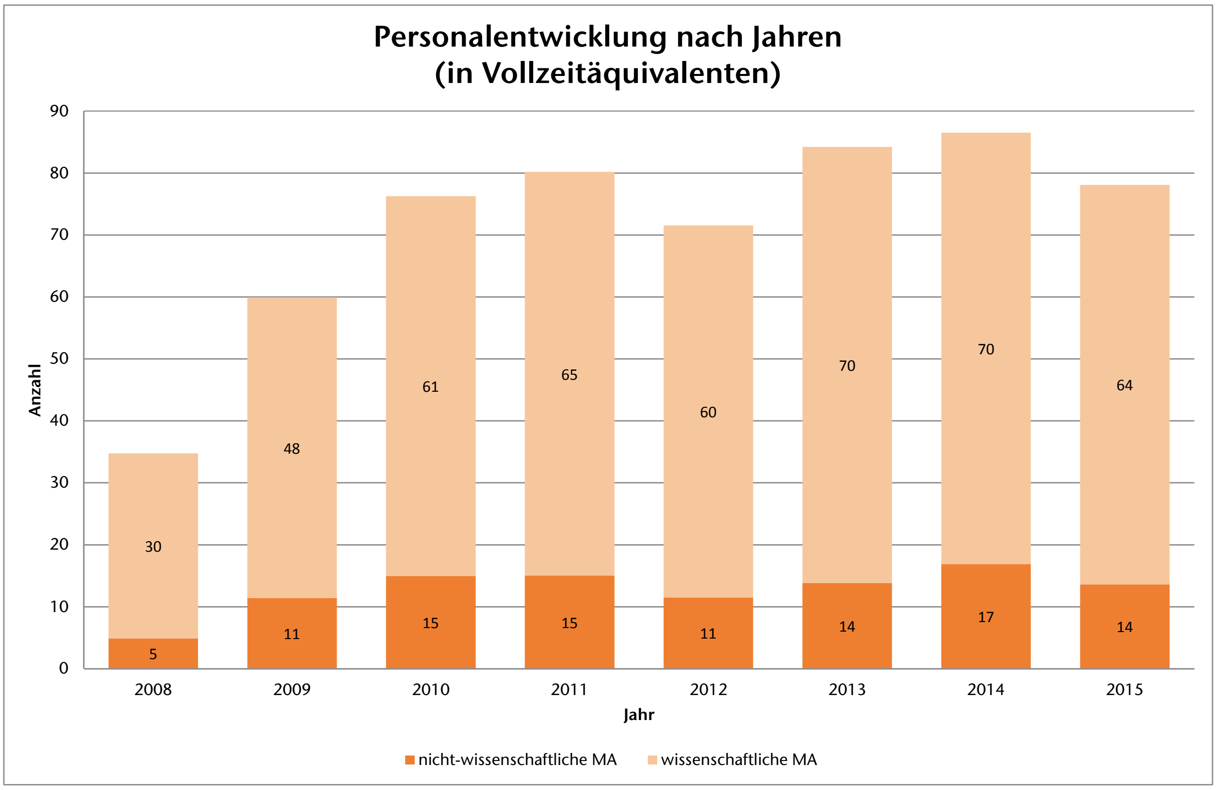
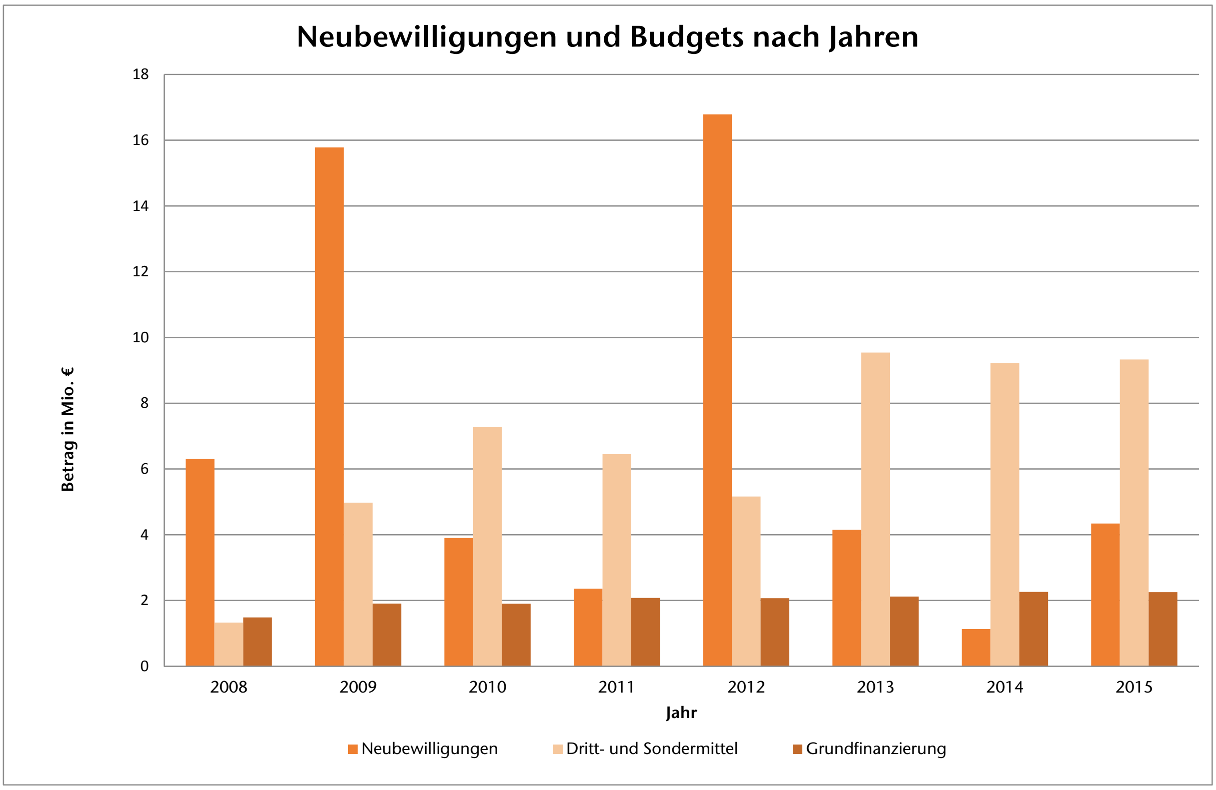
Annual Report and Infrastructure 2014/2015

In 2014 and 2015, the focus was on the completion of infrastructural measures, approved in the preceding years, at the EFZN sites Goslar and Celle. In summer 2014, the newly built "Battery and Sensor Test Centre", a joint centre of EFZN and the Department "Fiber Optical Sensor Systems" of Fraunhofer Heinrich Hertz Institute, was opened at the Energy Campus in Goslar. Additionally, the purchase of the EFZN battery test centre's research equipment, which was ERDF-funded by Lower Saxony, was successfully completed. In the course of 2015, the "Geomechanical Laboratory" for fundamental research on the energy-efficient utilization of the geological underground (for example, deep geothermal energy, underground energy storage) was set up in the new test hall. Funded by own EFZN resources, the research facility's centrepiece is a triaxial test bench for simulating thermo-hydro-mechanical-chemical (THMC) geo processes at great in-situ depths under extreme thermal, hydraulic and mechanical conditions (up to 250 degree Celsius at 4,000 to 6,500 metres). For example, it is suitable for the simulation of geothermal stimulation and production processes under in-situ conditions and for final numerical simulation. The resulting mathe-





matical models are then integrated into research studies made at the Drilling Simulator Celle and are further used for the modelling of deep drilling processes.

Within the reporting period, EFZN also set up new research infrastructure in its external facilities. Before completion of the "Battery and Sensor Test Centre", comparative studies on two different types of high-performance lithium-ion energy storage systems were already made within the scope of the BESIC project. Autumn 2014 was the start of the set-up of the "Test Bench for Charging Systems" operated by Leibniz Universität Hannover, which, among others, was ERDF-funded by Lower Saxony. The newly erected test bench especially facilitates research projects focusing on the charging of fuel cells and downsizing combustion engines as well as on research and development of electrical compressor systems and organic Rankine cycle (ORC) systems for residual heat recovery. Moreover, at the end of 2015, a quick charging station for electric vehicles was launched, which received funding within the scope of the "Showcase Electromobility".

In 2014/2015, the total investment volume for the creation of the new research infrastructure at the Energy Campus Goslar amounted to almost 7.5 million euro.

ERDF-funded by Lower Saxony, the construction work for the erection of the new building structure for the "Drilling Simulator Celle" (DSC) was successfully completed in summer 2014. Especially due to very favourable tendering results and an optimized building structure, more than one million euro of construction cost were saved, which could mainly be spent on the expansion of the large-scale research facility's operational infrastructure. A change in the DSC's scientific management at the beginning of 2015 was accompanied by an adaption of the institution's scientific and technological concept. In the middle of 2015, the federal state Lower Saxony released the funds already granted for the large-scale research facility equipment as well as the financing of the running costs during the research facility's five-year start-up phase. Completion of the basic scientific equipment is scheduled for end of 2016. In parallel, research activities with first projects started already during the second half of 2015.

Research Activities

In the years 2014 and 2015, EFZN research activities continued to concentrate on the main research topics "Energy Storage and Systems", "Deep Geothermal Energy" and "Energy Materials Research". A selection of distinguishing research projects is presented elsewhere in this report. Especially worth mentioning is the completion of research done within the scope of the Lower Saxony research association "Geothermal Energy and High-Performance Drilling Research Programme – gebo" at the end of 2014. Supported by the federal state Lower Saxony and industrial partners, the fundamental research results achieved in the programme will be transferred in a second step into first applications in industry, realized within the scope of the Drilling Simulator in Celle. Besides the aforementioned research activities, fundamental research was further intensified through application-oriented research projects focusing on the development of novel electrochemical energy storage systems.

The Centre's Scientific Equipment

In the years 2008 to 2011, the structural refurbishment of an existing historical building at today's Energy Campus Goslar as well as EFZN's scientific equipment were exclusively financed by the federal state Lower Saxony.

In 2006, the city of Goslar as real owner gave a building through leasehold to the federal state Lower Saxony, free of charge for 90 years. The Ministry for Science and Culture of Lower Saxony supported TU Clausthal with about 12.3 million euro for the organization of EFZN, including more than 3.5 million euro for scientific equipment to strengthen the intended main research topics and make them eligible for external funding right from the beginning. Furthermore, 280,000 euro of the funds for EFZN's general initial equipment were spent on the scientific library's basic equipment.

Laboratory "Active Distribution Grids"

The test bench in the laboratory "Active Distribution Grids" simulates an electric (low-voltage) distribution grid with a high percentage of distributed renewable power supply. The test bench facilitates the investigation of impacts on safe grid operation caused by increased use of power electronic components, such as PV inverters. For this purpose, the following equipment is available: two machine sets (each with one induction machine coupled with one synchronous machine), which can be used either as load or as generator, two highly dynamic and freely configurable inverters for simulating a large variety of generators and loads, an external PV system and additional resistive and motor loads. In a current project, the test grid is supplemented by adjustable equivalent grid elements (equivalent lines) to model different grid structures.

Storage Laboratory

The storage laboratory is employed for concept development and investigation of energy storage systems using different technologies. Available are lead-acid batteries (450V–650V, 40Ah), double-layer capacitors (250V–500V, 5F), a flywheel storage system (600V–800V, 6MJ), electrolytic

and snubber capacitors as well as lithium-ion batteries (300V–450V, 24Ah) and a redox-flow battery (10 KW, see photo) integrated into the in-house power supply system. The system is capable of supplying the required power, ranging from a few micro seconds up to approx. one hour. Another feature is the electronic load unit for bidirectional dynamic testing of storage technologies up to 200 kW.

Chemistry Laboratories

Research facilities in five electrochemical and materials science laboratories include two redox-flow test benches, one (own) zinc-air test bench and one glove box.

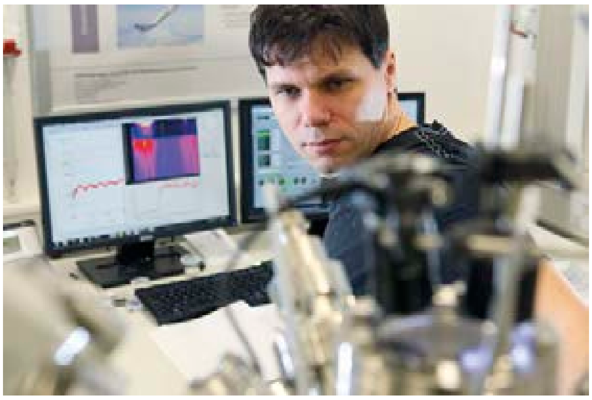
In the field of fuel cell research, one direct methanol fuel cell (DMFC) test bench, two (own) smaller DMFC test benches and one solid oxide fuel cell (SOFC) test bench are available. Moreover, there is a pressure electrolyser for testing long-term hydrogen supply into fuel cells.

The set-up of a modern test bench for charging fuel cells and supercharging downsizing engines shall facilitate future application-oriented research and development projects focusing on the charging of internal combustion engines, fuel cells and batteries.

Physics Laboratories

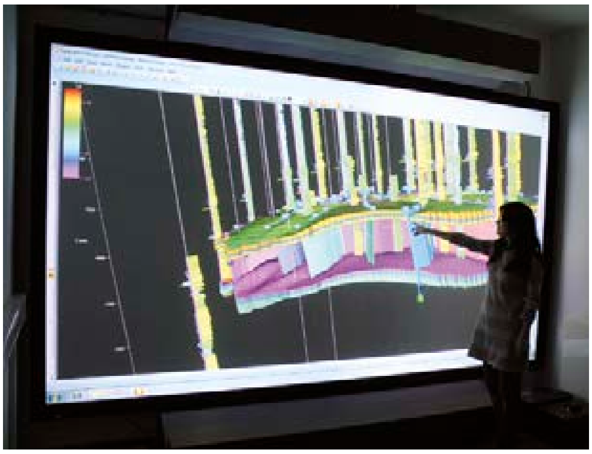
The physics laboratories are equipped with a femtosecond laser (fs laser) for tailored materials modification.

For example, it is used to write optical waveguides and photonic structures directly in glasses. Moreover, fs lasers are used to produce black silicon for solar cell processing. Glove box, coating system, excimer laser for pulsed laser deposition (PLD) and bonding tool for contacting processes are available for further processing. Material analyses can be done via secondary ion mass spectrometry (SIMS). In addition, there exists a solar cell characterization laboratory.



3D Visualization Room

Furthermore, EFZN set up a three-dimensional visualization system. The virtual reality (VR) wall, installed in a separate room, allows students and scientists to integrate the third dimension into their studies. Four computer-controlled data projectors project an image on a special projection screen. Viewers can see a three-dimensional image with the help of 3D spectacles. This is especially useful in economic geology, since this way engineers are



able to position wells efficiently. Another field of application is the three-dimensional presentation of flows in rock using three-dimensionally reconstructed computer tomographic scans, e.g. "Digital Rock", underground pump storage systems and subsurface spatial planning. The laboratory is also used by other departments for the visualization of spatial data.

Trigeneration at EFZN – Energy Laboratory in the Field

A combined cooling, heat and power (CCHP) plant linked to an absorption chiller supplies EFZN with electricity, heating and cooling energy. The trigeneration system complies with the approach of distributed power generation with direct waste energy recovery in connected buildings (even in summer). During the heating period, the natural gas-fired CCHP plant (210 kW thermal power and 150 kW electrical power) supplies the building with waste heat recovered from electricity generation. During the summer, the waste heat is utilized in an absorption chiller for the supply of 70 kW cooling energy.

The cooling energy (6 or 12 degree Celsius) is used to cool down the building as well as EDP rooms and laser labs. In the building, cooling energy is supplied by radiators with dew point control, designed as innovative heating and cooling surfaces. For harmonization of the CCHP plant operation, operating time is prolonged by one six cubic metre heat accumulator and one three cubic metre cold accumulator, each intercalating the production and distribution of heat and cold. A former water reservoir now used as cold accumulator provides additional 190 cubic metre storage capacity on site. The aim is to operate the plant in the way that heat, cold and power is produced with minimum use of fossil fuels and emissions.

The operation of the power supply system is scientifically steered by a monitoring system, capturing all energy flows and events during operation. The power supply system's control centre virtually changes into a laboratory with system equipment operated under real conditions. Hence, EFZN's power supply is setting standards regarding a modern organization of power supply, offering potential for optimizing control strategies in practice.

Battery and Sensor Test Centre

At the Battery and Sensor Test Centre (BST), the Energy Research Centre of Lower Saxony cooperates with several research institutions. The aim is to create a research infrastructure for large battery testing at a performance level, which is unique in Germany so far, leaving EFZN well prepared for the challenges of the future, when batteries in heavy goods vehicles and busses will be common practice.

Batteries, especially in the field of electromobility, are subject to high demands in terms of energy and power density, requiring highly integrated solutions. High energy and power densities in turn lead to high heat source densities, which have to be dissipated, demanding an elaborate heat management. Particularly under extreme conditions, like for example rapid charging of batteries or in case of highly dynamic loads at high or very low ambient temperatures, battery and heat management requirements are extremely challenging. Further attention has to be paid to battery behaviour under extreme conditions (high temperatures due to high charging currents or fire caused by an accident).

Within the scope of the funded project, project and cooperation partners jointly established the test centre with the aim to concentrate the partners' competencies as to characterization and investigation of batteries with respect to their electrical and thermal properties under extreme conditions. The project created entirely new test options which are very far reaching regarding electrical and thermal stress. Test benches at BST offer the following tests and corresponding load scenarios:

1. Electrical stress tests up to 1,000 V and 1,200 A (simultaneously), fire outbreaks tolerated. The power test bench purchased for this purpose is unique in its dimension. The test bench tolerates current rise times from 10 to 90 percent in less than 3 ms. Moreover, it is flexibly dividable into two channels with 600 kW power each. Efficiency is higher than 92%, and test bench channel reporting is possible in the 10 ms range. Voltages can be adjusted from 15 to 1,000 V with an accuracy of ± 1 V. Currents are adjustable from 0 to 1,200 A with an accuracy of 1.2 A.
2. The test bench was complemented with a voltage measuring system with 320 channels and an overall sampling rate of 20 kHz of 16 channels each. The channels are electrically isolated up to 1,000 V. The measuring range can be graded in four zones in decades from 10 V to 1,000 V. By this means, the system enables single-cell monitoring of a battery having 320 cells.
3. The high performance of the test bench is realized by a modern lead-acid backup battery without requiring supply from the grid, thus avoiding high energy cost and demand rates. The battery has 400 cells with an energy content of 800 kWh and is able to supply up to 960 kW power for about 20 minutes. Its advantage: Demand rates for 960 kW would amount to approx. 50,000 euro p.a., so when just considering the demand rates, the battery already pays off after a few years. Efficient use and energy savings are further advantages. Testing batteries through charge and discharge cycles until the end of their lifetime may amount to 3,000 cycles for today’s batteries. For current vehicle batteries with about 20 kWh energy content, this means 60,000 kWh for one battery which

do not have to be supplied by the grid but can be transferred back and forth between test specimen and backup batteries instead.

4. In addition to the electrical part, a gas monitoring system was installed to detect different types of gases. CO, CO_2, NH_3, HCN, HCL, HF, NO and H_2 are all measurable within detection limits below 10 ppm, except for CO_2. These are exhaust gas flow measurements in the furnace to analyse fire gases.
5. Furthermore, a fibre-optic temperature measuring system was purchased for sensing 300 measuring points simultaneously. The 300 measuring points are located in 50 glass fibres which can be inserted in the spaces between the cells. One great advantage is the sensors' small size, having a thickness which is similar to human hair. So, they can be retrofitted into practically every existing system. Another advantage is their immunity to electromagnetic fields. Since light, used for sensing, is electrically neutral, it is not affected by electromagnetic fields. This is of great importance especially in case of large currents generating large magnetic fields. The system's sample rate is 1 Hz with a temperature accuracy ±1 °C. It reliably covers a temperature range from -30 to 300 degree Celsius. Probably, even a wider range is possible.
6. A climate-controlled container, measuring 3.0 m x 3.0 m x 2.3 m, was purchased to be able to expose also larger vehicle batteries to temperature influences and the respective humidity. Humidity is adjustable from 5 to 95 percent, and temperature is controllable from -30 to 85 degree Celsius with a rate of temperature change of 1 K per minute. The climate-controlled container is flame-resistant and equipped with a nitrogen fire extinguishing system.
7. The FuelCon test bench with 16 channels with 6 V and 25 A each and one channel with 6 V and 400 A is available for testing single cells.

   In addition, eight channels can be combined arbitrarily from 25 A to 200 A to one channel. Furthermore, there are two flame-resistant, water-cooled test chambers. The equipment allows single-cell testing. A modular test bench is also available. Large batteries can be tested on the power test bench. This way, testing of all battery sizes is possible.
8. Last but not least, a large furnace with inside dimensions of 3.0 m x 3.0 m x 2.5 m and integrated emission control system permits the burn-up of entire batteries. The furnace is temperature-stable up to 1,300 degree Celsius and higher and can be heated up with natural gas to 2 MW and higher. The furnace is able to follow equivalent temperature curves.

Supplemented with further accessories like current and voltage measuring equipment and infrared cameras, the established test infrastructure is on an outstanding level nationwide, providing further options for battery system testing.

Drilling Simulator Celle

The Drilling Simulator Celle (DSC) is an important element to continue the research conducted within the Lower Saxon collaborative research association "Geothermal Energy and High-Performance Drilling Research Programme – gebo", successfully completed in 2014. Affiliated to TU Clausthal, the research institution is a branch office of EFZN located in Celle, the centre of German drilling and geothermal energy industry. DSC's goal is to promote the implementation of the "energy transition" by conducting top-level application-oriented research on the efficient and environmentally friendly exploitation of the geological underground. With two already existing and coupled scientific large-scale research facilities, the "Software and Hardware Simulator", the deep drilling process as well as concrete drilling projects can be simulated under conditions that are as close to reality as possible.

The aim is to avoid dangerous situations, which are harmful to the environment, reduce cost-intensive downtimes, improve the ecological footprint (including CO_2 footprint) and construct long-term stable underground buildings. For example, the obtained research results will be useful especially when designing, planning and realizing future geothermal energy and storage projects in Germany and abroad.

Construction work for the Drilling Simulator Celle (DSC) started in 2013 and was successfully completed in 2014. Thanks to a favourable cost development during the construction phase, the

Participants of strategy meeting of the association GeoEnergy Celle at DSC.

project, which was financed by the European Regional Development Fund (ERDF), the federal state Lower Saxony, TU Clausthal, the City of Celle and the association GeoEnergy e.V., received additional funding of about one million euro for enhancement of the research-related operational infrastructure. The second construction phase was completed in the middle of 2015.

Since March 2015, DSC is scientifically managed by Professor Joachim Oppelt, Head of the Department of Oil/Gas Production and Gas Supply at the Institute of Petroleum Engineering (ITE) of TU Clausthal. When the scientific concept became more concrete, the Ministry for Science and Culture of Lower Saxony (MWK) granted an investment volume of around 2.7 million euro for the equipment of DSC with the planned scientific large-scale research facilities. Moreover, MWK will take a share in labour and material costs each of 300,000 euro p.a. for a duration of five years.

In autumn 2015, DSC started with first third-party funded research projects. In parallel, further fundamental and application-oriented projects were prepared or are in preparation. By the end of 2016, the research facilities at DSC shall be completed and ready for use.

Besides promoting reliable energy supply, also in compliance with "energy transition" in Germany, DSC's "vision" is cost reduction for natural oil and gas, geothermal energy and underground reservoir drilling and improved safety and environmental sustainability of the drilling process. This shall be reached by creating a flexible and open software/hardware platform in order to simulate the complex drilling process as close to reality as possible. The research facility will be equipped with distinguishing features, making it unique on a world scale from the scientific and technological point of view.

This long-term vision leads to DSC's mission, based on the following principles:

- Real-time simulation of the complex drilling process based on virtual reality, considering measured values of separated system components (= drillstring segments)
- Enhancement of the software simulator, equipped with advanced visualization tools, with open interfaces (API) for continuous integration of newly developed algorithm modules and hardware test equipment

Hence, the main goal is to develop highly innovative approaches for the exploitation of the geological underground and their integration into one "tool" which supports planning and realization of drilling processes. It is planned to develop an "open" and networked simulator which, similar to flight simulators, simulates and animates a virtual drilling process as close to reality as possible, based on real or virtual underground events, and which is capable of controlling the process autonomously via embedded control algorithms.

Equipment and Research Objective

DSC's core components will be one software-based and one hardware-based simulator. The software simulator will be developed based on a "drilling simulator" to be purchased externally. In the initial situation, it will provide the possibility to simulate real-time processes on a typical drilling system. Since algorithms describing underground drilling processes only exist on a very rudimental level, the most important task will be to develop appropriate software programmes which replace the simple modules in the software simulator and thus improve its realistic performance significantly.

DSC's second large component will be the hardware simulator. In principle, this is a system which is capable of simulating the bottom part of a drillstring in the borehole in the laboratory by experiments. In this respect, it is of great importance to gain realistic measuring results, serving as real-time input parameters for the software simulator. For this purpose, the drilling process has to be simulated as close to reality as possible by using crucial parameters like for example hydraulic conditions or mechanical forces. Due to the large forces acting in real underground drilling processes, this is an extremely challenging task. At DSC, hardware and software simulator are coupled to one system, a so-called "Hardware-in-the-Loop" (HiL) system.

With the help of the aforementioned research infrastructure, which is unique in the world so far, research work at DSC will focus on the following topics:

- Development and testing of models (algorithms) first of all for the description of drilling sub-processes
- Development of automation algorithms for underground systems
- Development of a toolkit for inverse modelling
- Development of human-machine interface (HMI) systems for drilling applications
- Development of remote monitoring and control methods for drilling processes
- Integration of software and hardware simulator components into one reliable overall system
- Fundamental research on transport phenomena in non-Newtonian drilling fluids in high-pressure and high-temperature environments
- Function, stress and reliability tests for drilling systems
- Development and testing of real-time measuring systems to determine (relevant) dynamic underground conditions in drilling systems
- Development of tribo system-compatible test methods to analyse abrasive and erosive wear in tubes and pumps used in drilling engineering
- Development of high-performance coating alloys as wear protection in tubes and pumps used in drilling engineering
- Development of high-performance materials used in drilling engineering and mining industry
- Development and improvement of extremely hard materials for drill bits
- Creation of a lifetime model for extremely hard materials

- Investigation and optimization of well integrity in clay rock based on logging-while-drilling (LWD) measurements
- Improvement of 3D voltage measurements based on wireline logging methods
- Feasibility studies and design of horizontal multi-borehole stimulation for an efficient and environmentally friendly stimulation of geothermal energy reservoirs

Thematically, research at Drilling Simulator Celle is closely connected to the Institute of Petroleum Engineering (ITE) of TU Clausthal. The intensive cooperation is based on complementary competencies. A precise definition of the respective scope of activities is seen as further key to success of their joint efforts. The Institute of Applied Mechanics (ITM) and the Institute of Welding and Machining (ISAF) are further partners associated with TU Clausthal in terms of research topics.

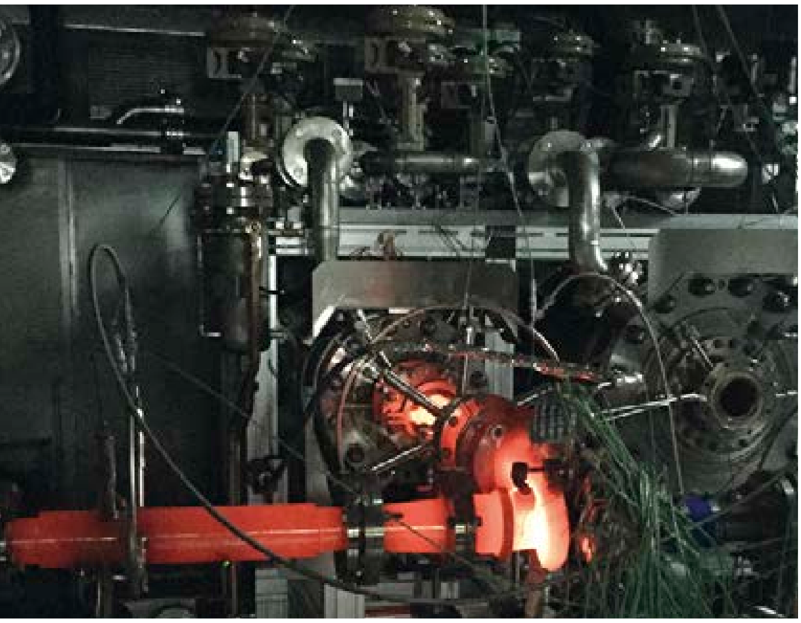
The research facility DSC offers a joint platform in Lower Saxony for the cooperation of EFZN with the Clausthal Centre of Material Technology (CZM) and the Simulation Science Centre Clausthal-Göttingen (SWZ). Considering the overall target, research results achieved at DSC also support the goals of EFZN in terms of energy technology and energy policy. DSC makes particular use of simulation science (SWZ) and material technology (CZM) instruments. Affiliated to EFZN and through cooperation with the aforementioned centres, DSC is also accessible for research of other universities in Lower Saxony (PhD students and candidates for habilitation included), previous gebo research partners and other cooperation partners. Especially worth mentioning is the active participation of the Institute of Dynamics and Vibrations (IDS) of TU Braunschweig, when applying for funding of joint research projects. The scientific management of IDS will also participate actively in the scientific management of DSC by initiating and realizing relevant projects.

Furthermore, the explicit objective of DSC is to transfer research results into practice, in favour of intense cooperation with industry and appropriate partnerships also with the mainly small and medium-sized enterprises in the region of Celle. A strategic partnership already exists with GeoEnergy Celle e.V., an association of many of the companies working in the relevant sector in Celle and abroad. In addition, it is planned to get in touch with interest groupings in the oil, gas and geothermal energy sector, which might also lead to partnerships.

Last but not least, DSC will actively strive for becoming part of a worldwide network of similar scientific institutions, with the aim to strengthen the significance and visibility of the centre in Celle. For example, these are Montanuniversität Leoben (Austria), IRIS (Norway), Colorado School of Mines (USA), Texas A&M University (USA), Brigham Young University (UK), University of Aberdeen/School of Engineering (UK), Heriot Watt (UK) and University of Stavanger (Norway).

Test Bench for Charging Systems

Within the scope of the ERDF-funded project "Test Bench for Charging Systems", the Institute of Turbomachinery and Fluid Dynamics (TFD) and the Institute for Power Plant Technology and Heat Transfer (IKW) of Leibniz Universität Hannover jointly set up a new test bench located at the Energy Research Centre of Lower Saxony (EFZN). Construction work at EFZN was completed at the beginning of 2015. The project was financed by the European Regional Development Fund (ERDF), about 1.8 million euro of which were granted by the federal state Lower Saxony for setting up the research building at EFZN. As with all ERDF-funded projects, the difference was funded by own resources of Leibniz Universität Hannover (LUH) and EFZN. The erected test bench especially facilitates research projects focusing on the charging of fuel cells and downsizing combustion engines as well as on research and development of electrical compressor systems and organic Rankine cycle (ORC) systems for residual heat recovery.



Alternative Fuels

The increasing demand for environmental safety and sustainability of future drive systems is very challenging for developers of vehicle drives. Regulations for climate protection, exhaust emission standards, CO_2 exposure limits and shortage of fossil fuels require continuous reduction of fuel consumption and exhaust emission as well as research on new drive concepts. Besides innovative, long-term strategies, as for example the use of alternative fuels, hydrogen and fuel cell technology as well as electromobility, further development of today's internal combustion engines promises in the short run great potential to solve the new challenges for the entire automotive fleet. For this reason, there is currently a strong demand for research capacities in the field of charging systems. Especially, high exhaust gas temperatures in modern, charged petrol engines require high-temperature resistant test benches in order to realize application-oriented research projects. For a successful realization of future research projects, the new test field will be equipped with the latest high-precision measurement and control technology, ensuring high flexibility with respect to possible applications. For versatility reasons, the test bench requires a modular structure with precisely matched infrastructure, realized by use of a modular container design solution. The necessary conditioning and exhaust systems are designed as weather-proof roof structures to ensure highest flexibility with respect to the internal test equipment. The core component of the new test bench is the natural gas combustion system, designed as dual combustion chamber system made from stainless steel and located in the control room of the test bench. The smaller combustion chamber has a power of 250 kW and the larger one a power of 800 kW.

A high-pressure gas compressor supplies natural gas to the combustion chambers. Compressed

In December 2014, the test bench for charging systems of Leibniz Universität Hannover was set up at the Energy Campus in Goslar.

air supply and cooling capacity is realized by use of an oil-free screw-type compressor and a water cooler. Both compressor systems are each integrated in a separate technology container, located in proximity to the test container itself. In this way, testing is possible at exhaust temperatures from 150 to 1,200 degree Celsius in a pressure range from 1 to 8 bar(abs). Adjustable mass flow spreading ranges from 0.01 to 0.25 kg/s for the 250 kW combustion chamber and from 0.1 to 1 kg/s for the 800 kW combustion chamber. The dual combustion chamber design facilitates future development and research work on the charging of both low swept volume downsizing engines for passenger cars and high swept volume engines for commercial vehicles. In addition, the dual combustion chamber system supports fundamental research and further development of twin-scroll turbines.

Organic Rankine Cycle (ORC) Module

The aforementioned basic equipment of the test bench for charging systems was enhanced by an organic Rankine cycle (ORC) module. This is to promote development and research on residual heat recovery in combustion processes. In the medium term, the cost-benefit ratio when optimizing existing components in the combustion engine will be reduced due to the high standard of the components already used. To improve efficiency, it is profitable to apply additional systems, which have not been used so far for financial or technical reasons. Such a system is residual heat recovery using a combined steam cycle. The system is known from large-scale power plants, where increased power and overall efficiency is achieved by combining a gas turbine with a steam cycle. Due to the current demand for lower operating costs and reduced CO_2 emissions, established car manufacturers and suppliers are developing complete systems and subcomponents for exhaust gas heat recovery in the automotive sector. From the technically point of view, future automotive applications will consequently call for increased research and development efforts regarding exhaust gas heat recovery through steam Rankine cycles using organic fluids (ORC). Since experiences with cycle components and operating media are limited so far, design concepts have to

be validated by experiments on ORC test benches specifically designed for such applications and the resulting requirements. The test benches must be highly variable for two reasons: On the one hand, there exists no generally preferred cycle medium so far. On the other hand, the test bench must tolerate replacement of all relevant single components, as for example evaporator, condenser, pump, and the use of recuperators or expansion machines. Moreover, the ORC enhancement of the EFZN test bench also allows stationary applications to pursue research and development work for large-scale industrial plants on a pilot plant scale. In this way, an improved efficiency through waste heat recovery using ORC cycles could be achieved.

Goal of Research and Development Projects on New Test Bench

Hence, the goal of research and development projects realized with the new test bench is to further develop fluid conducting components close to series production and to improve system properties and system integration of charging systems. In addition, efficiency and system sustainability aspects have to be considered. The new test bench will strengthen and expand cooperation of TFD with industrial partners and research institutions in Lower Saxony already existing for many years. The planned research and development activities are meant to be a direct contribution to reduce fuel consumption and exhaust emissions of today's and future vehicle drives. Hence, strategic support is provided regarding future compliance with regulations for climate protection, exhaust emission standards and CO_2 exposure limits. The findings shall contribute to environmental safety and sustainability of future drive systems and mobility concepts. In the end, this supports and strengthens the compatibility of car manufacturers and suppliers in Lower Saxony, Germany and Europe.

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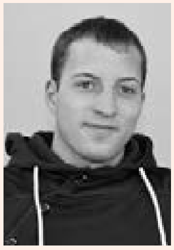

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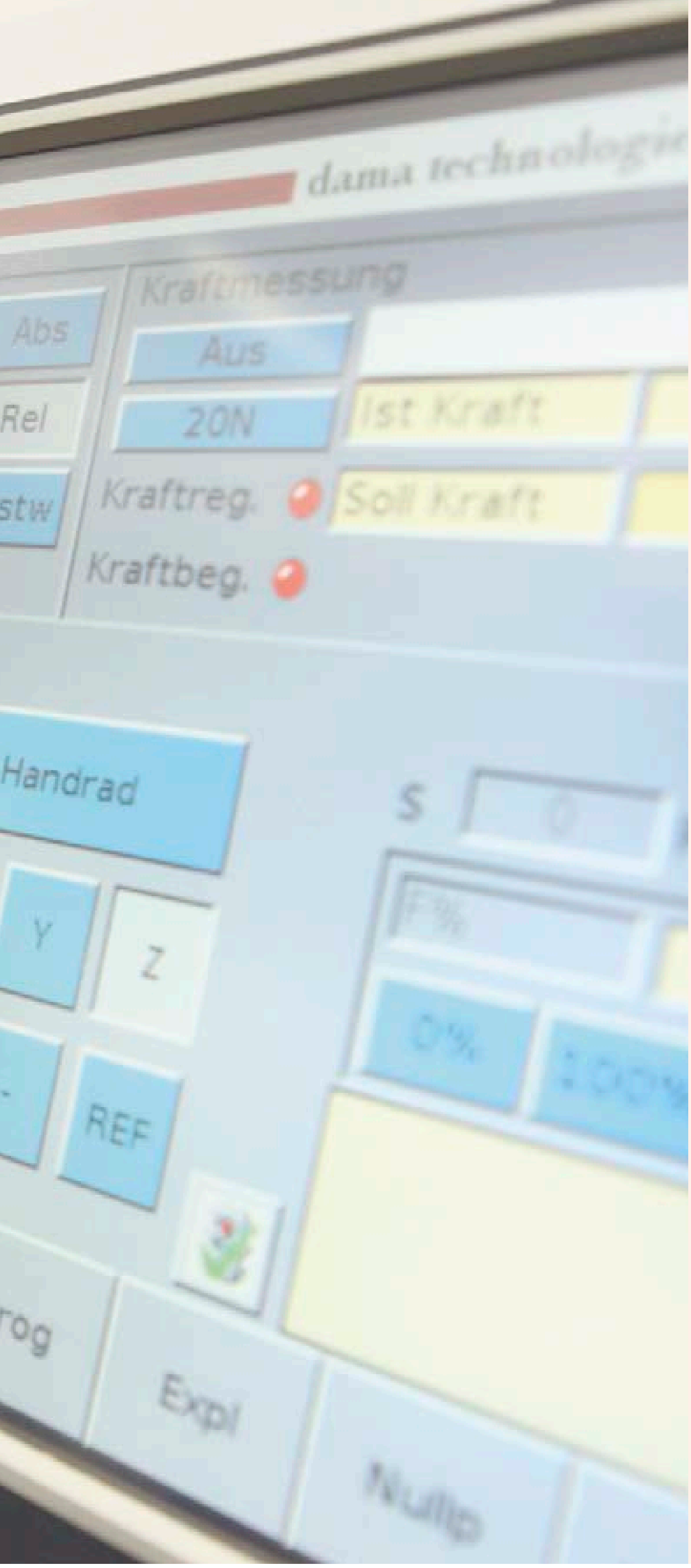

Presentation of Strategically Important Projects 2014/2015

2

BESIC: Battery Electric Heavy Goods Vehicles in Intelligent Container Terminal Operation

In private households, electromobility has not become generally accepted yet. In commercial applications, however, electric vehicles already play an important role. Vehicles for light and medium heavy goods, for example used by Municipal Sanitation Departments or public transit busses, are increasingly powered by electrical energy. As shown by the project "Battery Electric Heavy Goods Vehicles in Intelligent Container Terminal Operation" (BESIC), container transporters are even more suitable for reaching economic feasibility. Such closed transport systems offer almost optimal conditions for the use of all-electric vehicles: They are characterised by regular vehicle use, minor conflicting use and constant daily kilometres travelled. BESIC is part of the research programme "ICT for Electric Mobility II" funded by the Federal Ministry for Economic Affairs and Technology (BMWi).

Project partners

Project coordination unit:
- Energy Research Centre of Lower Saxony

Research institutions:
- Universität Oldenburg
- Energy Research Centre of Lower Saxony
- Universität Göttingen

Partners
- HHLA Container Terminal Altenwerder GmbH
- Gottwald Post Technology GmbH
- Vattenfall Europe Innovation GmbH

The project gave impetus to a wide-ranging study on electromobility in commercial transport.

BESIC project partners are HHLA Container Terminal Altenwerder GmbH, the transport vehicle manufacturer TEREX MHPS GmbH, the energy provider Vattenfall Europe Innovation GmbH and the universities of Oldenburg and Göttingen as well as Technische Universität Clausthal. In practice-oriented cooperation, automated guided diesel-electric vehicles are compared to vehicles which are powered by conventional lead-acid battery systems or innovative lithium ion battery systems. In 2011, the prototype of a battery-powered automated guided vehicle went into use at the HHLA Container Terminal Altenwerder (CTA) at the port of Hamburg. At the highly automated CTA, the vehicles transport containers with up to 70 tons of weight between ships and the yard – 24 hours a day throughout the whole year. Especially in case of many short driving cycles, i.e. many start-stop manoeuvres, electric vehicles are particularly advantageous in terms of economic feasibility compared to vehicles driven by internal combustion engines.

Since the daily operation of container transporters requires a large amount of energy in relation to their final velocity and electrical power needed, the development of battery-powered vehicles was focused on lead-acid battery systems available on the market. As to their basic design, they are presently available at considerably less cost compared to lithium ion battery systems. Due to the rapid advances in the field of lithium ion battery technology development, accompanied by a constant drop in price, the BESIC project investigates two different types of lithium ion battery systems by experiments. The main advantages of lithium ion battery systems over lead-acid battery systems are that they are chargeable in considerably less time

Research project BESIC at the HHLA Container Terminal Altenwerder: At the battery swapping station, the batteries of automated guided heavy goods vehicles are charged with surplus green power.

and that lithium ion battery systems are much lighter. At the terminal, the performance of lithium ion battery systems is tested under everyday conditions and compared to lead-acid battery systems. Further factors such as humidity and ambient temperature are also considered.

Through logistic simulations, design problems, as for example the number and capacity of exchange batteries as well as the number of charging stations and the required connected power, could be solved.

A considerable reduction of operating costs through smart battery swapping and charging strategies may be trend-setting for heavy goods transport in other industrial sectors. Previous fleet experiments at CTA showed that the battery swapping concept means additional benefit regarding the quasi-stationary battery storage volume. Controlled charging in logistics business holds a certain temporal load displacement potential, which could be exploited commercially by the terminal operator in exchange with energy providers or aggregators. While exchange batteries are located in the charging stations, they are able to supply reserve energy or store surplus energy, when necessary, on a large scale. In contrast to conventional models and resource management methods for generation and storage units, the focus of the BESIC project was on the conditioning of battery storage systems as integral part in energy management for the respective closed transport system.

In this way, surplus green power can be used profitably, thus reducing the overall charging costs by

Ten battery-powered automated guided heavy goods vehicles (AGV) are currently in use at the HHLA Container Terminal Altenwerder. The aim is to charge their batteries with surplus green power.

a two-digit percentage. Simulation-based predictive data highly contribute to the predictability of container transporters' electricity requirements and make sure that next day's charging at the station is controllable as scheduled. The comprehensive ICT support at the container terminal in Hamburg is pioneering controlled charging in commercial transport.

Within the scope of BESIC, the planning and control tool prototypes developed for the container terminal are already under test in a live system, using the OpenADR communication standard. The container terminal's energy management system, equipped with newly developed tools, has the functions of a so-called virtual end node (VEN). The virtual top node (VTN), using the OpenADR communication structure, is an information system for virtual plant management at the external plant aggregator.

Despite busy circulation of the exchange batteries, the container terminal's energy management system is capable of receiving demand signals and switching on and off individual charging processes, as required, to supply reserve energy.

Project Data

Project name:
BESIC: Battery Electric Heavy Goods Vehicles in Intelligent Container Terminal Operation

Funded by:
Federal Ministry for Economic Affairs and Technology, BMWi

Grant number:
O1ME12095

Project duration:
01.01.2013 to 30.06.2016

Reporting period:
01.01.2013 to 31.12.2015

Project manager:
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Research Network “Smart Nord“

The Lower Saxony research network “Smart Nord“ has achieved its goals. Within the scope of the research network, supported with an amount of approx. 4.1 million Euro by the Lower Saxony Ministry of Science and Culture, about 40 scientists of the universities of Oldenburg, Brunswick, Hanover and Clausthal as well as the OFFIS Institute for Information Technology, the Energy Research Centre of Lower Saxony and the EWE Research Centre of Energy Technology e.V. have worked together for three years (from March 2012 to February 2015) in six sub-projects (SP).

The research network “Smart Nord” investigated the coordinated, decentralised provision of active power, control power and reactive power in distribution grids with the aim to allow stable system operation with a small remaining number of conventional large-scale power plants. This requires the development of a new ICT infrastructure, including all components of the distribution grids.

The sub-projects of “Smart Nord“ were motivated by the transformation of the European and especially the German power system which includes the shutdown of nuclear power plants, the replacement of fossil power plants with converter-based decentralised generation units, the liberalisation of the European electricity market and the installation of smart grids and their ICT infrastructure. In addition, the transformation of the energy system requires a large amount of new power lines and transformers, in order to fulfil the changing transmission and distribution tasks and to integrate the new control strategies.

Project partners

Research institutions
- Energy Research Centre of Lower Saxony
- TU Clausthal
- Universität Oldenburg
- Universität Hannover
- TU Braunschweig

Partners
- NEXT ENERGY
- OFFIS – Institute for Information Technology

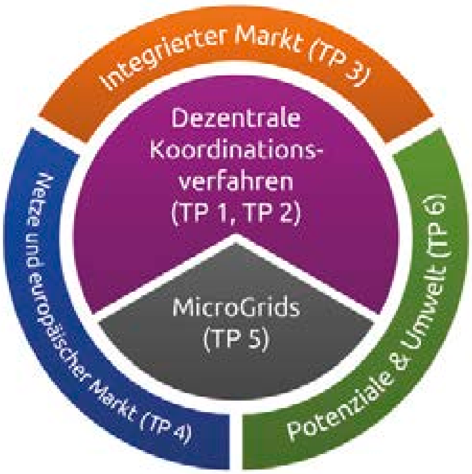
Within SP 1, methods were developed to allow decentralised active power supply in the distribution grids through coordinated coalitions of generation units and an adapted consumption of the predicted generation with as much accuracy as possible. The formation of such coordinated coalitions allows the generation units to contribute also to a higher-level electricity market.

SP 2 was focused on the development and testing of methods to open up the market for ancillary services like provision of control power and reactive power to support the power grid in real time and to give the units the opportunity to participate in the future market for control power.

Design and requirements of the above-mentioned future markets were set within SP 3. This included the design of new products and marketing opportunities for active and reactive power of the decentralised generation units.

Based on the unit dispatch, which resulted from SP 1 to 3, the resulting states of the transmission and distribution grids were evaluated in SP 4, using stationary and dynamic simulations to analyse the frequency stability, in order to identify measures to ensure frequency stability in future grids.

Control strategies for distribution grids with a large amount of volatile converter-connected gene-



Overview of "Smart Nord" sub-projects

ration units were evaluated in SP 5. This included strategies for distribution grids connected to the transmission grid and islanding distribution grids without connection to other grids.

On the one hand, the aim of SP 6 was to evaluate the potential for the construction of new renewable generation units. On the other hand, scenarios were simulated for unit and gid structure development and then analysed with respect to their impact on environment and ecosystem services.

Detailed information on the research results are given in the final report of the research network "Smart Nord". The final report can be downloaded on the project web page or ordered as hardcopy from Dr.-Ing. Torsten Rendel (while stocks last).

Project Data

Project name:
Research Network Smart Nord

Funded by:
Ministry of Science and Culture

Grant number:
VWZN2764

Project duration:
01.03.2012 to 28.02.2015 (phase 1 & 2)

Reporting period:
31.12.2013 to 28.02.2015

Project manager:
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Research Association Geothermal Energy and High-Performance Drilling Research Programme (gebo)

The goal of energy transition in Germany is the transformation of the energy system towards a sustainable, environmentally friendly energy system, while maintaining security of energy supply and economic efficiency. To meet these targets, the main issues are consistent development of renewable energies, reduction of greenhouse gas emissions and a basically more efficient energy system. To transform today's energy supply structures from fossil fuels towards renewable energies, geothermal energy could make an important contribution – considering the three objectives "climate and environmental protection", "security of supply" and "economic efficiency/ affordability".

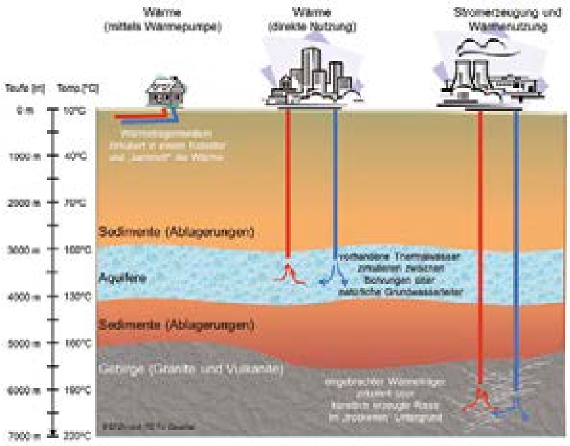

Figure 1: Schematic diagram of possibilities to exploit geothermal energy in Northern Germany.

The main advantages are availability, irrespective of time, seasonal fluctuations and weather conditions, and its substitution potential in the base load range as well as prospects concerning clean energy supply independent of fossil resources. Making geothermal energy usable is expected to make a solid contribution to climate protection and secure energy supply in the future. The goal of the Federal Government of Lower Saxony is the extensive exploitation of the existing geothermal potential of Lower Saxony's subsurface for future heat and power supply. Despite relatively moderate temperatures in the geological subsurface, Lower Saxony offers the best conditions to achieve the respective goals: It possesses considerable geothermal potential, and knowledge of the deep geological subsurface is available from existing oil and natural gas wells. Additionally, the scientific and industrial infrastructure for its exploration and development has demonstrated excellent reputation.

For power supply based on geothermal energy, petrothermal systems and some hydrothermal systems are of importance. Hydrothermal systems use the energy which is contained in the water of the deep subsurface. Petrothermal systems use the energy which is stored in the rocks of the deep subsurface. Petrothermal systems are also called hot dry rock (HDR) or enhanced geothermal systems (EGS). Up to now, the exploitation of deep geothermal energy using petrothermal systems is related to high cost and risk. The reasons are above all high costs for the deep boreholes required and for the development of the necessary geological heat exchangers. All systems require deep boreholes – except for areas affected by volcanic activities (Figure 1).

Within the scope of the research association Geothermal Energy and High-Performance Drilling Research Programme (gebo), scientists of the Energy Research Centre of Lower Saxony want to meet these challenges through joint research. Engineers, geologists and physicists are working on solutions how to exploit geothermal energy. After all, geothermal energy is always available and independent of weather conditions, time of the day and seasonal fluctuations, compared to renewable wind and solar energy. The research association was supported by VolkswagenStiftung with several millions of euros. Although funding expired in 2014, the scientists have been continuing with great intensity to pursue the topic of the future – the exploitation of geothermal energy.

To be able to use geothermal power nationwide, many obstacles have to be removed first. For example, in Lower Saxony, drillings of 6,000 metre depth are needed to reach layers with temperatures from 200 to 250 degree Celsius, as required for geothermal power plants. The main obstacle is high cost. Every drilling costs millions of euros, and every geothermal power plant needs two deep drillings, one to pump in cold water, the other one to extract the hot steam which is then converted by a turbine into electrical power.

The technology currently available for deep wells is adapted to the needs of the oil and natural gas industry. Oil and natural gas wells are drilled to provide a reliable connection between a reservoir in the subsurface and the surface installations for the duration of exploitation. In principle, this is also valid for geothermal wells, especially for hydrothermal wells with final depths of 3,000 to 4,000 metres.

Compared to typical oil and natural gas wells, well requirements of petrothermal systems, which shall recover the heat stored in the dry and hard rock formations, are quite different:

- the average temperature is higher,
- the target is hard rock, for example volcanic rock,
- system operation requires large contact areas, sustainable subsurface heat exchangers, either

Project Data

Project name:
Lower Saxony Research Association Geothermal Energy and High-Performance Drilling Research Programme (gebo)

Funded by:
Lower Saxony Ministry of Science and Culture
Baker Hughes INTEQ GmbH

Grant number:
ZN2481, ZN2525, ZN2649, ZN2741

Project duration:
01.02.2009 to 31.01.2014

Reporting period:
01.02.2009 to 31.01.2014

Project manager:
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Georg-Peter Ostermeyer


Frank Mattioli

naturally existing or artificially created,

- minimisation of the hydraulic resistance in the wells during production, and injection requires large flow cross-sectional areas,
- the average depth is larger.

These less favourable conditions require new solutions (Figure 2).

To meet the aforementioned challenges, the research association gebo aims at developing new concepts for a highly efficient and effective production of geothermal energy in deep geologic layers with low geological and technical risks. These new concepts are supposed to make this renewable energy source economically more efficient. With the focus on innovative aspects in the production of drillings and the development of subsurface heat exchangers, the research association addresses exactly those research fields of a geothermal project, where cost and risk (about 70 percent of the total investment) are highest.

Project partners

Project coordination unit:
– Energy Research Centre of Lower Saxony

Research institutions:
– TU Braunschweig
– Energy Research Centre of Lower Saxony
– TU Clausthal
– Universität Göttingen
– Universität Hannover
– Leibniz Institute for Applied Geophysics
– Federal Institute for Geosciences and Natural Resources

Advisor
– Baker Hughes INTEQ GmbH

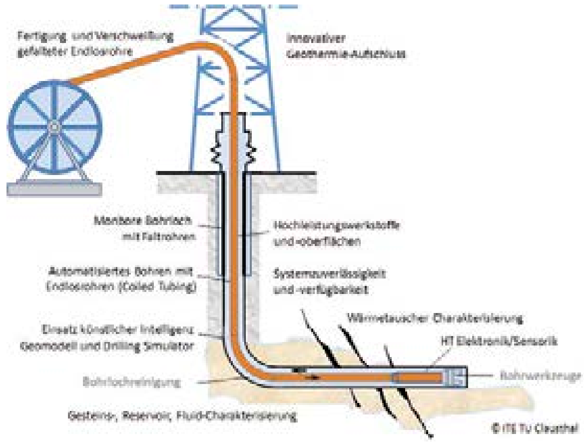

Figure 2: The drilling concept to be realised within the scope of the research association gebo with associated topics investigated in the respective main research fields.

Geologists, physicists and engineers of gebo research partners are currently trying to find out which regions are especially suitable for geothermal exploitation. Moreover, they are developing new measuring methods to be able to predict cost and security of wells with as much accuracy as possible. Additionally, the researchers are working on alternatives to the mechanical drill bit normally used today, but which needs to be replaced during the process for several times. Further subject of current research are the materials used. They must be able to withstand temperatures up to 250 degree Celsius and pressures up to 1,000 bar as well as saline groundwater. The same applies to measurement equipment used to navigate in the subsurfaces and collect crucial data.

The superior goal of the research association gebo is to make important contributions on a high scientific level with regard to safe future drillings under hot hard rock conditions, as they are typical for Lower Saxony, and their development towards geothermal drillings with sustainable geological subsurface heat exchangers. Research at gebo includes:

- reduction of drilling costs,
- improved drilling technology for hard and hot rock drilling,
- improved success ratio.

The goal shall be achieved with the development of highly innovative technology approaches, which serve as modules within an overall concept for novel methods to realise deep geothermal drillings in hard rock, and through interdisciplinary joint work of engineers and scientists in cooperation with industrial and scientific partners (Figure 3).

In detail, this includes:
- the development of technologies for an appropriate mapping and characterisation of the geological subsurface,
- the achievement of high drilling production rates through sustainable geological subsurface heat exchangers,
- presentation and investigation of approaches and concepts for the reduction of deep drilling production costs, which are dominant in geothermal power plants,
- critical contributions to the reliable use of modern drilling technology at temperatures > 200 degree Celsius,
- improved outcrop of hard rock by means of new materials and tools,
- controllability of technical risks caused by high temperatures and production rates, changing operational demands, salt percentage, et cetera.

The research association gebo unites the traditional competencies of all participating universities and non-university research institutions of Lower Saxony in the field of geo sciences, drilling technology, materials sciences and technical systems. More than 40 scientists and engineers from all disciplines collaborate to develop and evaluate new concepts, materials and devices (Figure 4).

Within the scope of the research association gebo, scientists and technical staff from different research institutions and universities of Lower Saxony are working in four research areas: Geosystem, Drilling Technology, Technical Systems and Materials. The cooperation of the four research areas is assured by a steering committee consisting of the research area coordinators, the speakers of the association and representatives of the participating industry.

The steering committee is supported by the advisory board which deals with scientific, financial and energy policy goals. Speakers and steering committee are supported by an administrative office located at EFZN in Goslar.

In September 2011, the research association was evaluated by the Scientific Commission of Lower Saxony (WKN) on behalf of the Ministry of Science and Culture of Lower Saxony (MWK). The final report says: The expert group evaluates gebo as an innovative, pioneering project on regional, national and international level. gebo is able to make considerable contributions to the development of deep geothermal energy exploitation (in the base load range) with large contact areas and large power plants, which is seen as important part in the future mix of renewable energies.

Establishing gebo (before the energy transition introduced by the German Federal Government in 2011) was courageous, visionary and in retro-

Figure 3: Research association gebo with its four main research areas Geosystem, Drilling Technology, Materials and Technical Systems, embedded in the global development activities of Baker Hughes.

spect exactly at the right time. Nowhere in Continental Europe, the prerequisites for the realisation of such a research project are as favourable as in Lower Saxony, offering an ideal constellation of university and non-university research institutions as well as worldwide operating industrial enterprises.

From the experts' point of view, the topics addressed within the scope of gebo should be pursued beyond the termination of the project in 2014. The expert group expressly encouraged the Federal State Lower Saxony and industry to continue their research on geothermal energy and drilling technology beyond the end of gebo.

The results achieved within the scope of the research association gebo are perpetuated, among others, at the Drilling Simulator Celle (as mentioned in this report).

At the end of 2015, the research association gebo was terminated successfully. All of the 32 projects from the four main research areas Geosystem, Drilling Technology, Technical Systems and Materials recorded their scientific findings in final reports. Due to the significance and attention the results from the research association Geothermal Energy and High-Performance Drilling Technology Research Programme attracted on national and international level, EFZN published the "Final Report of Geothermal Energy and High-Performance Drilling Collaborative Research Programme" (Volume 30; ISBN 978-3-7369-9080-7) in four parts, issued as part of the EFZN scientific publication series.

Figure 4: The gebo community: More than 40 scientists and engineers of the research association collaborate in an interdisciplinary team to develop and evaluate new concepts, materials and devices, supported by the industrial partner Baker Hughes.

In future, further challenges for the exploitation of geothermal energy will have to be met. This requires “understandable“, realized geothermal projects! The scientists have already developed plenty of ideas. From 2012 to 2013, the “post gebo strategy group“ worked out concrete proposals in a review board, with the participation of representatives from politics and industry.

In parallel with the gebo activities, construction of the Drilling Simulator Celle started in 2013 and was completed in spring 2015. To perpetuate the research work of gebo, scientists came up with the idea to develop a hybrid drilling simulator (see Figure 5).

The layout is particularly suitable for the development and testing of innovative drilling methods and rock fracturing mechanisms for the exploitation of petrothermal geothermal energy under consideration of entire drillstring dynamics. To realise this idea at Drilling Simulator Celle, a comprehensive R&D project is in the application phase.

The hybrid concept combines the advantages of a virtual model with those of a hardware test bench. On the one hand, the “shortcomings” of a mathematical model are compensated by the integration of physical models, e.g. complete drillstrings, into the test bench. On the other hand, the mathematical model provides the opportunity to consider the drillstring from the interface upwards, which sometimes can be many kilometres.

Last but not least, irrespective of all technical challenges, acceptance problems have to be solved. At least since the discussions about hydraulic fracturing for the exploitation of natural gas, many people are worried about the environmental impact of such drilling projects. Therefore, the researchers’ aim is to convince people that geothermal energy is safe and not harmful to the environment and that the exploitation of geothermal energy once again gives Germany the opportunity to lead the way towards clean and safe energy supply.

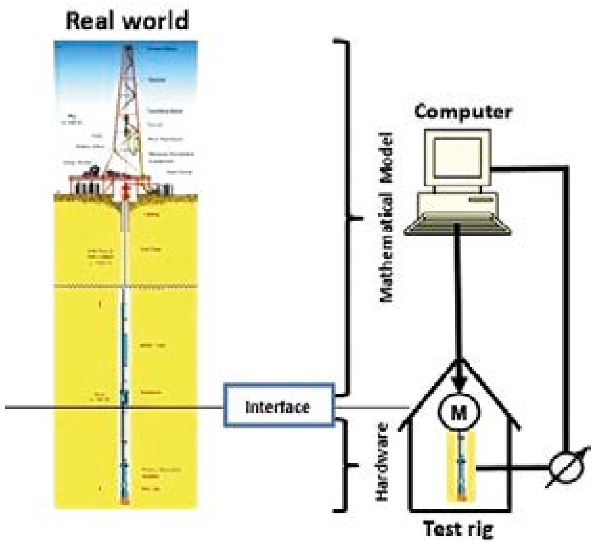

Figure 5: Basic layout of an HIL drilling simulator (SPE/IADC-173045-MS)

e-home Energy Project 2020

E-home Energy Project 2020 is a joint research project of the Energy Research Centre of Lower Saxony (EFZN) and Avacon with the aim to analyse the various consequences of new components in the low-voltage grid. The study is backed up by concrete consumption data from participating households and mains supply by Avacon. By this means, research work done within the project is closely related to practice. The joint project started in 2010 and was initially scheduled for a duration of two years (phase 1). In August 2013, EFZN and Avacon agreed upon an extension by three more years (phase 2), meaning that the fifth year of the project started in summer 2015. Due to the flexible nature of the work packages, this modification could easily be integrated into the schedule of the project. At the same time, Professor Lutz Hofmann (University of Hanover) handed over the scientific project management to Professor Jutta Geldermann (University of Göttingen). The project coordination remained with EFZN, though with some personnel changes.

In the course of the extension, the focus of the research activities was slightly shifted from questions primarily related to grid planning and technology in the first phase towards cross-cutting research in the second phase (see Figure 1).

Figure 1: e-home-consortium

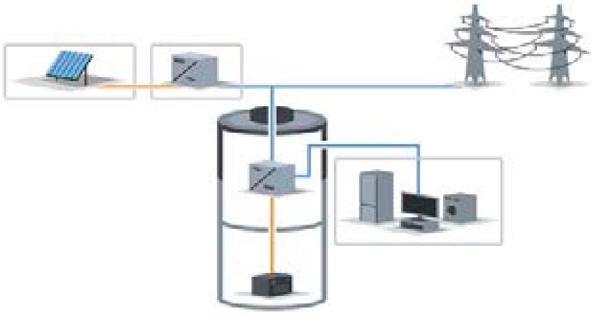

Figure 2: Installation example of a battery storage system in series connection (Source: H. Loges)

Apart from photovoltaics and smart meters, the participating households from the region of Bremen were provided with a battery storage system. As additional grid component, electric vehicles were implemented into the project. This constellation led to new questions for cross-cutting research. For the battery storage system, the major focus was on economic efficiency, customer acceptance and ecological valuation.

Technical Research

When using storage systems, it is possible to perpetuate the fluctuating power generation of wind and solar plants and adapt it more efficiently to the customer needs. Whereas in the past batteries were only used in peripheral areas of power supply (e.g., battery backup in hospitals), technological progress made storage systems also usable for private households. In combination with photovoltaic systems, the self-consumption rate can thus be increased. The rate indicates the share of solar power which is consumed on site and not fed into the public grid.

Technically, there exist various possibilities to integrate a storage system into a house grid equipped with a photovoltaic system. They were investigated in detail by Professor Bernd Engel (TU Braunschweig). An example installation is shown in Figure 2. To guarantee the system's islanding capa-

Project Data

Project name:
e-home Energieprojekt 2020

Funded by:
Avacon AG

Project duration:
01.05.2013 to 30.06.2016 (Phase 2)

Reporting period:
01.05.2013 to 31.12.2015

Project manager:
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Jutta Geldermann

Jan Ahmels

bility, the storage system is series-connected to the grid. Therefore, its overall efficiency is only 61 percent, since all power goes through the converter.

Efficiency increase is possible with AC wiring by using a stub. In this way, the overall efficiency can be increased to up to 72 percent. On the contrary, 94 percent are achievable when the storage system is DC-connected (see Figure 3).

Project partners

Project coordination unit
- Energie-Forschungszentrum Niedersachsen (EFZN)

Participating institutes
- Institute of High-Voltage Technology and Electrical Power Systems, TU Braunschweig, Prof. Dr.-Ing. Bernd Engel
- Institute of Electrical Power Engineering and Energy Systems, TU Clausthal, Prof. Dr.-Ing. Hans-Peter Beck
- Institute of Electric Power Systems, Electric Power Engineering Section, Leibniz Universität Hannover,
- Prof. Dr.-Ing. habil. Lutz Hofmann Faculty of Economic Sciences, Chair of Production and Logistics, Georg-August-Universität Göttingen, Prof. Dr. Jutta Geldermann
- Institute of German and International Mining and Energy Law, TU Clausthal, Prof. Dr. Hartmut Weyer
- Institute of Psychology, Research Methods and Biopsychology, TU Braunschweig, Prof. Dr. habil. Frank

External partners
- Avacon AG (formerly E.ON Avacon AG)

The improvement can mainly be explained by reduced conversion losses. In all investigated cases, the self-consumption rate could be increased with the installation of a storage system. In some cases, even rates of up to 70 percent per household could be achieved.

Besides the losses "behind the meter", technical research was also focused on those losses occurring in the public grid and on how to reduce them. For this reason, various investigations and simulations were made during the reporting period. Special attention was paid to operating losses caused by controllable local grid transformers (rONT). Research was directed by Prof. Hans-Peter Beck (TU Clausthal). With alternative control concepts (for example, mono-sensor operation with variable setpoint setting depending on the measured solar radiation), the existing grid can be utilized more efficiently with little additional effort with respect to voltage tolerances, compared to multi-sensor operation.

Moreover, voltage can be increased at the substation during periods of high loads in order to reduce the grid losses in times of predominantly non-linear loads. In parallel, the Institute of Electric Power Systems (IfES) of Leibniz Universität Hannover analysed further options. By the creation of low-voltage grid models, further measures for the

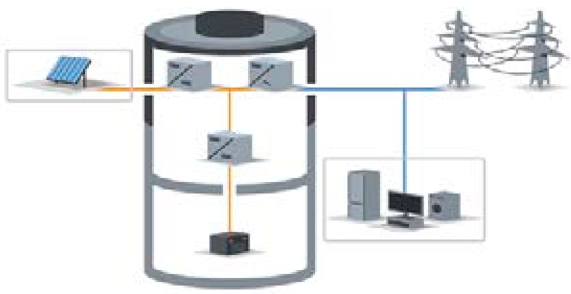


Figure 3: DC-side installation scheme of a battery storage system (Source: H. Loges)

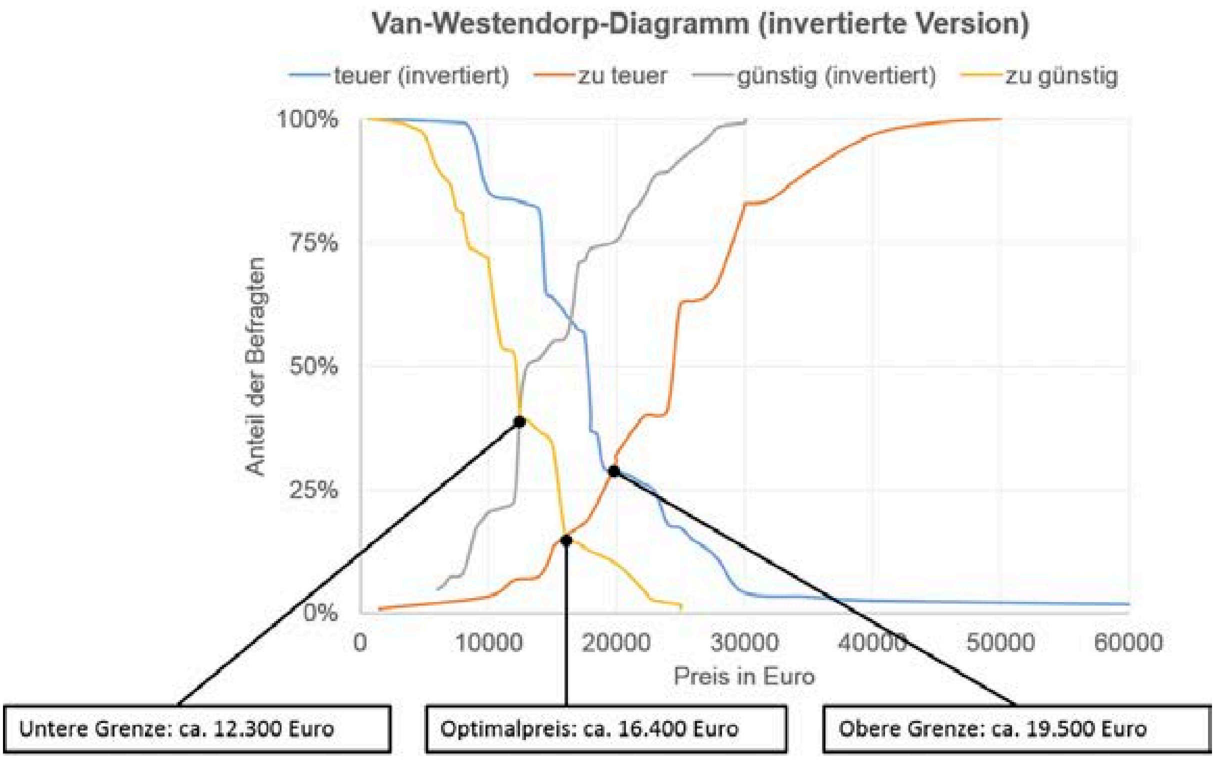


Figure 4: Determination of minimum, maximum and optimal price for an electric vehicle (Source: M. Horn)

reduction of grid losses were proposed. Both institutes will continue their research until the end of the project to permit a comparison of the losses, in order to reduce low-voltage grid losses in the future by the use of rONT and an appropriate control system.

Cross-Cutting Research

Besides the technical parameters, cross-cutting research within the e-home project considers various non-technical aspects. During the second phase of the project, the emphasis was shifted to this part of research. Together with Avacon, the focus is put on the customer, in order to analyse his needs and motivations and the options to get him involved in energy transition. In this context, the next step is to have a look at system profitability, an important aspect which is investigated in detail by the Chair of Professor Geldermann. Beyond that, there exist other, partly psychological, reasons why customers buy a battery storage system or an electric vehicle. These questions are addressed by the Chair of Professor Eggert at TU Braunschweig. Finally, legal aspects are investigated in detail by Professor Hartmut Weyer (TU Clausthal).

From the customer's point of view, key barriers to the adoption of electric vehicles are the high purchase price and their limited range. Survey research identified the optimal price for an electric vehicle (see Figure 4). A survey among households participating in e-home gave a first indication for this price. Additionally, a comparative survey was carried out to find out the willingness of less involved people to pay for the technology.

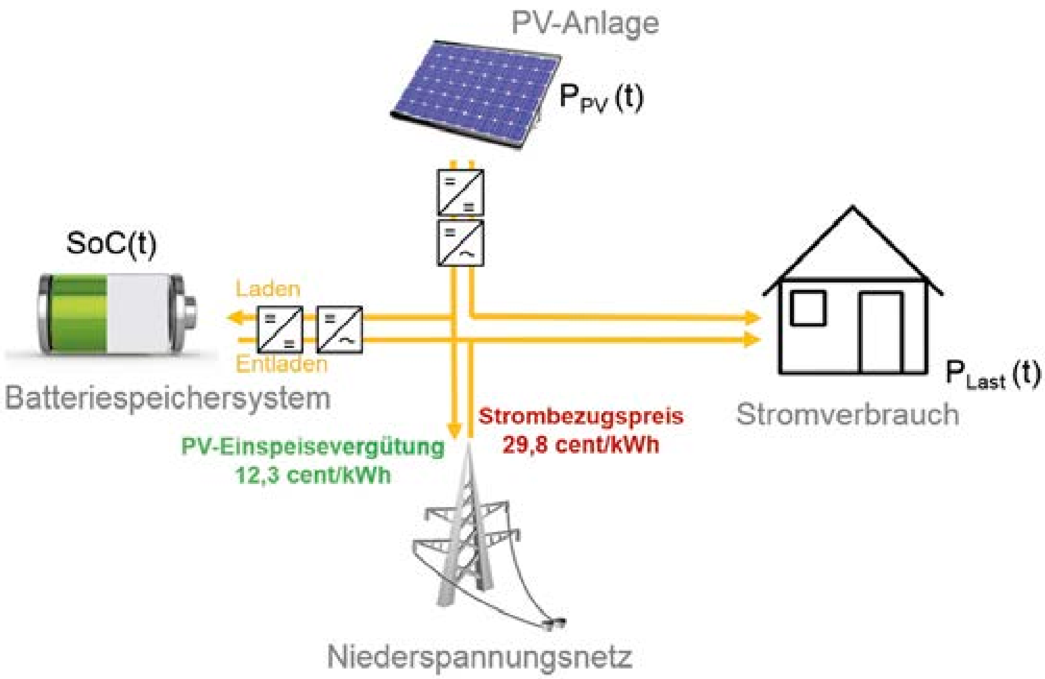


Figure 5: Diagram of power flows in a household with PV systems and battery storage system (Source: T. Lühn)

The results from the comparative survey were just marginally below those obtained from e-home participants, meaning that the willingness of uninvolved people to pay for electric vehicles (provided they approve the technology) is similarly high. There are also similarities in how customers rate the importance of electric car features. For example, the importance of car features is ranked in the same order in both groups. Maintenance costs in particular are ranked high among participants of the comparative survey. Looking at the single subcategories, it becomes apparent that those approving the technology attach less importance to the (supposed) disadvantages of electric cars (charging time and range) compared to those disapproving the technology. The greatest difference is observable with respect to CO2 emissions. Those approving electric cars attach more importance to this aspect than those disapproving the technology.

While mobility costs still differ vastly between gas-fuelled and electric cars, there is another picture considering electricity. With the constant decrease of PV feed-in tariffs, grid parity was reached in 2012. Since then, it was cheaper for the customer to use electricity from the own roof system instead of getting it from the grid. With further decreasing EEG tariffs, it became more and more attractive for households to use solar power. However, since simultaneous power generation and consumption as well as availability of solar radiation are mandatory, the aforementioned self-consumption rate is subject to various restrictions. With an energy storage system, power generation and consumption can be decoupled from each other, so that solar power can also be utilized after sunset.

In mathematical analysis, the economic efficiency of self-consumption systems with and without battery storage system was investigated. For this purpose, different load flows, consumptions and storage capacities were considered. Purchase price of the battery system, level of the PV feed-in tariff and increase of the conventional electricity tariff were identified to be the central parameters.

In summary, it can be stated that today self-consumption systems with small battery storage system can already be operated economically. Due to decreasing purchase prices for storage systems, returns will possibly increase in the next years. Nevertheless, self-consumption systems without storage system will probably achieve still higher returns than systems with storage system. In the future, there will be further need for research with respect to electric vehicles and electric heat pumps as additional loads in a household.

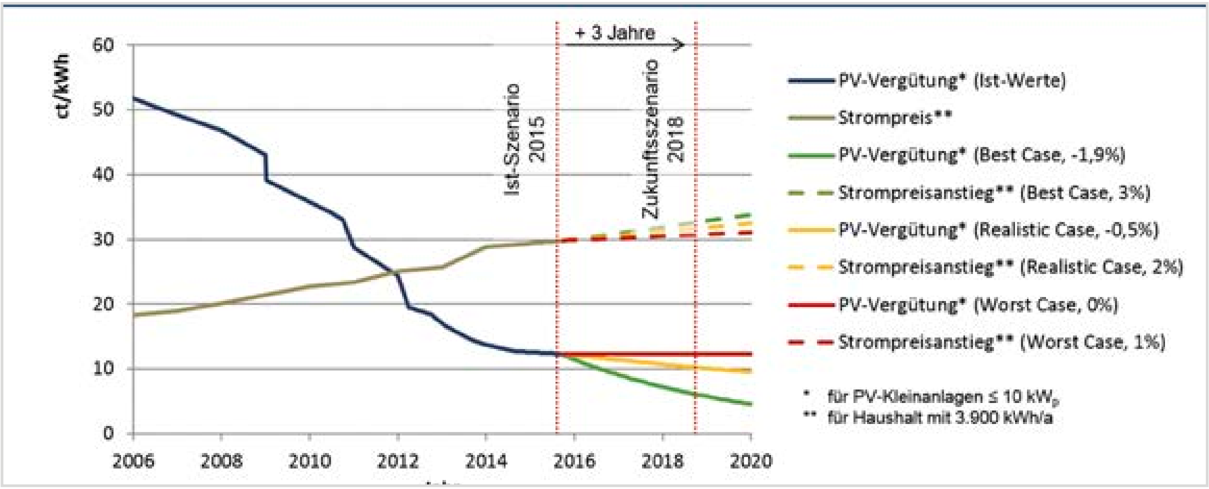


Figure 6: Prediction of future cost trends (Source: T. Lühn)

NEDS – Sustainable Energy Supply Lower Saxony

The aim of NEDS is to develop and evaluate sustainable future energy supply scenarios in Lower Saxony and to determine technically feasible transition paths, in order to achieve this aim in consideration of sustainability criteria. The project considers a power supply system to be sustainable, if all sustainability criteria as well as the needs of the current population and future generations are met to the greatest possible extent. This includes the condition of the landscape in Lower Saxony, the use of natural ressources by using renewable energies as well as the socio-economic impact and social acceptance of the future system. Besides the necessary technical requirements, such as decentralised renewable energy supply, adapted grid structures and system management, economic, ecological and social sustainability aspects have also to be considered when developing and modifying the respective energy supply structures and institutional conditions. Development and modification of the energy supply structures has become necessary due to the ongoing radical transformation of the electrical energy system, which in turn is and was initiated by the trend towards an increased use of renewable energies and a resource-friendly use of our environment, where Lower Saxony plays a pioneering role (e.g., increased use of wind power, grid development). Apart from the aforementioned technical challenges, the transformation of the whole electrical energy system implicates a substantial change of the economic relations between market players, but also of the long-standing social conditions and relations in our society.

Sustainable development of energy supply structures with all its aspects can only be achieved when the requirements of people and society and those resulting from technology, economics and ecology are in perfect agreement. In this context, the inter- and transdisciplinary research project wants to make a major contribution as well as an interdependent overall evaluation, based on multi-criteria decision analysis, of potential energy supply structures and their transition paths from the current state towards the target state, considering all relevant technical, economic, ecological and social aspects.

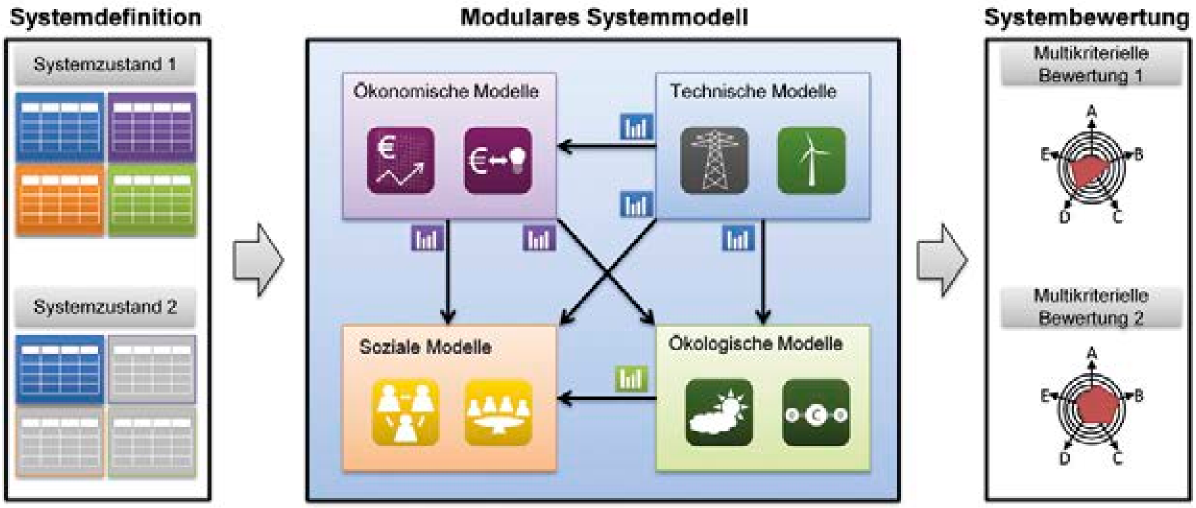
The future scenarios to be investigated, aiming at a sustainable energy supply in Lower Saxony, and their technological transition paths will be considerably different in terms of system technology required and forms of evaluation criteria. In an inter- and transdisciplinary exchange, the scenarios shall be evaluated and defined within the scope of symposia involving relevant groups in society. Particular emphasis will be placed on the dynamic development of technology components.

Work Schedule

At the operational level, the joint research project is subdivided into the sub-projects SP 1 to SP 8. The project's interdisciplinary approach requires all partners to work together in a strong network. Among others, market price developments have to be analysed by means of market simulations to be able to make an economic evaluation of the future electricity price. This in turn requires a simulation of the power generation park, including transmission system and modelling of the future load situation. Since future load development cannot be attributed exclusively to technical aspects, an interconnection with socio-scientific studies considering the consumer behaviour is necessary, too.

Sub-project 1 – Evaluation criteria and behaviour adaption within the scope of sustainable energy system development

A sustainable energy system consists of various technology components. The development of



Sustainable development of energy supply structures with all its aspects can only be achieved when the requirements of people and society and those resulting from technology, economics and ecology are in perfect agreement.

such a system, which is representable within the outlined paths, involves various combinations of these technology components. People, whose supply with energy is a sub-goal of the system, are directly or indirectly confronted with some of these components (cf. SP 3). Other components are at least partly beyond their immediate range of experiences (cf. SP 6). Besides abstracting considerations of an energy supply system itself and the requirements imposed on it, above all the concrete changes, which are connected with changing technology components or their combination and which have consequences for the individual or social behaviour of people, are a decisive factor for individual evaluations. In this context, various evaluation criteria may be relevant, with varying importance depending on the context.

In the context of the overall project, the aim is to analyse in theory the interaction among technological, economic and ecological changes through changes of the energy system considering the individual representation of the related consequences and evaluation processes depending on it. The parameters required for the respective modelling shall be estimated, at least exemplarily, by means of empirical paths.

Apart from various technology components, a sustainable energy system also includes the consumers who define through their behaviour essential characteristics of the power supply system.

Changes in the power supply system might require behaviour adaption, or changed behaviour can be a crucial factor for the development of a changed power supply system. The aim of the sub-project is to investigate the potential role of individual behaviour as component or maybe as barrier considering the changes regarded in this context. Apart from analysing the interdependencies between technological attributes of the power supply system and behaviour adaption, the focus is also on intervention-oriented questions, i.e. in how far and in which way relevant behaviour components of consumers are manipulable. This is to be considered above all with regard to the settings investigated in SP 3.

In the context of the overall project and above all in close agreement with the investigations planned in SP 3, the interaction between technological and behavioural changes through changes of the energy system shall be analysed in theory. Theoretical predictions derived for the respective single questions shall then be validated, at least exemplarily, by means of appropriate empirical paths.

Sub-project 2 – Transformation of energy systems as social diffusion

Acceptance and adoption of an innovation by so-called "adopters" depends on their motives and interests as well as on the characteristics and the state of the respective diffusion system. The latter includes four dimensions:

- Innovation characteristics considering relative advantages for potential adopters (economic advantageousness, cultural integrability, trialability, observability, potential for reinvention).
- Social structure within the diffusion system: key actors (change agents, opinion leaders), characteristics of potential adopters, networks, formal and informal institutions, communication routines.
- Temporal structure and stage of development of the previous diffusion process: (a) stages in the individual decision process (adoption process), (b) different degrees of propensity to adopt an innovation, measured over time, (c) cumulated number of adoptions taken place, plotted over a length of time.
- Communication channels: Apart from technical (mass) media, immediate ways of interpersonal communication prove to be important; communication as well as cultural theories are appropriate ways to analyse and develop the interactive context of social diffusion.

One central feature of diffusion-oriented paths is the assumption that decisions taken by potential adopters do not only depend on structural characteristics but especially on the number of adoptions already taken place, which have been observed by decision makers (cf. [22]). The social interdependency of adopter behaviour is the basis for networking and communication strategies which may release or promote diffusion dynamics (social "chain reaction"). To transfer this logic to the object of research in the NEDS project, apart from diffusion research also concepts of network, institutional, communication and consumer research are applied.

In the context of the overall project, this sub-project is linked with SP 5 and SP 8, from which relevant objects of the necessary diffusion are derived, namely design of technological transformation elements (power generation systems, distribution grids, information systems, efficiency innovations) and necessary behaviour patterns (energy demand, use of information systems by energy consumers, integration into smart grid or other decentralised energy systems, prosumer activities, investment in own power supply systems). The description of the diffusion system based on this is necessary to describe the different transformation scenarios considering social relations and dynamics, in order to derive management and action concepts for the development of settings not related to technological aspects.

Sub-project 3 – Smart Home in a Smart Grid

With regard to a future smart grid accompanied by sustainable energy supply in Lower Saxony, the sub-project is focused on the techno-economic consideration at house connection level, hereafter called smart home. From the grid-related point of view, among others regulations on grid connection and plant specifics concerning grid-compliant behaviour in connection with the low-voltage grid are considered. Moreover, grid simulations of the low-voltage grid are made in some specific cases. In the context of the overall project, the sub-project describes the stakeholder "end consumer" in an energy supply system. The knowledge and detailed estimation of future household structures as well as the development towards individual smart homes are of vital importance for the development of a sustainable energy supply and the creation of development paths.

The sub-project deals with the following questions/tasks:

- How do we define the future smart home and what will technical developments at house

connection level look like? In this respect, SP 1 together with SP 2 will work on developments regarding technological penetration levels.
- Based on the technological developments, the technical possibilities and interfaces, which require behaviour adaption or which may subserve it, will be investigated in cooperation with SP 1.
- Based on conventional and novel technologies, future house connection profiles will be modelled, assuming a sustainable influencing of behaviour as well as a plant network exerting influence on the operating modes of customer-owned power generation systems. This will be analysed in cooperation with SP 1 and SP 4.
- The question, in how far the load situation of a sustainable smart home operation permits a sustainable distribution and transmission grid operation, will be answered together with SP 6. In addition, own calculations in the low-voltage grid will be made.
- The question concerning a sustainable development and integration of smart home into future energy supply will be answered by collection of economic and ecological data at house connection level. The data will be used for multi-criteria evaluation in SP 8 and as the basis of economic evaluations in SP 7.

Sub-project 4 – Scenario-based analysis and optimisation of sustainable smart grids
In addition to the considerations made concerning the overall system (SP 6) and concerning individual smart homes (SP 3), systematic development and analysis of sustainable operating strategies for smart grids at distribution grid level (low-voltage and medium-voltage grid) at least require consideration of the following effects:
- (Local) use of renewable energies: Do smart grids directly facilitate better (local) use of renewable energies?
- Grid stability: Which impact do smart grid concepts have on the overall system in combination with conventional power plant capacities?
- Emissions and resource consumption: Which effect do smart grids have on the use of conventional power plant capacities?

Project Data

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NEDS – Sustainable Energy Supply Lower Saxony

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Lutz Hofmann

Torsten Rendel

- Short- and medium-term development of electricity prices: How do electricity prices develop under the influence of smart grids in the short and long run? Which social impact do they have?
- Long-term development of (conventional) power plants: How do (conventional) power plants develop in dependence on electricity price development and resulting power plant operating times?

The main focus of the sub-project is on intelligent, multi-criteria optimised operating strategies for smart grids which are to be evaluated with the help of simulation-based analysis of smart grid scenarios. Such a smart grid scenario at least comprises the description of the assumed electrotechnical infrastructure (electric grids and grid resources, penetration with decentralised energy systems, ...), the description of the assumed ICT infrastructure (availability and extension of communication technologies and standards, plant management concepts, ...) as well as the documentation of economic, social and environmental requirements. Based on the evaluation criteria jointly defined within the project, indicators and metrics will be developed, serving as input for models of other sub-projects or for an overall evaluation considering the aforementioned effects.

The evaluation particularly relies on results derived from simulations carried out within the scope of SP 5 based on the scenarios defined here and on the operating strategies developed in this SP. Moreover, when developing the operating strategies, smart home strategies developed within SP 3 have also to be considered, because they may have a strong influence on the available control degrees of freedom of decentralised systems. Furthermore, there are interfaces with SP 6, since reasonable evaluation of smart grid concepts concerning the effects of grid stability, emissions, electricity prices and power plant development is only possible when regarding the overall system. For multi-criteria evaluation made within the scope of SP 8, investment and operating cost data of ICT infrastructure is processed, too.

Project partners

Project coordination unit
- Leibniz Universität Hannover

Research institutions:
- Technische Universität Braunschweig,
- Carl von Ossietzky Universität Oldenburg
- OFFIS – Institut für Informatik
- Leibniz Universität Hannover
- Georg-August-Universität Göttingen

Sub-project 5 – Simulation platform for sustainability evaluation of smart grid scenarios
The simulation platform mosaik developed at OFFIS for integrating smart grid component models permits an evaluation of complex smart grid scenarios by simulations. For this purpose, it must be guaranteed that all relevant system parameters identified throughout the project as well as interfaces to other sub-projects are integrated and considered. Analysis and evaluation of the data resulting from such comprehensive simulations require a component which facilitates an automated extraction of indicators for the evaluation of sustainability aspects.

Such kind of software component must be able to derive in an automated or semi-automated manner indicators, such as CO_2 emissions, user strategies, aggregated costs or violations of technical constraints, from the simulation data of the respective scenarios and make these indicators available for a tool-based multi-criteria comparison of the scenarios. Another important task is permanent and compact storage of models, scenarios and their evaluations to make them accessible for participatory processes.

The sub-project deals with the following questions:
1. How can data resulting from complex simulations be stored permanently in an efficient and reliable way?

2. How is it possible to evaluate these data, so that the sustainability indicators identified in the course of of the project can be evaluated?
3. How is it possible to optimise the performance of comprehensive fine-grained simulations, in order to obtain optimal simulation times?
4. Which models have to be considered and composed for such comprehensive simulation scenarios?

With regard to the overall project's architecture, this SP is primarily linked to SP 1 and SP 4. In particular, SP 4 provides optimised operating strategies for smart grid simulations as well as metrics and variables for data evaluation. In return, SP 4 receives detailed system models. SP 1 is supplied with an estimation of the space required for PV and wind power plants in the low-voltage and medium-voltage grid.

Sub-project 6 – Sustainable grid development planning for renewable energy supply

The sub-project is focused on technical and economic system aspects and their interactions with sociological and environmental system aspects. On the one hand, the goal is to develop models and methods for an automated, optimal grid development planning at various voltage levels and on the other hand, to develop and analyse variables for an evaluation of the technical and economic aspects and their interactions with respect to sustainability aspects within the scope of multi-criteria sustainability evaluation made in SP 8.

In the first step, the models and methods to be developed shall describe and analyse the technical and economic aspects resulting from increasing integration of decentralised renewable energy power plants into electric grids.

In the second step, this model is coupled with an electricity market model which analyses the European wholesale market as well as the electricity prices and the use of power plants resulting from supply and demand (SP 3) of ENTSO-E, the European Network of Transmission System Operators, and adjacent TSOs. Based on preset voltage level specific planning principles, this model has to be enhanced in the way that more or less automated optimised grid development planning is possible across all voltage levels. Based on the results of this model, technical system aspects and alternative plant management concepts can be analysed in cooperation with SP 4 and SP 5.

Besides the determination of the grid development demand, further technical research aspects include stability of the resulting overall system, voltage stabilisation and provision of ancillary services, grid losses as well as error occurrence, supply of short-circuit power and short-circuit withstand capability. These aspects are investigated by time series simulations (e.g., hourly in annual tranches).

Based on the system design and on the analysis of the technical and economic aspects and their interactions, the second step is to analyse the interactions between technology and economics and social (SP 1 and SP 2) and environmental system aspects and to describe them appropriately by variables. The description and evaluation of these interactions requires a close cooperation with the sub-projects SP 7 and SP 8, the definition of interfaces and transfer parameters and a joint determination of reasonable variables.

Sub-project 7 – Macroeconomic sustainability evaluation

The sub-project investigates the sustainability of long-term development paths of power generation technologies in Lower Saxony from the macroeconomic point of view.

In this context, the focus is on the development of renewable energies until 2050. For this purpose, a dynamic general equilibrium model is newly developed and calibrated to economic data for Lower Saxony. The model includes a labour market, a capital market and a resource market as well as external effects (environment and social issues, where necessary, as well as knowledge spillovers), enabling long-term intertemporal optimisation in consideration of sustainability aspects. With the help of the model, welfare and distribution effects (influences on producers of electricity and other producers as well as on consumers) of the investigated policies can be determined. Moreover, the optimal use of policy instruments (taxes and subsidies) is determined to implement the optimal sustainable strategy on economic-political grounds. The results derived from economic analysis enable us to determine the appropriate sustainable development goal of an energy system development in 2050 as well as the input variables for multi-criteria sustainability evaluation.

Within the scope of data exchange between the project models and by applying various technologies and maximum capacities, data concerning (marginal) costs of power production are used as model inputs (maybe also with regard to electricity prices), considering the percentage of renewable energies. Additionally, quantitative data of external effects (environment, social issues), derived from other sub-projects, are implemented in the model. As output for other project models and for multi-criteria analysis, optimal economic growth paths (timing) and targets for 2050 are developed, which for example contain information on overall economic welfare, the optimal development of renewable energies, their costs and cost distribution. The paths also include optimal selection of policy instruments, i.e. taxes and subsidies, for economic energy strategy implementation. This is done in consideration of economic influences on various economic agents, such as consumers, power producers and other producers. They also contain information on optimal exploitation of resources, environmental impact and social aspects (labour market, costs for various producers and consumers). The sub-project focuses on the following questions:

1. Regarding the transition of the energy system in Lower Saxony, which timing and goal (for example percentage of renewable energies) does result from welfare maximisation?
2. In how far are negative external effects (environment and social issues) economically efficient?
3. Which overall economic costs and distribution effects do arise from the transition?
4. Which policy instruments are suitable for implementing a sustainable transition of the energy system in Lower Saxony?
5. Which is the role of learning curve effects and technical progress?
6. Which role do path dependencies and lock-in effects play through existing capacities of traditional energy technologies and a delayed transition?

Sub-project 8 – Multi-criteria evaluation of transition paths

The sub-project uses methods for multi-objective decision support and develops them further according to the present research problem. For power and heat supply, there exists a variety of technical alternatives. When selecting energy technologies, aspects of economic efficiency, security of supply, acceptance and environmental impact have to be considered. For this purpose, multi-attribute methods are well-suited, because they permit an assessment of a priori known discrete alternatives based on simultaneous consideration of multiple criteria, which are expressed in different units. Alternatives are various combinations of energy technologies permitting power and useful heat supply through conversion to primary or secondary energy carriers.

Established methods like PROMETHEE (or other multi-attribute methods) are based on the determination of criteria (cf. other sub-projects) and their specificity. Furthermore, criteria weighting must be quantified, reflecting the subjective values concerning the relative significance of criteria, e.g. with respect to the goal of a sustainable energy supply in Lower Saxony. However, a dynamic change of the energy sector could be observed within the last years. In future, it can also be expected that the significance of evaluation criteria is not necessarily the same for all alternatives. The reason is that at a later date, the performance level of the older technology, which perhaps does not show considerable development potentials, might be exceeded. For multi-criteria assessment of transition paths, the different velocities of technology diffusion as well as path dependencies have to be considered. Up to now, there exist no suitable methods.

To define the different development stages of technologies and enable a weighting, which is adapted to the stage of development, the life cycle concept or the market cycle of a product might be used.

The sub-project deals with the following questions/tasks:

- Creation of a criteria hierarchy for modelling evaluation-relevant aspects of economic efficiency (SP 7), security of supply (SP 6), acceptance (SP 1)
- Determination of alternatives, i.e. technology combinations for sustainable power and heat supply in Lower Saxony
- Investigation of path dependencies to achieve the goal of a sustainable energy supply for Lower Saxony in 2050
- Further development of methods for multiple-objective decision support (MADM method PROMETHEE) to assess dynamic transition paths
- Sensitivity analysis and identification of corrective measures.

Consortium

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- Institute for Environmental Economics and World Trade (IUW)
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Technische Universität Braunschweig

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Universität Oldenburg

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ENSEA: The European North Sea Energy Alliance

The European North Sea Energy Alliance (ENSEA) is supported by the European Union under the European programme "Capacities", the seventh framework programme of the European Commission. ENSEA started on 1st October 2012 and ended on 31st December 2015 after a duration of three years. The European Union supported the project with a funding of nearly three million euros under the "Regions of knowledge" programme (RoK). The main objectives within this project are to promote cooperation among public, private and academic sectors (triple-helix structure) and to facilitate the development of knowledge regarding renewable energy system integration and demand management. Moreover, the European partners are working on Joint Action Plans to develop the North Sea region into a Region of Excellence for renewable energy, initiating lighthouse themes based on the notion that the North Sea is rapidly developing into an energy hotspot. As the largest European production site, the key area of this development includes Southern Norway, Northern Jutland in Denmark, Northern Germany, Northern Netherlands as well as Eastern Scotland. In all participating ENSEA regions, there is close cooperation among universities, industry and regional authorities. Nevertheless, the European challenges require more "critical mass" (fundamental research, applied research, academic education, pilot plants, lighthouse themes, demonstration projects) to be able to provide knowledge and information in

In November 2014, EFZN hosted together with the European Commission an international ENSEA workshop taking place at the Land office of Lower Saxony, the representation of Lower Saxony at the EU in Brussels.

good time and to modernise the energy system in accordance with the political agenda. Improvements in energy technology may reduce energy supply cost significantly and increase the quality of energy services at the same time. Nevertheless, today's fragmented approach leads to inefficient resource utilisation caused by mutual dependencies between energy production, distribution and consumption. To achieve the EU goal – towards a resource-efficient and low-carbon economy in 2050 – it is indispensable to pursue an integrated and formalised international approach and to find solutions for the implementation of the energy transition.

System Integration und Balancing of Fossil and Renewable Energy Sources

The share of renewable energies in the European energy system must increase quickly to achieve the EU's climate, energy and sustainability targets. The future energy supply system will be completely different from today's system. Generally, the share of volatile energy production from renewable energy sources will increase significantly. In North-western Europe, a considerable increase of offshore wind power from the North Sea is expected at the Dutch and German coast. Moreover, wave and tidal power plants will contribute to energy production at a later date. A large share in energy production is also expected to come from Scandinavian wind and hydropower. Hydropower stands for 15 percent of the whole European electricity production. Here, Norway is the sixth largest producer of hydropower worldwide. In addition, further energy is produced locally, for example through combined cooling, heat and power generation (trigeneration), bio mass, bio gas and decentralised energy production.

The present energy system is not able to balance fossil energy sources with the increasing share of renewable and decentralised energy generation plants. Up to now, there exists no cost-efficient solution for storing electricity. The focus is on system integration for an efficient use of European energy resources.

In this context, balancing means to stabilise the increasing share of fluctuating and decentralised energy production through back-up, e.g., by quick regulating gas power plants (bio gas and natural gas) within the electrical energy system. Moreover, constant power supply requires additional storage systems. At the same time, an energy management system is needed for the development of the electrical energy system. These innovations and system improvements require a holistic focus on the overall energy system, exchange of competencies and knowledge within different areas of expertise and a combination of technical, economic and social aspects in the international context.

Strategic Orientation and Objectives of the European North Sea Energy Alliance (ENSEA)

ENSEA aims to develop a network to bring together energy know-how and align regional, national and European research programmes through better coordination and exploitation of research. This is meant as a significant contribution to realise the aforementioned system integration.

As an ENSEA partner, EFZN belongs to the scientific part of the triple helix structure in Lower Saxony's cluster organisations. Through the cooperation with ENSEA, EFZN advances its internationalisation strategy with the aim to develop functional structures for raising EU funds and for creating a "European Energy Region of Excellence". Together with the Wachstumsregion Ems-Achse, Germany, EFZN is partner in all work packages and manages the project consortium in work package 3 (Joint Action Plans).

The long-term vision of participating ENSEA regions is to develop a European energy region of excellence. The intended transnational structure will represent the so-called "triple helix" structure and ensure the integration of political support (top-down) and topic-related cooperation (bottom-up) through alignment of research agendas. Through bundling of forces, the North Sea coastal regions together with the Baltic Sea coastal regions will develop towards a European hotspot of energy investments, which in turn entails funds for fundamental and applied research in the participating regions and further innovations.

Project Structure

The ENSEA project was divided into five work packages (WP).

WP1: Management and coordination
WP2: Structural analysis of regional clusters and integration of research agendas
WP3: Definition of a Joint Action Plan (JAP)
WP4: Measures to implement the Joint Action Plan
WP5: Exploitation and dissemination of results

Regional Triple Helix Cluster in the ENSEA Consortium

1. Netherlands: Energy Valley Groningen
2. Lower Saxony: Wachstumsregion Ems-Achse e.V.; Energy Research Centre of Lower Saxony (EFZN)
3. Norway: University of Stavanger; Centre for Sustainable Energy Solutions (cenSE); Lyse and Rogaland County Council
4. Scotland: Energy Technology Partnership (ETP); Scottish Enterprise; Scottish Renewables
5. Denmark: Northern Jutland energy platform "EnergyVision"; University of Aalborg

Non-european partner is the Chinese province Sichuan, represented by Sichuan University, with which a cooperation agreement was signed on the occasion of the fourth German-Chinese Energy Conference in Chengdu.

Project Results

At the project start, the focus was on an overall analysis of the innovation capacities in the ENSEA regions. To begin with, every region prepared a report, describing all regional activities related to energy system integration, including driving forces for innovations, the most important research policy driven regional and national concepts, R&D activities as well as regional energy systems.

Project Data

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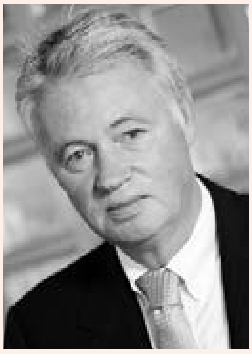

Koos Lok

Knut Kappenberg

This was to identify every region's (relative) strong points, weak points, chances and risks. Next, those regional analyses were transferred to an overall analysis of the ENSEA region.

Work regarding the overall analysis was accompanied by implementation of a communication plan comprising several regional and interregional workshops. Moreover, the results were discussed and disseminated on the occasion of various ENSEA events.

Analyses show several matching similarities between the regions: general difficulties to integrate small and medium-sized enterprises into the triple helix innovation process; sometimes insufficient transfer of scientific research results into marketable products; lack of communication and coordination between traditional fossil fuels companies (and related stakeholders) and renewable energy companies; lack of awareness of the particular urgency of energy system integration and general lack of a joint vision how to develop the North Sea region as an energy region.

However, there are also some clear differences: The Energy Valley region has a strong focus on gas, based on natural gas reserves, and consequently on production, transport, storage and research services. Recently, innovation topics like "green gas", small-scale LNG applications, power-to-gas systems as well as gas in connection with mobility have been emerging to an increasing degree.

North-western Germany's main focus is on renewable energies and technology development, such as wind power plants, offshore technology, bio gas production and energy storage. Common features of the Energy Valley region and North-western Germany comprise a strong development of production capacity and rapidly increasing activities in the North Sea offshore wind sector.

In the Rogaland region, there are considerable offshore oil and gas activities and a strong focus on hydropower (flexible generation). Norway's water capacity is already or will be interconnected in the near future with the other regions of the ENSEA project, thus making a substantial contribution to load balancing. Carbon capture and storage was identified as a further strong point and asset of the Rogaland region. Similar to Rogaland, Scotland has also a strong oil and gas cluster with close cooperation between companies and innovative research groups. Core areas of central importance for energy system integration are electricity grids, smart grids and system integration methods (data management, information and communication technologies, power electronics). With respect to renewable energies, large potential offshore wind and ocean energy resources are important for the region. Onshore wind power was identified as an area of particularly high industrial activity.

In total, all investigated ENSEA regions are highly involved in all important themes related to energy system integration. The regions are strongly focused on technology developments in the field of renewable energies with special emphasis on bio mass and onshore wind power. Nearly every investigated technology based on renewable energies was identified as a strong point of the particular region. Just solar and especially geothermal technologies were beyond the regions' focus, except in Lower Saxony.

After completion of the second work package, the focus of activities shifted towards the development of regional innovation strategies, in order to develop action plans for every region. They include, among others, an innovation strategy for every region as well as a variety of project ideas, leading to regional action plans which in turn are the basis for the development of a Joint Action Plan (JAP) for the whole ENSEA region. The most important result drawn from the JAP is the identification of joint cluster activities developed from a collection of more than 160 project ideas.

Based on the Joint Action Plan and to perpetuate the ENSEA cluster, the following cluster activities and projects are to be developed in future:

- Development of joint education programmes and knowledge transfer between universities and educational institutions around the North Sea

- Creation of SME networks in the North Sea region
- Creation of networks for a sustainable development on the North Sea region's county level
- Development of a joint research pool, exchange programmes for PhD students and postdoctoral researchers
- Projects for flexibilisation of Norwegian hydropower plants and their integration into the North Sea energy system
- Projects for reuse of existing infrastructure of oil and gas platforms in the North Sea for modern renewable energy generation systems
- Technology development projects concerning novel storage options, e.g., power-to-gas
- Projects for model-based decision support for political decision-makers (Directorate-General for Energy, Directorate-General for Maritime Affairs) regarding identification and analysis of efficient strategies for the transformation towards an efficient low-carbon energy system
- Transfer of research results for system integration of renewable energies
- Further development and strengthening of sustainable partnerships among science AND economics AND politics in the ENSEA regions and the whole North Sea region
- Expansion of the ENSEA project to other regions/countries

Project partners

Project coordination unit:
– Energy Valley Foundation, Groningen, Netherlands

Research institutions:
– Hanze University Groningen, Netherlands
– Energy Research Centre of Lower Saxony, Germany
– University of Stavanger and Centre for Sustainable Energy Solutions (cenSE), Norway
– University of Strathclide with Energy Technology Partnership (ETP), Scotland

Since 2009, the Institute of Chemical and Electrochemical Process Engineering (ICVT, Professor Ulrich Kunz, Professor Thomas Turek), is doing research in the field of redox-flow batteries (RFB). In such batteries, ionic solutions are employed to store energy. Due to redox reactions at the electrodes, the ions exist in different oxidation states, thus charging or discharging a battery. A particularly promising example for such type of battery is the vanadium redox-flow battery (VRFB), using vanadium ions in a solution of sulfuric acid in the oxidation states +2 to +5. During battery discharge, the reactions are

at the positive electrode:

$$V^{5+} + e^- \rightarrow V^{4+}$$

or $$VO_2^+ + 2H^+ + e^- \rightarrow VO^{2+} + H_2O$$

and at the negative electrode:

$$V^{2+} \rightarrow V^{3+} + e^-$$

The total formula is:

$$V^{2+} + VO2^+ + 2H^+ + e^- \rightarrow VO^{2+} + V^{3+} + H_2O$$

When the battery is charged, the reactions are reversed. One great advantage of RFBs is the separation of energy capacity, adjustable by the volume of the electrolyte storage tanks, from power, depending on the electrode surface area in the cell or stack. The principle of a VRFB is shown in Figure 1.

Compared to other storage batteries, a further advantage of energy storage in the form of ionic solutions is that no solids are deposited on the electrodes. For this reason, RFBs can withstand

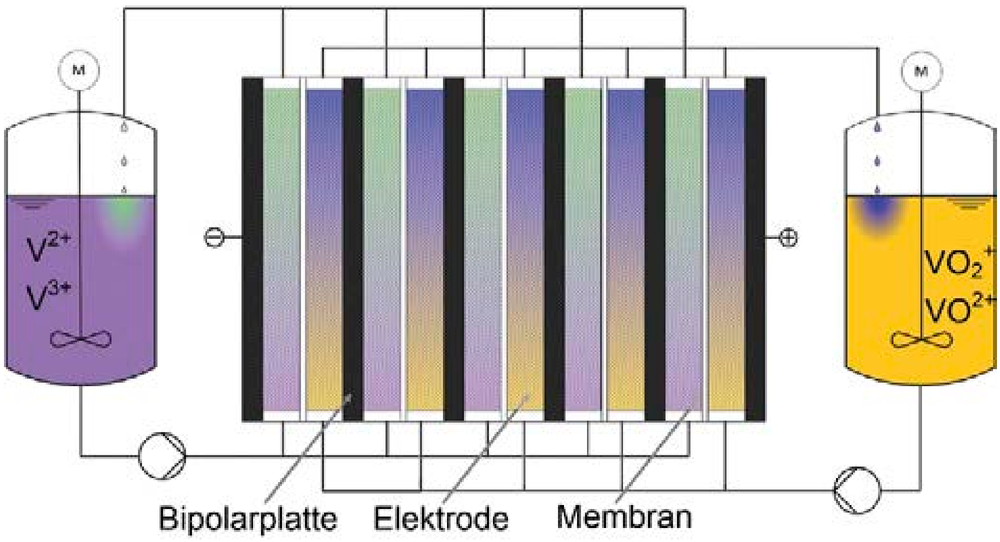

Figure 1: Principle of a vanadium redox-flow battery with tank for negative (V2+ / V3+) and positive (V4+ / V5+) electrolytes.

Project Data

Project	Funded by	Partners	Project coordinators	Project managers	Project duration
Development of elastomer bipolar plates for use in vanadium salts containing redox-flow	EFRE	Eisenhuth	Dr. dos Santos	Prof. Kunz	7/2009 – 6/2012
Scale-up of redox-flow batteries I	Industrie	Thyssen-Krupp Industrial Solutions	M. Becker	Prof. Turek	1/2012 – 4/2015
Increased efficiency in redox-flow batteries through novel bipolar plate integrated seal concepts and innovative materials for bipolar plates	BMWi	Eisenhuth	Dr. dos Santos	Prof. Kunz	7/2012 – 6/2015
Application of porous glass membranes in redox-flow batteries	DFG	Prof. Enke, Universität Leipzig	H. Mögelin	Prof. Kunz	4/2015 – 3/2018
Scale-up of redox-flow batteries II	Industrie	Thyssen-Krupp Industrial Solutions	K. Schafner	Prof. Turek	5/2015 – 4/2018
New large-size bipolar plates for redox-flow batteries produced with the extrusion process	BMWi	Centroplast, Eisenhuth, Thyssen-Krupp Industrial Solutions, ZBT	Dr. dos Santos, E. Prumbohm	Prof. Kunz, Prof. Turek	11/2015 – 10/2018


Thomas Turek


Ulrich Kunz

more than 10,000 cycles which is a lot more compared to the cycle life of, for example, today's Li ion batteries.

Based on previous experiences made with direct-methanol fuel cells and energy-saving electrolysis processes with fuel cell electrodes, ICVT raised since 2009 a total of external funding of about 2.4 million euros for a variety of projects, which will be carried out by the ICVT working group at the EFZN site in Goslar.

In the field of redox-flow batteries, ICVT has meanwhile acquired comprehensive competencies regarding material characterisation (bipolar plates, carbon electrodes, separators and seals), determination of electrochemical reaction kinetics as well as mathematical modelling of electrodes, cells and battery systems. Furthermore, redox-flow batteries are evaluated, also in comparison to other battery types, from the technical and economic point of view.

Selected Project Results

BMWi project "Increased efficiency in redox-flow batteries through novel bipolar plate integrated seal concepts and innovative materials for bipolar plates"

Up to now, redox-flow batteries have been using graphite plates which need to be connected to a separate plastic frame. These frames ensure the stack's mechanical integrity and serve for media supply to anode and cathode. This structure is relatively complex and prone to error, such as mechanical instability, assembly errors, leaks or thermal expansion. The aim of the project was to develop an integrated plate where monopolar or bipolar plate and frame are either made of the same material or where they are integrated in one component (in case of monopolar plates even the current collector). This integration makes assembly easy, reduces the number of components and thus increases reliability at lower cost. Of course, the material must be processable and consist of low-cost basic materials. Figure 2 shows a sample plate, as developed in the course of the project.

To achieve constant electrochemical capacity over the whole plate surface, bipolar plates must exhibit high and uniform electron conductivity over the whole surface. For this purpose, a conductivity scanner was developed to create a conductivity profile of the bipolar plate. An example for this

Figure 2: Injection-moulded frame with cast-on monopolar plate and current collector.

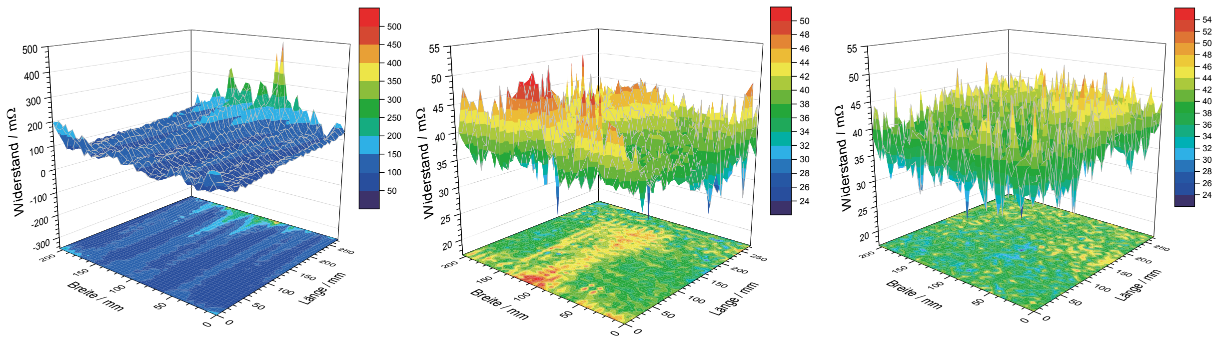

Figure 3: Conductivity profile for injection-moulded bipolar plates: unmachined (left), machined (middle) and compressed (right).

type of non-destructive conductivity evaluation of bipolar plates is depicted in Figure 3.

For example, conductivity measurements show that injection-moulded plates always have an area of high resistance at the side of the mould's filling holes and that compression-moulded plates are more uniform, featuring a lower resistance than injection-moulded plates. Manufacturers of bipolar plates may use this knowledge to optimise the moulds used in injection and compression moulding processes. The non-destructive scanner technology developed at EFZN is of particular importance for the evaluation of large-size bipolar plates.

Industry projects "Scale-up of redox-flow batteries I + II"

Within the scope of the two projects, large-size cells with cell areas from 2 to 3 m² shall be developed, as already known from electrolysis technology in chemical industry. This requires new concepts, since the traditional construction principles of vanadium redox-flow batteries are only applicable to small cells or stacks up to cell areas of about ¼ m².

When using conventional technology with larger cells, for example, the electrolytes' pressure loss when flowing through the porous carbon electrodes would be too high. In this regard, EFZN carried out comprehensive theoretical and experimental investigations. Figure 4 exemplarily shows the modelling results of VRFB cells of 1 m height; as typical for this technology, the electrolyte flows through the porous electrode over the entire cell height.

For electrodes with a porosity of 95 percent, the optimal electrode thickness is about 1.5 mm to achieve maximum voltage efficiency (of the final value). However, this implies a pressure loss of the higher viscous negative electrolyte of 30 bar.

Project partners

Project coordination units
- TU Clausthal
- Energy Research Centre of Lower Saxony

Participating institutes
- Institute of Chemical and Electrochemical Process Engineering
- Dr. Jochen Kerres, Universität Stuttgart
- Prof. Joachim Schmidt, Dennis Düerkop, Ostfalia
- Prof. Sabine Beuermann, Dr. Marco Drache, TU Clausthal

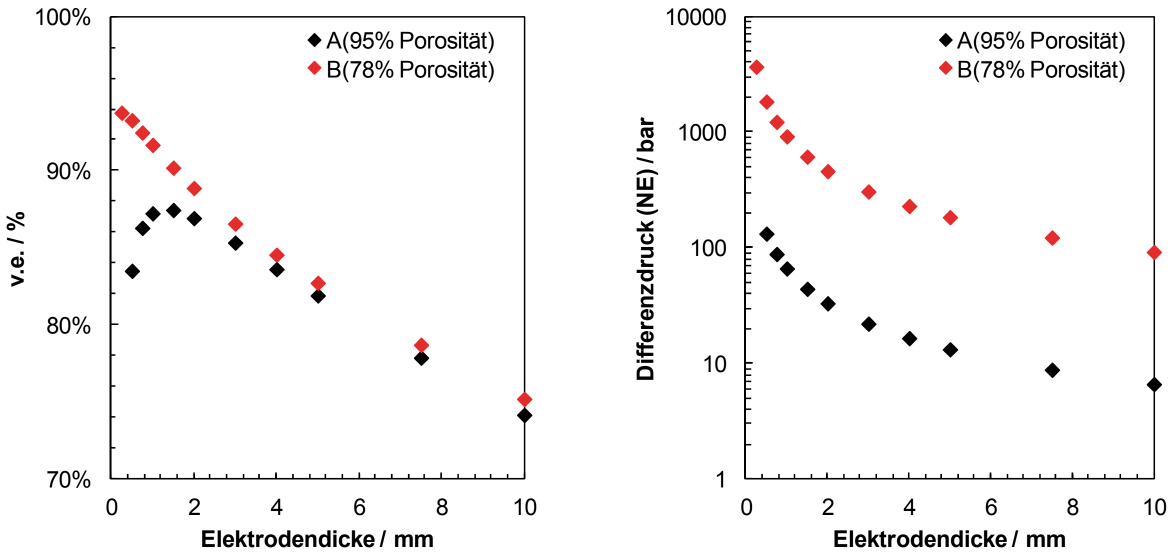

Figure 4: Voltage efficiency (in % of final value) of a VRFB cell of 1 m height (left) and corresponding pressure loss of negative electrolyte (right) for two differently compressed carbon electrodes as a function of the electrode thickness.

Especially in case of smaller thicknesses, higher compressed electrodes show a considerably higher efficiency, but do not tolerate throughflow any longer. It can be concluded that it is necessary to select other flow principles (e.g. flow channels) for the electrolytes. Appropriately modified flow systems have already been tested successfully. Presently, they are tested on a pilot plant scale by our industrial partner.

DFG project “Application of porous glass membranes in redox-flow batteries”

According to the state of the art, only polymer membranes have been used in redox-flow batteries so far. The electrolyte has a highly oxidizing effect on the cathode, causing gradual degradation of the membrane’s polymer. Porous glasses do not degrade under redox-flow battery conditions, thus enabling longer lifetime. In cooperation with the University of Leipzig, samples of tailored porous glasses are evaluated as separators and membranes in test cells in a surface-functionalised version (Figure 5). First results prove that porous glasses are a promising alternative to polymer-based membranes.

BMWi project ”New large-size bipolar plates for redox-flow batteries produced with the extrusion process“

RFB capacity depends on the size of the active area of the electrochemical cells and thus directly on the size of the bipolar plate.

The development of larger sizes is the aim of the consortium of industry (Centroplast, Eisenhuth and Thyssen-Krupp Industrial Solutions) and research (EFZN and ZBT).

According to the present state of the art, the cell area of commercial RFBs is approx. 0.1 m²; thus, the capacity of each cell just reaches about 80 Watt. To be able to realise future large-scale industrial applications, the active cell area is to be increased by more than a factor of 30 to 2.7 m². Connecting some hundred to several thousand cells to larger units leads to energy storage systems in the two- to

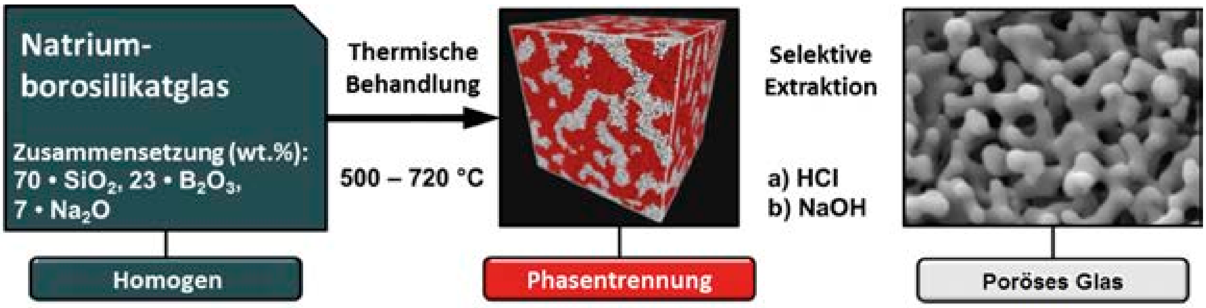

Figure 5: Development of porous glasses for membranes of redox-flow batteries

three-digit MW range. The principle is not a new one and already in use in other electrolysis applications like chlorine production.

Within the scope of the project, which has just started with the development of a manufacturing process for novel bipolar plates, Eisenhuth is responsible for the implementation of the research results into industrial production and for the manufacturing of bipolar plates with small cell areas. Supported by Eisenhuth, ZBT is in charge of the selection and development of materials and substances which are suitable for the production of bipolar plates considering the novel technology.

The plastics specialist Centroplast is responsible for scaling up the bipolar plates and for demonstrating the feasibility of their production on m² scale using the new technology. The focus is above all on an errorfree and high-quality production of the bipolar plates, and this with good reproducibility and in a robust process.

During the development process, the research institutions ZBT and EFZN will support the production of the bipolar plates carried out by Eisenhuth and Centroplast through comprehensive material characterisations and electrochemical investigations.

Finally, ThyssenKrupp Industrial Solutions is in charge of integrating the newly developed bipolar plates into RFBs and of optimising the cell design towards large-scale applications. The joint project of bipolar plate production is coordinated by Eisenhuth.

Cooperation Partners and Future Continuation of Work

Working groups of the University of Stuttgart, of Ost- falia and of TC/TU Clausthal are developing polymer-based membranes, pursuing completely different chemical approaches. At EFZN, samples of such membranes are evaluated from the electrochemical/procedural point of view. Together with the University of Stuttgart, a joint proposal has already been submitted to the DFG. Another interesting topic is the development of redox-flow batteries based on organic molecules, for example chinones. In this context, ICVT is cooperating with the Institute of Organic Chemistry (Professor Dieter Kaufmann) at TU Clausthal. In this promising field, proposals for research projects are also under way.

AKZEPTANZ – Social Acceptance of Energy Transition

Research Issues

The transformation of the German energy supply system going along with energy transition involves additional costs which have to be distributed among German society. While economic theory postulates that questions of efficiency and justice should be addressed separately, behavioural economic studies show that subjective feeling of justice and perceived additional burden determine preferences for political projects. The research project AKZEPTANZ investigates influencing factors regarding the social acceptance of energy transition. The research and development project AKZEPTANZ aims to derive empirically substantiated statements on the social acceptance of energy transition based on a systematic identification of the individual's climate protection preferences. AKZEPTANZ pursues a positive scientific approach with an open-ended investigation on how different design parameters of energy transition affect its acceptance. The research project combines fundamental research on theory of justice with empirical methods of experimental economics and panel survey. In this context, the identified positive preferences expressed by the population are used to draft normative guidelines and concrete policy recommendations.

Project partners

Project coordination units

- TU Clausthal
- Energy Research Centre of Lower Saxony

Participating institutes

- Universität Bremen; Prof. Dr. Dagmar Borchers, Marcus Hrach
- Helmut-Schmidt-Universität Hamburg; Prof. Dr. Stefan Traub, Ole Kutzschbauch
- Rheinisch-Westfälisches Institut für Wirtschaftsforschung (RWI), Essen; Prof. Dr. Manuel Frondel, Stephan Sommer
- Technische Universität Clausthal; Prof. Dr. Roland Menges, Gregor Beyer

Organisation and Structure

AKZEPTANZ is a joint research project which receives funding within the framework programme "Research for Sustainable Development" (FONA) of the Federal Ministry of Education and Research (BMBF) for the project duration from 1.06.2013 to 31.05.2016. The joint project unites economic and philosophical competencies at three sites.

Project coordination takes place at EFZN and is managed by Professor Dr. Roland Menges of the Institute of Management and Economics at Technische Universität Clausthal. It includes the planning, control and coordination of research which is organised in five work packages. The work packages deal with the following topics:

WP Justice: Fundamental research on theory of justice: acceptability of additional burden, general ethical attitude towards energy transition, impact of global issues of justice.

WP Expenses: Empirical determination of the distributional effects of energy transition (forsa Household Panel), measurement of expressed acceptance of cost increase.

WP Behaviour: Empirical determination of climate protection and justice preferences, willingness to pay for climate protection under varying socio-political conditions.

WP Aggregation: Methodical combination of knowledge derived from single analyses, aggregation and interpretation of research results.

WP Policy: Formulation of policy guidelines and recommendations based on the aggregated work results.

As expression of a holistic and transdisciplinary research approach, policy recommendations are derived from the research process in accordance with an Advisory Board. The Advisory Board consists of representatives from energy companies and associations, consumer organisations, environmental and charity organisations as well as German municipalities and ministries (cf. Table 1).

Intermediate Results

Previous empirical results concerning the distributional effect of energy transition and the ex-

Figure 1: Work packages and organisation

Project Data

Project name:
Akzeptanz – Social Acceptance of Energy Transition

Funded by:
Federal Ministry of Education and Research (BMBF)

Grant number:
01 UN 1203 (A-D)

Project duration:
01.06.2013 to 31.05.2016
(applied for extension)

Project manager:
Prof. Dr. Roland Menges

Project coordinator:
Prof. Dr. Roland Menges

E-Mail: roland.menges@tu-clausthal.de
gregor.beyer@tu-clausthal.de

Internet: www.akzeptanz.tu-clausthal.de

Roland Menges

Table 1: Members of the Advisory Board

Section	Member of Advisory Board	Institution
Consumer organisations, associations and trade unions	Udo Sieverding	Consumer Organisation NRW
	Prof. Dr. Michael Jischa	German Association for the Club of Rome
	Dr. Holger Krawinkel	Federation of German Consumer
	Frederik Moch	German Trade Union Confederation
	Michael Rothkegel	BUND Regional Association Hessen
Energy companies	Guido Obschernikat	RWE AG
	Dr. Stefan Ulreich	E.ON AG
	Dr. Sebastian Tschentscher	Lichtblick SE
Associations of energy industry	Michael Nickel	German Association of Energy and Water Industries
	Nicole Knudsen	German Association of Wind Energy
Authorities and public administration	Helge Spehr	Public Services Rendsburg
	Andreas Breitner	Ministry of the Interior Schleswig Holstein
	Andreas de Vries	Community Organisation St. Michel-Energy GmbH
	Dr. Gustav Sauer	Ministry of Science, Economy and Transport (SH)

pressed acceptance of future cost increase are derived from a survey of 7,800 households conducted within the scope of the forsa Household Panel. For three survey periods from 2006 to 2008, 2009 to 2010 and 2011 to 2013, comprehensive information was obtained on the energy consumption of a representative sample comprising consumption data, costs and prices of all relevant energy sources. Data analysis shows that the households' electricity cost burden has increased during the last years. Especially low-income households are affected by increasing electricity costs, since a more and more increasing share of the household income has to be used to pay for heat and electricity demand.

Further results were derived from mirroring the individual behaviour based on expressed attitudes. Two incentivized experiments were developed which respond to various research issues under controlled conditions and for alternative institutional settings and socio-political constellations in an incentive-compatible manner. The first experiment dealt with the measurement of individual distributional preferences in heterogeneous groups regarding the expenses of energy transition. The second experiment examined the impact of different government measures on private investments in energy efficiency measures.

Both experiments were applied in six surveys conducted over a period of fifteen months. To receive valid responses to the investigated research questions, the main surveys were conducted in shopping centres in Bremen and Brunswick (cf. Figure 2).

Although the samples were not representative for Germany, the demographic characteristics of around 1,000 study participants were mapping important features of the German population: 17 percent of the participants were at least 51 years old; 27.2 percent of the participants had a monthly net income of less than 1,000 euros (12.8 per-

Figure 2: Data survey in the field (experimental lab of TU Clausthal/EFZN in the shopping centre Schlossarkaden Braunschweig, 12.03.2015)

cent after exclusion of pupils and students); 4.8 percent of the participants were seeking work or were not employed and 7.2 percent of the respondents were retired persons or pensioners. In particular, the declared aim to identify the preferences of older and low-income individuals was achieved.

The attitude measurements on the basis of questionnaires made during the experiments confirmed existing research results. 71 percent of the respondents said that climate change had to be combatted actively. 70 percent of the respondents were willing to pay for additional burden in order to combat climate change and expressed high acceptance of energy transition. Nevertheless, 30 percent of the respondents evaluate the current financial burden from combating climate change as too high.

The identified preferences concerning the preferred distribution of energy transition costs among heterogeneous household types revealed the desire for cost distribution proportional to income level. This preference persists when introducing social security for low-income households, and it also persists when, instead of energy transition costs, costs of an arbitrary public project are to be distributed. However, the cost distribution preferred by the median of society changes significantly as soon as energy transition costs are uncertain: In a situation where the exact costs are unknown, study participants prefer independently of their income level a regressive cost distribution, where low-income households have to spend a relatively higher share of their income for the financial burden of energy transition. In case that not the costs but the own income situation is uncertain, the opposite phenomenon is observable: study participants then prefer progressive cost distribution.

The second series of experiments, evaluating the effect of government measures on private energy efficiency investments, was mapping households with different income levels. In the absence of government measures, study participants were cooperating independently of relative income levels in the sense that investments exceeded the individual's utility maximizing level. Subsidies promoting investments in the form of flat-rate grants reduced cooperation; households which received grants reduced their investments. It could be shown that the deadweight effect also prevails in case of varying subsidies. Nevertheless, subsidies proved to be suitable for stimulating private energy efficiency investments under certain conditions: A significant increase in investments of those who received government subsidies was observed when subsidies were not limited in the form of flat-rate grants but instead were unlimited in the form of constant marginal additional payments. It was observed that not alone the amount of subsidy but the incentive effect determined the increase in investments. Moreover, it could be proved that different financing mechanisms to cover public expenditure resulting from government subsidies have no impact on the investment behaviour of the study participants.

Outlook on Future Research Activities

The regressive distributional effect of increasing electricity prices identified in the work package "Expenses" will continue in the future, if Germany pursues the stipulated development path of renewable energies. However, in the long run, this bears the risk of a decreasing social acceptance of energy transition, especially if mitigating the regressive effects is not successful.

The experimental results concerning the preferred distribution of cost related to energy transition emphasize that households should be burdened considering viability for all income groups. Nevertheless, it becomes apparent that energy transition is perceived as a macroeconomic task, implying preferences for social security of low-income households. In environmental communication, a crucial factor for the public evaluation of energy transition is the plausible political communication of the expenses of energy transition.

Additional research activities are increasingly dealing with the question whether and in how far certain distributional effects have an influence on the acceptance of energy transition. In the context of government measures to increase private energy efficiency investments, it has, for example, to be investigated in how far public information and advisory services have an effect on individual investment decisions. Another aim is to strive for a broader application of experimental economic research methods, when investigating the social acceptance of energy transition. Within the framework research programme FONA of BMBF, a cooperation in the field of game engineering and game design between TU Clausthal/EFZN and the University of Applied Sciences in Augsburg is under development.

Publications and Working Papers

The aforementioned intermediate results have been published in German and English language:

- Frondel, M., Sommer, S. (2014): Energiekostenbelastung privater Haushalte - Das EEG als sozialpolitische Zeitbombe? List Forum für Wirtschafts- und Finanzpolitik 40 (4).
- Frondel, M., Sommer, S., Vance, C. (2015): The Burden of Germany's Energy Transition: An Empirical Analysis of Distributional Effects. Economic Analysis and Policy 45.
- Menges, R., Beyer, G. (2015): How to Support Energy Efficiency - An Experimental Investigation of Individual Preferences, in: Proceedings of workshop "Entscheidungstheorie und -praxis" of GOR working group on 27 and 28 March in Clausthal-Zellerfeld.

Linking of Model and Commercial Active Materials for Lithium Ion Batteries by *In-Situ* Determination of Thermodynamic and Kinetic Data

Project Background

The project is embedded in the Priority Programme 1473 “WeNDeLIB“ (Materials with New Design for Improved Lithium Ion Batteries) of the German Research Foundation (DFG). It is a joint research project of the Energy Research Centre of Lower Saxony (Division Fundamentals of New Energy Technologies, Working Group Prof. Fritze) and Technische Universität Ilmenau (Faculty of Electrical Engineering and Information Technology, Working Group Prof. Bund).

Basic Concept

Essential requirements for the development of high-performance lithium ion batteries include the knowledge of kinetic limitations and thermodynamic stability.

Within the scope of the project, thin-film calorimetry was developed as a new measurement technique to determine temperature and enthalpy of phase transformations as a function of composition and lithium content. Thin films of electrode materials are deposited on the surface of a piezoelectric resonator (monocrystalline langasite) which is able to detect very small temperature fluctuations of about 10 mK. The newly developed concept facilitates resolution capacities for energy fluctuations of approx. 0.7 mJ. At the same time, further methods such as X-ray diffraction and impedance spectroscopy are applied. In this way, methods and materials developed within the project are suitable for interdisciplinary use also in other EFZN battery projects.

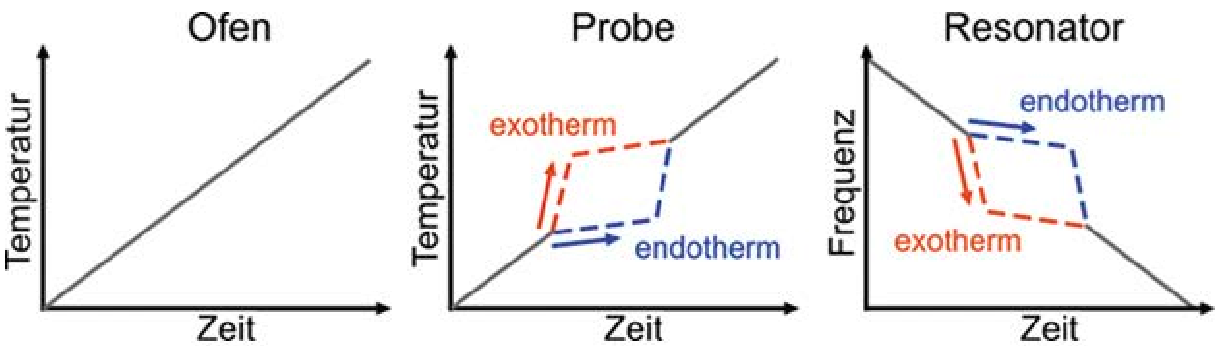

Figure 1: Scheme of thin-film calorimetry measurement principle

Project Data

Project name:
Linking of Model and Commercial Active Materials for Lithium Ion Batteries by In-situ Determination of Thermodynamic and Kinetic Data

Funded by:
German Research Foundation

Grant number:
SPP 1473, FR 1301/16-1 and -2

Project duration:
01.01.2011 to 30.04.2017

Reporting period:
01.01.2011 to 30.08.2015

Project manager:
Prof. Dr.-Ing. Holger Fritze

Project coordinator:
Dipl.-Phys. Hendrik Wulfmeier,
M.Sc. Alexander Omelcenko

E-Mail: hendrik.wulfmeier@efzn.de,
alexander.omelcenko@efzn.de

Internet: www.spp1473.kit.edu/

Holger Fritze

Hendrik Wulfmeier

Previous Research Activities

Thin-film calorimetry based on high-temperature stable piezoelectric langasite resonators:
The focus of previous research activities was on the development and establishment of the novel measurement technique "Thin-Film Calorimetry". For this purpose, the material to be investigated by calorimetry is deposited as a thin film on a piezoelectric resonator which is excited in the range of its resonance frequency. When there are no phase transformations, the temperature of the active material coated resonator follows the furnace temperature permitting a detection of continuous frequency changes by means of a high-speed network analyser.

In case of continuous temperature increase, an undisturbed langasite-based (La3Ga5SiO14) resonator shows a continuously decreasing resonance frequency. When coated with active material, during its endothermic phase transformation, thermal energy supplied by the furnace is not used to heat up the system, consisting of resonator and active material, but to apply the required enthalpy; despite increasing ambient temperature, the sample's temperature change during phase transformation is very small, shown in the resonance frequency/time diagram (cf. Figure 1). The same is valid for exothermic phase transformations. In this case, additional heat is released spontaneously during phase transformation, which is transformed to the resonator causing a step in the resonance frequency/time diagram (cf. Figure 1). Using these information, the enthalpies of the phase transformations, occurring in the thin films, can be determined.

Since thin-film calorimetric systems are used for investigating battery materials, certain boundary conditions have to be considered: Materials examined within the Priority Programme show considerable reactivity with CO2 and humidity which has to be avoided in order to obtain exact measurements (especially fast reacting thin films). To make sure that the complete sample treatment from preparation to end of measurement takes place in inert atmospheres, a portable PLD

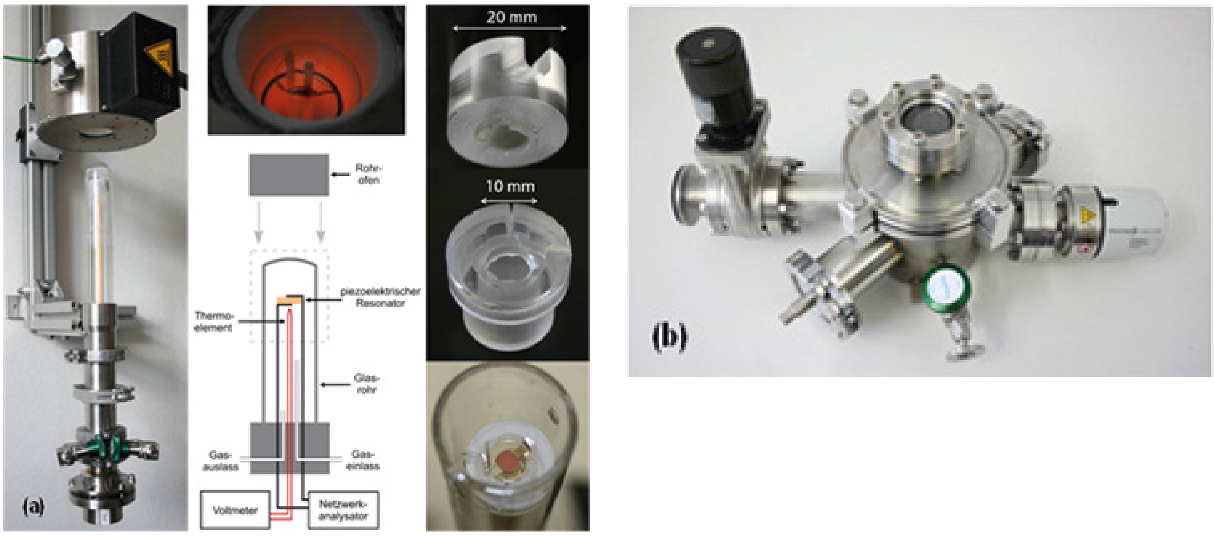

Figure 2: (a) Photo of thin-film calorimetric system with tube furnace (left); resonator in thin-film calorimetric system during measurement at 800°C (top middle); scheme of setup (bottom middle); photo of quartz glass sample holder machined by ultrasonic milling (top right); LMO thin-film coated resonator inserted in sample holder (bottom right); (b) portable PLD chamber

(Pulsed Laser Deposition, laser ablation) chamber and a sample holder were developed and constructed, so that the system can be inserted into a glove box (Figure 2); sample contamination by atmospheric influences is thus practically excluded.

First, the measurement technique “Thin-Film Calorimetry” was tested with various materials whose calorimetric properties are known, in order to obtain reference values. Since the measured enthalpies match very well the values given in literature, the principal functionality of the system developed within this project is validated, making it applicable to the investigation of new materials.

Molybdenum disulfide (MoS2) as anode material:
Like graphite, MoS2 is a layered compound with sheets consisting of molybdenum atoms placed between two layers of sulfide atoms, making it a promising active material for Li ions. As anode in lithium ion batteries, MoS2 has a theoretical capacity of over 1,100 mAh/g (cf. graphite: 372 mAh/g). Besides high capacity, a key feature of molybdenum disulfide is the variability of morphologies (it can be prepared as bulk material, several nano crystalline powder variations or nano tubes depending on the synthesis route). These different morphologies allow to study the effects of size and

Project partners

Project coordination units
- Energy Research Centre of Lower Saxony
- Karlsruhe Institute of Technology

Participating institutes
- Institute of Energy Research and Physical Technologies (IEPT))

External partners
- Technische Universität Ilmenau, Prof. Dr. rer. nat. Andreas Bund

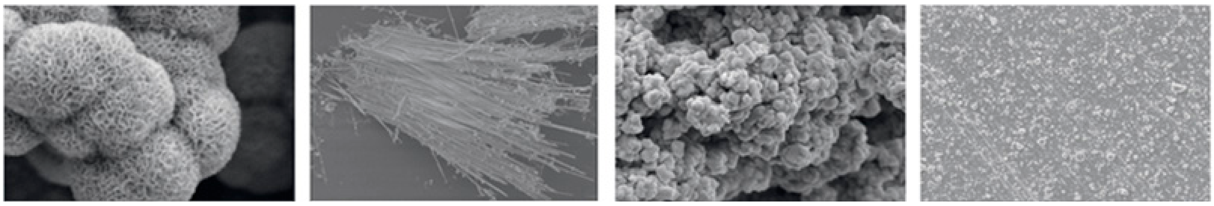

Figure 3: Molybdenum disulfide (MoS2) as nano flowers, tubes, flakes and PLD-based thin film (from left)

form on the electrochemical (kinetics) as well as on the thermodynamic behaviour without changing the material composition.

Within the scope of the project, several synthesis routes were tested (Figure 3) for the preparation of nano-crystalline MoS2. The results were characterised (REM, XRD) and evaluated thermodynamically by use of thin-film calorimetry (Figure 4). Furthermore, cyclic voltammetry experiments (against metallic lithium) were carried out (Figure 5).

Application example: Lithium manganese oxide (LMO) as cathode material

Lithium manganese oxide is a promising cathode material for lithium ion batteries. Although there exist several phases of higher theoretical capacity, the spinel (LiMn2O4, capacity of 100-150 Wh/kg) is technically the most promising stoichiometric variant due to its high structural stability, requiring high cycle and lifetime stability of the cathode. The thermal behaviour of LMO thin films was investigated in ambient air and at low oxygen partial pressure (pO2) in 0.5 % H2/Ar by means of a thin-film calorimetric system from room temperature up to high temperatures (approx. 800 °C) (Figure 6). While there are three phase transformations in ambient air (at 330 °C, 410 °C, 600 °C), four phase transformations are observable in 0.5 % H2/Ar (at 389 °C, 471 °C, 730 °C, 758 °C). The corresponding transformation enthalpies were determined and the crystallographic phase identified by means of X-ray diffraction and Raman spectroscopy. Depending on the atmosphere,

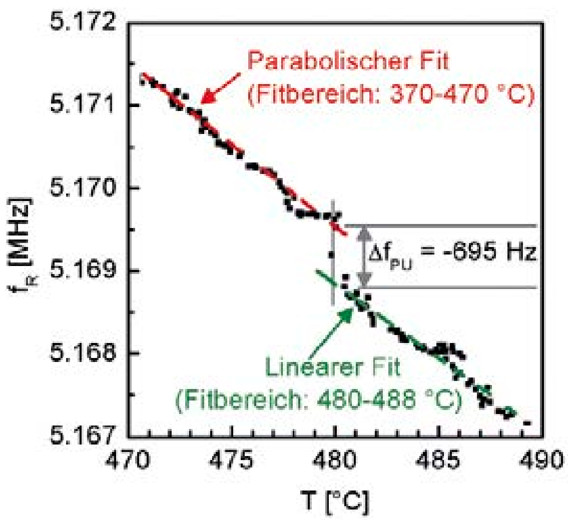

Figure 4: Crystallisation of amorphous MoS2, measured via thin-film calorimetry

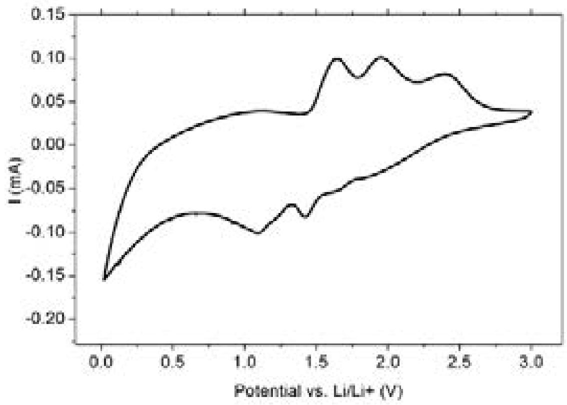

Figure 5: Cyclic voltammetry characterisation of molybdenum disulfide nano flower structure

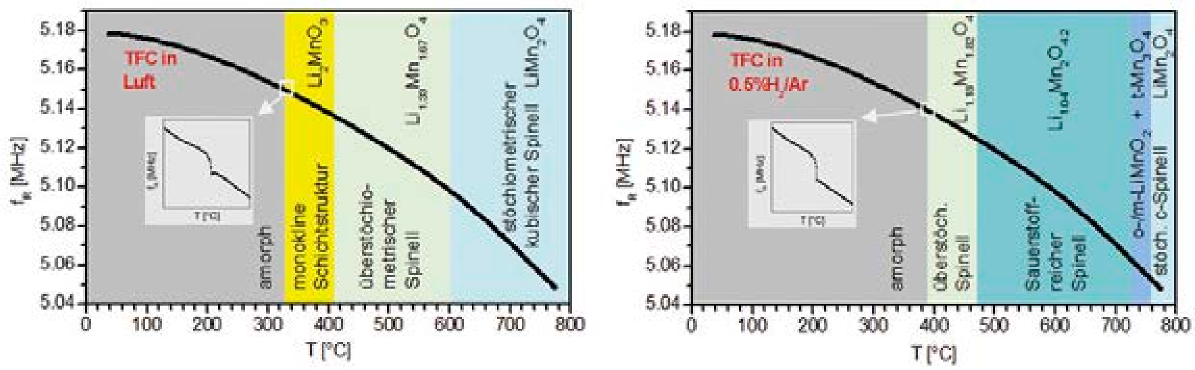

Figure 6: Temperature curve of resonance frequency of an LMO coated resonator in ambient air (left) and 0.5 % H2/Ar (right). The inlays show increased frequency steps in the resonance frequency/temperature curves always for the first phase transformations (one example each).

the spinel-like LiMn2O4 phase occurs at different temperatures, in ambient air much earlier than in 0.5 % H2/Ar. It can be noticed that the monocline layered Li2MnO3 only occurs in ambient air. In contrast, in 0.5 % H2/Ar, there is no non-spinel like transformation phase; instead, there is direct transformation from the amorphous state into a basic spinel structure.

The investigations give an insight into the material structure’s dependency on different atmospheres and thus promote material synthesis optimisation.

Setup of an improved thin-film calorimetric (TFC) system:

After establishment of the TFC measurement technique’s functionality, a second TFC system (Figure 7) was set up in the course of project extension. Enhancements and improvements are based on experiences made with the first system and allow for improved measurement capacity and systematic research on materials of the Priority Programme’s project partners. Enhancements include a DC power supply with an improved furnace control algorithm in order to minimise electromagnetic fields disturbing data evaluation. Moreover, temperature control was improved, minimising frequency fluctuations to ±0,1K.

In addition, the second TFC system was equipped with a larger sample holder (Figure 8), permitting two samples to be measured at the same time. This way, it is possible to test two layers of active material of varying compositions and thicknesses under the same conditions.

Moreover, one sample can serve as a reference. To optimise the measurement technique, “freestanding resonators” are machined using a CNC ultrasonic mill. The resonators’ oscillating part is thermally and mechanically decoupled from the rest of the resonator (Figure 9). This improves the sensitivity of calorimetric measurements to a considerable extent. In this context, the resonance behaviour or resonators is examined by applying well defined amounts of energy. For this purpose, the electrodes deposited via PLD are first electrically isolated with a thin film of aluminium oxide (Al2O3). Then, a spiral-shaped platinum heater structure is deposited via mesh printing. At temperatures where phase transformations occur, well defined voltage pulses are applied to these structures, in order to simulate heat and thus frequency changes caused by the active layers (Figure 10).

Calorimetric characterisation of langasite crystals via STA

Since data evaluation requires precise knowl-

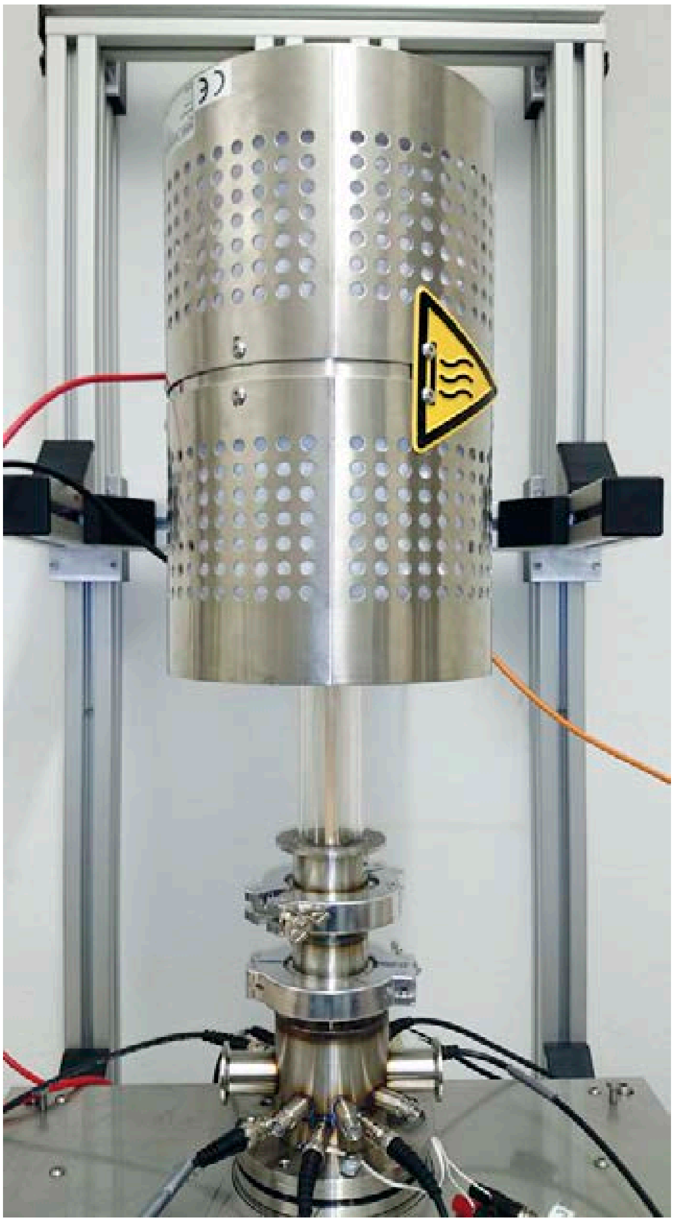

Figure 7: Second thin-film calorimetric system

Figure 8: Sample holder with two resonators

Figure 9: Freestanding, thermally and mechanically decoupled resonator

Figure 10: Resonator with Pt heater structure

edge of the piezoelectric resonators' thermal behaviour, the temperature behaviour of langasite monocrystals is characterised via STA (Simultaneous Thermogravimetric Analysis). For this purpose, the measurement methods Thermogravimetric Analysis (TGA) and Dynamic Scanning Calorimetry (DSC) are used simultaneously. With TGA, the mass change of a sample is measured as a function of temperature and time; DSC serves for calorimetric analysis of consumed or generated amounts of energy of a sample during heating and cooling. With this measurement method, the temperature curve of the specific heat capacity of langasite monocrystals was determined for temperatures from 40 to 1,000 degree Celsius. Precise knowledge of such data is essential for an exact evaluation of thin-film calorimetric data.

Project-Related Publications

Thin Film Calorimetry – Device Development and Application to Lithium Ion Battery Materials
Hendrik Wulfmeier, Daniel Albrecht, Svetlozar Ivanov, Julian Fischer, Rolf Grieseler, Peter Schaaf, Sven Ulrich, Andreas Bund, Holger Fritze
Materials Research Society Symposium Proceedings Vol. 1496 (2013); DOI: 10.1557/opl.2013.104

Synthesis of Different Molybdenum Disulfide Nanostructures and their Applicability in Lithium Ion Batteries with Ionic Liquid Electrolytes
Daniel Albrecht, Hendrik Wulfmeier, Svetlozar Ivanov, Andreas Bund, Holger Fritze
Materials Research Society Symposium Proceedings Vol. 1496 (2013); DOI: 10.1557/opl.2013.126

High-temperature thin-film calorimetry: a newly developed method applied to lithium ion battery materials
Hendrik Wulfmeier, Daniel Albrecht, Svetlozar Ivanov, Julian Fischer, Sven Ulrich, Andreas Bund, Holger Fritze
Journal of Material Science 48 [19], 6585-6596 (2013); DOI 10.1007/s10853-013-7455-x

Electrochemical Performance of Ionic Liquid - Molybdenum Disulfide Li-Ion Batteries
Daniel Albrecht, Hendrik Wulfmeier, Svetlozar Ivanov, Andreas Bund, Holger Fritze
Journal of Applied Electrochemistry 43 (2013) 559-565; DOI 10.1007/s10800-013-0548-z

Messsystem zur Bestimmung thermodynamischer Eigenschaften dünner Schichten bei hohen Temperaturen
Hendrik Wulfmeier, Daniel Albrecht, Holger Fritze, Svetlozar Ivanov, Andreas Bund
Proceedings 11. Dresdner Sensor Symposium, Dresden/Germany, 2013-12-09 – 2013-12-11 (2013), 34-39; DOI: 10.5162/11dss2013/2.2; ISBN: 978-3-9813484-5-3

Thin-Film Calorimetry: Analytical Tool for In-Situ Characterization of Lithium Ion Batteries
Hendrik Wulfmeier, Daniel Albrecht, Julian Fischer, Svetlozar Ivanov, Andreas Bund, Sven Ulrich, Holger Fritze
Journal of the Electrochemical Society 162 [4]: A727-A736 (2015); DOI:10.1149/2.0741504jes

Dünnschichtkalorimetrie auf der Basis piezoelektrischer Langasit-Resonatoren: Einfluss der Schichtdicke auf die Bestimmung der Schmelzenthalpie von Zinn-Schichten
Sebastian Schröder, Hendrik Wulfmeier, Holger Fritze
Tagungsband zur 49. Metallographie-Tagung Materialographie im Rahmen der DGM-Werkstoffwoche 2015

ESPEN – Potentials of Electrochemical Storage Systems in Power Grids in Competition with Other Technologies and System Solutions

Sub-Project

Reduced potential of electrochemical storage systems due to alternative and additional technologies and system solutions.

Aim of the Project

The aim of the project is to develop a roadmap for the use of electrochemical storage systems and their further development, in order to promote optimal stabilisation of the future energy system.

In the context of the joint project, it is to be analysed which electrochemical storage systems are qualified to contribute to economic efficiency, stability and security of the future power supply system in Germany. Moreover, alternative energy storage technologies, such as pumped water, compressed air as well as material storage technologies and system solutions like load management concepts are considered, in order to identify particularly suitable applications for electrochemical storage systems.

State of the Art

To secure the stability of the electrical power supply system, supply and demand of electricity have to be balanced – among others by the use of reserve power. Up to now, reserve power is primarily supplied by thermal power plants fired for example with coal or natural gas. The technical features of such power plants, which are required to meet fast changes in power supply,

lead to increased investment and operating costs with simultaneous reduction of efficiency.

In today's electrical power supply system, there exist two types of energy storages. On the one hand, energy is stored in the rotating masses of turbine and generator sets in large high-capacity power plants which compensate for short-term frequency fluctuations. In this way, generators in large thermal power plants, such as nuclear and lignite-fired power plants, highly contribute to stabilise the electrical power supply system. In the course of energy transition, the number of large-scale generators will decrease, since they will be more and more replaced by smaller renewable energy generation units. As a consequence, the frequency-stabilising effect will decrease too, so that alternatives have to be found (see [1]).

The second type of existing energy storages includes pumped storage and compressed air storage systems. As peak-load power generation plants, they are able to supply power with high capacity in times of high demand, provided that the energy storage is charged. Energy is stored during off-peak hours – when demand and thus energy cost is low. Energy storage systems are used for balancing supplied and consumed power, i.e. for supplying negative and positive reserve power.

In today's electrical power supply system, there exist no further energy storage systems. And due to the sufficiently flexible capacity provided by existing power plants and the transmission capacity of the electric grid, there presently is no further demand for additional systems. If the electric grid's capacity limit is reached by increased installation of additional local renewable energy systems, grids will be enhanced by the construction of new or the extension of existing transmission and distribution lines (see [2]).

Approach

Joint project

Within the scope of the joint project, it is dealt with the following topics:

1. Development of reference grids for analysis of different scenarios with large systems with centralised power generation or systems with mostly decentralised renewable power production
2. Definition of application scenarios for storage systems and determination of the technical and economic requirements to integrate storage systems into the grid
3. Investigation of alternative solutions to the use of energy storage systems, such as grid extension, demand-side management, use of quick-response peak-load power plants or of additional loads
4. Investigation of electrochemical storage systems concerning efficiency, response time, dynamics and lifetime cost for the expected load collective
5. Potential use of energy storage systems which are primarily intended to be used in other applications like UPS units and electric vehicles
6. Calculation of life cycle costs of energy storage systems based on the developed load profiles
7. Investigation of the potentials of energy storage systems, stabilising the grid depending on frequency and voltage, and development of appropriate control concepts
8. Analysis of communication systems and evaluation of the resulting benefits with respect to the expected additional costs
9. Analysis of the legal framework for the supply of storage capacities and development of proposals to modify legal and technical regulations concerning operation of small-scale decentralised storage systems
10. Evaluation of acceptance problems and possible impact on decentralised storage systems

The focus of the joint project is on investigating the suitability of various storage technologies

First power-to-heat dialogue platform hosted by EFZN in 2015.

Project Data

Project name:
ESPEN – Potentials of Electrochemical Storage Systems in Power Grids in Competition with Other Technologies and System Solutions

Funded by:
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Grant number:
0325530 A

Project duration:
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Reporting period:
01.11.2012 to 31.12.2015

Project manager:
Prof. Dr.-Ing. Hans-Peter Beck

Project coordinators:
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Heinz Wenzl


Verena Spielmann

in different fields of application. In this context, based on previous grid simulations, requirement profiles (for electrochemical storage systems) were determined considering the following areas of application:

- Voltage stabilisation by reducing the (local) feed-in peak
- Promotion or adoption of reserve power supply
- Avoidance of grid congestion
- Smoothing of residual load profile

In an economic study, the best storage technology and design was determined for each of the defined areas of application, based on the identified requirements (power, capacity, load) and considering the ageing effects of each investigated storage technology. The results derived from experimental storage investigations, also carried out within the project, are integrated in the economic feasibility study. First project results were implemented in the VDE study "Batteriespeicher in der Nieder- und Mittel- spannungsebene" [3].

Apart from technical aspects for the use of storage systems, legal as well as acceptance aspects for the use of electrochemical storages are of particular relevance. For this reason, legal and regulatory frame conditions for the use of storages were also analysed. First proposals for adaptions were developed with the aim to improve possible applications of storage systems in the energy system. Moreover, the ecological impact and acceptance problems were analysed, in order to identify non-technical constraints for the use of storage systems in the considered applications.

Research at the Institute of Electrical Power Engineering and Energy Systems

Analysis of alternative technologies: The main task of the sub-project conducted at the Institute of Electrical Power Engineering and Energy Systems refers to analysis of alternative solutions for integrating renewable energies into the energy system. The following alternatives to the use of electrochemical storage systems are analysed which may reduce the potential of such systems in certain applications.

- Use of heat and gas grids (power-to-heat and power-to-gas)
- Peak-load power plants
- Extension of electric grids
- Demand-side management
- Additional loads

The aim is to describe possible alternatives, their costs and impact on grid quality, efficiency and reliability of supply as well as their influences on other social and economic aspects. In this work step, the focus is not on precise analysis of such alternatives but on the identification of areas where electrochemical storage systems will have especially good prospects and where alternative solutions might have particular benefits. Combinations of such alternatives with storage technologies will also be taken into consideration.

During the project period, it became clear that when applying the power-to-heat (P2H) concept, the use of thermal grids becomes a particularly interesting alternative

to the use of electrochemical storage systems, regarding the local consumption of feed-in peaks in the low-voltage grid as well as the use of local surplus energy, which otherwise would be limited by feed-in management measures (see [4]).

Within the scope of the exemplary study on a low-voltage grid, the following possibilities for voltage stabilisation were compared for different PV penetration levels:

- Use of P2H in households for surplus energy storage
- Use of PV in-house storage systems to increase self-consumption
- Use of centralised electrochemical storage systems at the end of line
- Combination of a centralised storage system with the use of P2H in households

It could be observed that operation of decentralised storage systems (1 kWh storage capacity per 1 kWp of installed PV system) with the aim to maximise self-consumption only has, as expected, a marginal effect on voltage increase in the grid, since storage systems are mostly charged already at times of peak feed-in. Similarly, the centralised battery storage system with a capacity of 240 kWh installed at the end of line (similar to the pilot project of the public utility company of Neustadt and IBC Solar in Fechheim) has little influence on voltage increase, because storage capacity is not sufficient in case of increasing installed PV power.

Although heat demand of households is most significant during winter time (heat demand time series analysis according to [5] and [6]), the use

Project partners

Project coordination units

– Energy Research Centre of Lower Saxony
– Institute of Electrical Power Engineering and Energy Systems, TU Clausthal

Research institutions

– Fraunhofer Institute for Solar Energy Systems (ISE) in Freiburg
– Fraunhofer Institute for Wind Energy and Energy System Technology (IWES) in Kassel Centre for Solar Energy and Hydrogen Research (ZSW); Department Electrochemical Accumulators (ECA) in Ulm
– TU München (TUM); Institute for Electrical Energy Storage Technology (EES) Rheinisch-Westfälische Technische Hochschule Aachen (RWTH Aachen); Institute for Power Electronics and Electrical Drives (ISEA), Chair of Electrochemical Energy Conversion and Storage Systems
– Otto-von-Guericke-Universität Magdeburg (OvGU); Chair of Electric Power Networks and Renewable Energy Sources (LENA)

of the P2H concept considerably reduces the extent and number of feed-in-related voltage range violations. This is due to the relatively high and constant demand for thermal energy compared to the demand for electrical power also during the summer period. Regarding the reduction of number and duration of overvoltage events (exceeding of nominal voltage by more than 10 percent for an input voltage of 107 percent of the nominal voltage at the MV/LV transformer), the combination of a decentralised use of P2H systems in combination with a centralised electrical storage system proves to be the most favourable solution from the technical point of view.

The study was presented on the occasion of the P2H dialogue platform hosted by EFZN in Goslar in Mai 2015 and published in the conference proceedings [7].

Besides the impact of the use of decentralised P2H systems on the distribution grid, research also includes the use of a centralised system for storage of otherwise limited surplus energy via P2H system within a district heating grid [8].

Based on an exemplarily analysed district heating grid (data from public utility company) which supplies 434 buildings (primarily multi-storey dwellings) with heat, it was analysed in how far it is possible to install an electric heating system (5 MW) to store regional surplus energy (at a fictitious market), in order to participate in the secondary and tertiary reserve power market and in the EEX (day ahead and intraday market). The system contains a heat storage with a capacity of 16 MWh. Heat is supplied by a biomass-fuelled thermal power plant with a thermal power of 17 MW. The system is also equipped with a natural gas boiler for peak-load supply and for redundancy reasons.

Publicly available data of the local distribution system operator are used to determine the surplus energy of the region. Then, a time series estimation of surplus power is made based on feed-in management intervention data. Regarding the surcharge for consumed electricity, analysis focuses, on the one hand, on today's frame conditions and, on the other hand, on a reduction of the EEG surcharge and of the respective marginal costs and price per kWh according to [4].

It can be seen that the existing storage system with a capacity of 16 MWh is sufficient for commercialisation at reserve power markets. Under the assumed frame conditions, 20 percent of the otherwise limited surplus energy can be used for heat supply.

Analysis proved that it is possible to use surplus energy in the example region in Mecklenburg-West Pomerania by use of a power-to-heat system in the investigated heat grid. However, system efficiency is only given, if energy can be traded with 0 ct/kWh and without surcharge at the regional surplus market.

Dissemination of results:
Within the scope of the project, the Institute of Power Engineering and Energy Systems organised and held open workshops on different topics. The results are discussed with industrial companies, especially energy suppliers and grid operators, and policy, in order to promote the roadmap's implementation.

Since the start of the project, workshops were carried out with active participation of industry and research, dealing with the following subjects:

- Pumped storage power plants (February 2013 in Goslar)
- Large-scale battery storage system for grid stability (April 2013 in Frankfurt am Main)
- Voltage stabilisation (May 2013 in Magdeburg)
- Power-to-heat – with the State Initiative Energy Storage and Systems and Stiebel Eltron (October 2013 in Holzminden)
- Power-to-Gas (November 2013 in Munich)
- Grid extension (March 2014 in Magdeburg)
- Large-scale battery storage system – with the State Initiative Energy Storage and Systems and Power Innovation (May 2014 in Achim)
- Legal and regulatory frame conditions (May 2014 in Aachen)
- Sustainable security of power supply – with

the State Initiative Energy Storage and Systems and enercity (November 2015 in Hanover)
- UPS and emergency power systems – with the State Initiative Energy Storage and Systems and Piller (March 2015 in Osterode/Harz)

Project Status

The main issues of the project have already been completed. The joint final report is still to be prepared.

Literature

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Ageing Models for Lithium Ion Batteries Using the Example of Electric Vehicles

Problem

The aim of the project is to investigate ageing development of lithium ion batteries used in electric vehicles, if additional ancillary services (with large dynamic requirements but small power throughput) are to be supplied (vehicle-to-grid). As can be seen from literature, the ageing behaviour of lithium ion batteries has already been investigated in many studies, but mostly just regarding some specific ageing sources. The complex combination of ageing processes resulting from variable operating conditions and load collectives is more or less unknown. Real applications require lifetime prediction based on the knowledge of such complex interactions between all ageing processes, depending on the operating conditions, as well as of the overall effect on lifetime-relevant properties.

Project partners

Project coordination unit
- Energy Research Centre of Lower Saxony

Research institutions
- Energy Research Centre of Lower Saxony
- TU Clausthal

Objectives

The objectives of the project include development of different lifetime prediction models, which are cross-checked to secure consistency of results, experimental validation of common assumptions in case of lifetime predictions (additivity of lifetime loss, independence of order, validity of Arrhenius law for combinations of loads and complex load collectives) and application to the use of batteries in electric vehicles for grid-supporting measures.

After completion of the research project, the description of the ageing behaviour of lithium ion batteries is expected to be more precise than in the past, in particular with respect to complex and highly dynamic loads without remarkable SOC changes. This includes an itemised description of the influencing factors of ageing mechanisms by appropriate model structures and a reliable lifetime prediction of lithium ion batteries under arbitrary operating conditions, considering interactions between different ageing mechanisms. Based on the knowledge of the most important ageing sources, a model-based design of an optimal operating strategy of a lithium ion battery is developed, while minimising storage load and maximising grid-stabilising measures.

Moreover, statements are possible to evaluate grid stabilisation by means of decentralised storage systems with particular consideration of electric vehicles.

State of the Art

There exist first results relating the ageing of lithium ion batteries to vehicle application, partly with “vehicle-to-grid“ (V2G) functionality. Investigating ageing processes without thorough

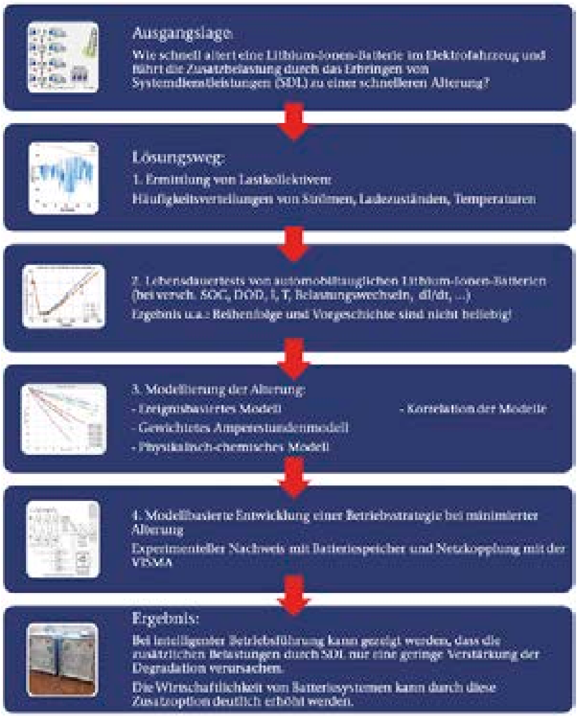

Figure 1: Proceeding in the project

consideration of these interactions and their dependencies on operating conditions is generally not sufficient for lifetime prediction. It is evident that due to the variety of ageing mechanisms and the wide range of operating conditions in particular, a purely experimental determination of the expected lifetime would require long-term tests with many test samples and cause high temporal and financial effort.

For this reason, model-based approaches have to be pursued which make complexity manageable. The combination of three different lifetime prediction models proposed in the project is going beyond the approaches published so far.

Approach

After determination of relevant load profiles, lifetime tests and further tests necessary for the parameterisation and verification of ageing models are carried out. For ageing simulation, three model approaches are created in parallel. Apart from a physical-chemical model, a weighted ampere-hour model and an event-based lifetime model are developed. Depending on the accuracy and validity which is obtainable with the different model approaches, they are either used alone or in combination with one another.

Based on the developed ageing models, the load profiles are then analysed concerning their changes of the ageing gradient. From this, a model-based innovative charge/discharge strategy is derived, allowing for optimal storage utilisation with minimum ageing of the lithium ion battery. The algorithm shall avoid the battery's premature capacity loss and increase its lifetime, while it is used for ancillary services at the same time.

For an experimental verification of the previous assumptions, a lithium ion battery system with VISMA (virtual synchronous machine) inverter is set up in the laboratory and tested by means of load scenarios, as they would be expectable when using a vehicle battery with V2G functionality. The charge/discharge strategy for grid stabilisation has to be designed for best possible minimum battery ageing and optimal storage utilisation.

Afterwards, the effect on battery lifetime and grid-beneficial properties is evaluated.

Project Status

At the beginning of the project, real load data were measured and evaluated by a load collective analysis known from theory of fatigue.

To determine the ageing behaviour, lithium ion cells are subjected to cyclic as well as to calendrical ageing at different temperatures. Furthermore, cyclic load analyses with alternating loads are carried out. Data is evaluated in particular with respect to the development of capacity and resistance and is used for parameterisation of an event-based and an electro-chemical model (see Figures 2 and 3).

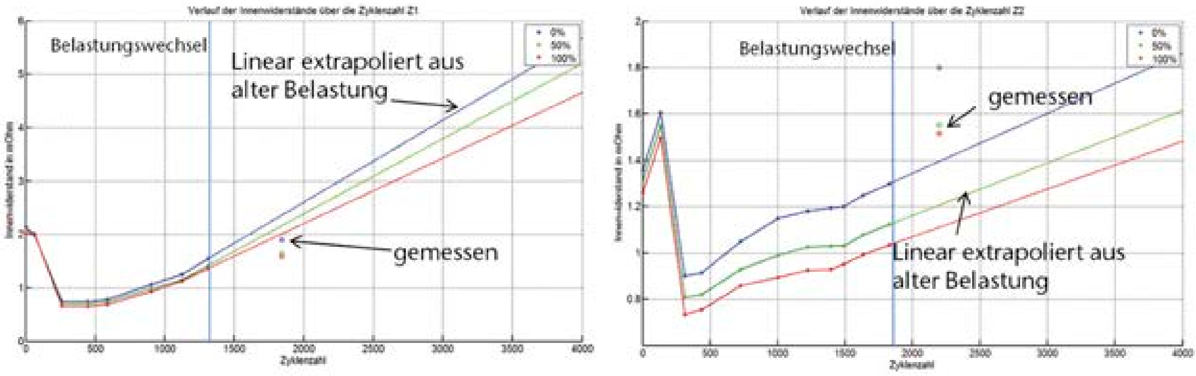

Figure 2: Ohmic resistance of two 40Ah NMC lithium ion pouch cells with changing load profiles over the number of equivalent full cycles. Cell Z1 (left) was charged in one cycle with an alternating current of 60A and 100A (each for 5s, average value 80A) and was then fully discharged. From cycle 1300 and higher, it was charged and discharged each for 43s with 100A at a state of charge of 80 % and a death of discharge of 3 %. Cell 2 (right) was loaded in the opposite order, i.e. charged and discharged each at 3 % death of discharge and then charged from cycle 1800 and higher with an average current of 80A.

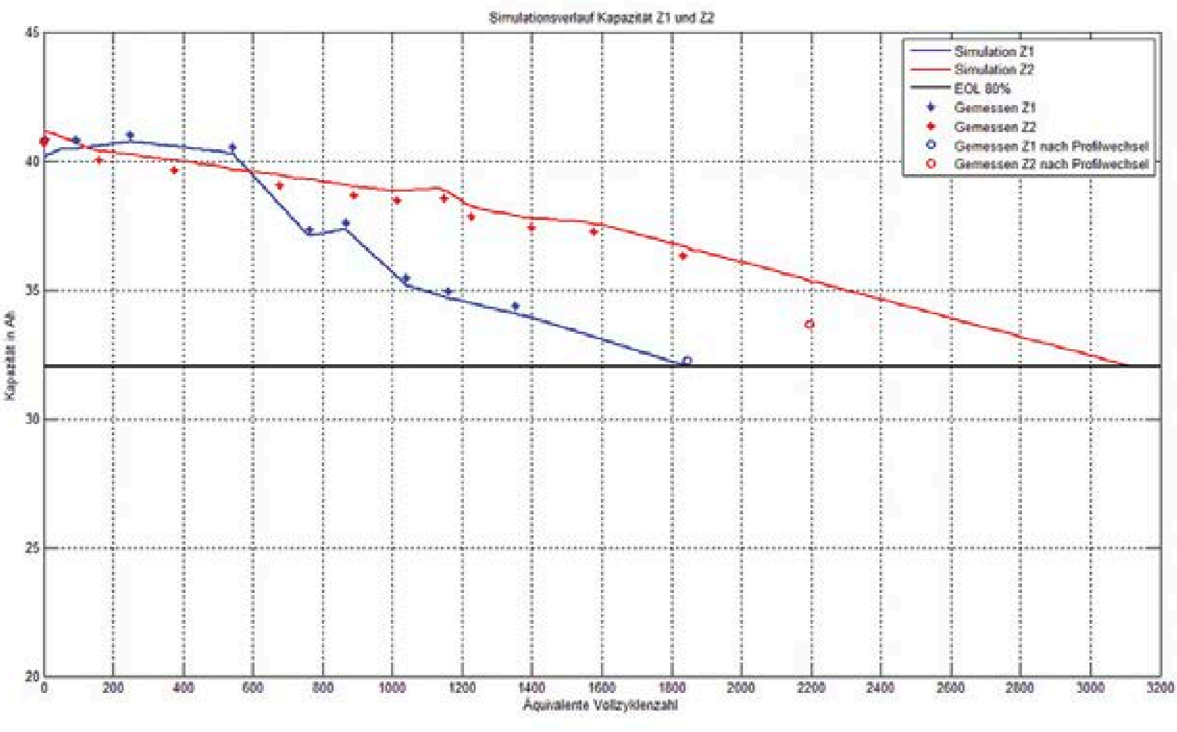

Figure 3: Capacity of two 40Ah lithium ion pouch cells with changing load profiles over the number of equivalent full cycles.

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Project Data

Project name:
Ageing Models for Lithium Ion Batteries Using the Example of Electric Vehicles

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Reporting period:
01.07.2011 to 30.06.2015

Project manager:
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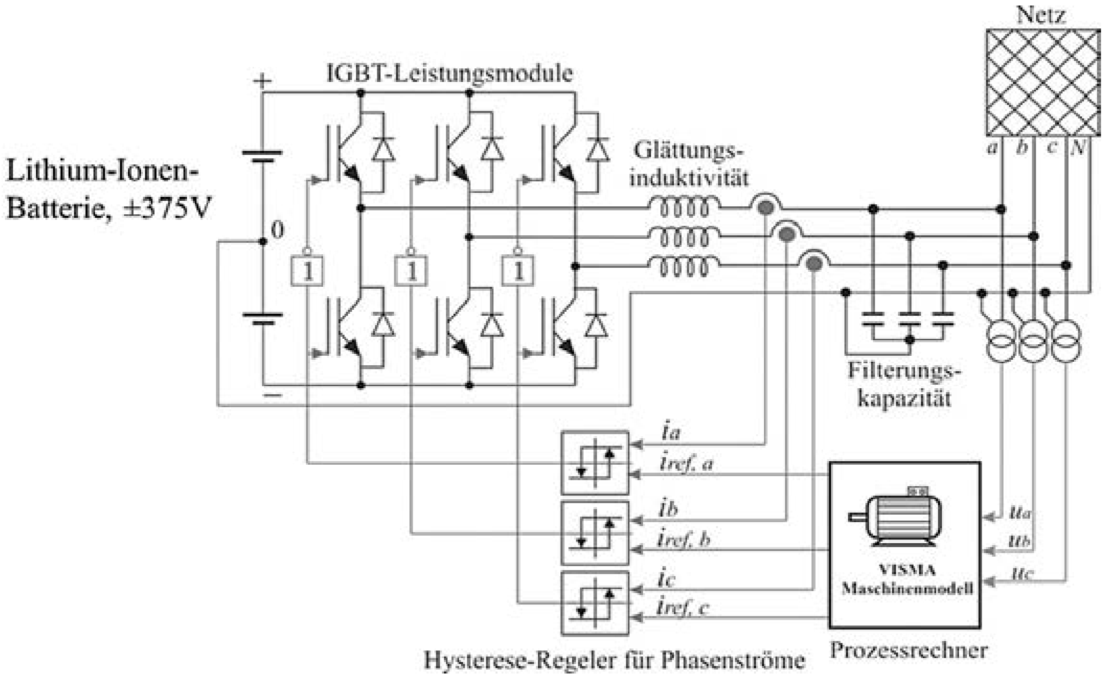

Figure 4: Setup for grid stabilisation, consisting of lithium ion battery, IGBT converter, VISMA process computer and grid connection according to [Chen, Y.; Werther, B.; Schwake, B.; Beck, H.-P.: Netzstabilisierung durch die „Virtuelle Synchronmaschine“ (VISMA) mit überlagerter Frequenz- und Spannungsregelung, Internationaler ETG-Kongress 2013, Berlin 2013].

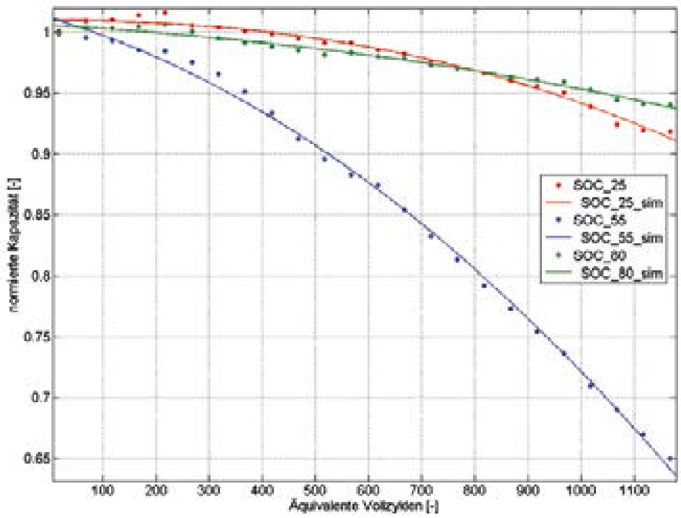

Figure 5: Measured (dots) and calculated (line) normalised capacity curves over number of cycles of 8 Ah LFP round cells loaded with 2C at 40 °C, death of discharge 10 %, medium state of charge 55 % (blue), 25 % (red), 85 % (green).

Smart Microgrids – Efficient Use of Renewable Energies through Resource-Optimised Smart Microgrids

Objective

Joint project: The overarching objective pursued in the project is to open up potentials of locally generated renewable energy sources and their decentralised use through dynamic adaption of supply and demand. Moreover, the aim is to reduce the energy system's vulnerability as a whole and increase its flexibility as to the potential for integrating renewable energy sources. The social acceptance of the use of renewable energy sources is analysed in two model regions in cooperation with various project partners from practice.

Project work is focused on answering the question, if and in how far smart microgrids are able to contribute to the development of smart supply structures which receive electrical power from different sources and supply consumers on demand. A major aspect is to investigate the temporal demand-supply balance within the local energy system.

SP 2 – Energy system technology: The aim of the sub-project is to develop an energy management concept for grid-beneficial power exchange with the upstream grid, considering the potentials for energy supply from renewable energy sources (photovoltaics, wind and bio energy) in the participating communities and for load management in agricultural and business enterprises.

Background

The aim of the sub-project is to conduct a technical and economic feasibility study of the local temporal energy demand-supply balance. From the economic point of view, the approach contributes to meet the increasing grid requirements caused by decentralised power plants which generate fluctuating power [1]. Within the liberalised electricity market, the intended local balance is to be investigated considering free competition between energy generation, energy trade and customers. Due to potentially conflicting economic objectives of the market players aiming at local balance within the energy system, regulatory measures are necessary [2].

Approach

Within the scope of the project, the considered energy systems are analysed in two separate case studies, on the one hand, concerning the economic targets of the market players and on the other hand, regarding the technical objective with respect to the overall system.

Within sub-project 3 (Financing Concepts), Leuphana University of Lüneburg investigated which incentive systems and business models are currently available for the single players with respect to local temporal demand-supply balance [3]. Based on the results, appropriate business models and corresponding marketing strategies are derived for the plants integrated in the system (PV, wind and biogas plants as well as controllable and non-controllable loads and storages) and implemented into an economic model. The result of these considerations are economically motivated schedules for single plants and the corresponding storage capacities. Summing up the single plant

Project Data

Project name:
Smart Microgrids – Efficient Use of Renewable Energies through Resource-Optimised Smart Microgrids

Funded by:
Federal Ministry of Education and Research

Grant number:
03EK3524 B

Project duration:
01.06.2013 to 31.05.2016

Reporting period:
01.06.2013 to 30.09.2015

Project manager:
Prof. Dr.-Ing. Hans-Peter Beck

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H.-Peter Neitzke


Verena Spielmann

schedules yields the power exchange between the analysed system and its environment. The economically motivated overall storage capacity is determined likewise.

Within the scope of sub-project 2 (Energy System Technology), the Institute of Electrical Power Engineering and Energy Systems developed a modular model of an energy management concept which is based on available data (feed-in and load time series in 15-minute intervals). The aim of the management concept is energy balance compensation of power exchanged with the surrounding system for a given time series in every simulation step. Possible aims are for example the reduction of grid extension measures, energy supply at peak-load hours or reserve power supply as time series of the power exchanged between the analysed energy system and the upstream grid. Depending on the respective power exchange specified, the management concept is suitable for grid-connected as well as for islanding operation mode.

For the analysed example communities, different types of producers and consumers may be considered which primarily differ as to their controllability. From the producer side, photovoltaic and wind power plants are considered as non-controllable plants. From the consumer side, all systems considered via (standard) load profiles like households belong to this category. As controllable plants, those plants are considered whose power output and power consumption can either be shifted in time and/or can be modulated as to the amount. From the producer side, this category includes biogas CHP plants, while from the consumer side, for example, systems in agricultural enterprises are considered, whose power consumption can be shifted in time depending on the level of the respective storage system. For every system, restrictions, such as minimum running and break time, maximum running and break time, level of respective storages and minimum partial load, are considered. The technical investigations result in plant schedules, based on the preset power to be exchanged within the overall system and on the corresponding storage capacities.

Table 1: Plants in analysed example system (data derived from: [4], [5], [6], [7]).

	Plant	Annual energy	Time behaviour	Power range
Consumer	100 households	353 MWh	H0-SLP	13,5 – 75,6 kW
	Farming business	620 MWh	Base load +	
Periodic consumption	62,2 – 108,2 kW			
	2 stirrers	19,7 MWh	3 hours per day	9 kW
	Self-consumption plant and office equipment	105 MWh	Base load	12 kW
Producer	Biogas CHP plant	< 1.314 MWh	flexible (1,500 m³ storage)	50 – 100% CHP nominal power

The resulting exchanged power and storage capacities are compared, in order to analyse the contribution of every single incentive system and of the derived marketing strategies to achieve the intended technical goals. Within the scope of sub-project 4 (Business Concepts), biogas generation potentials as well as load management potentials in the agricultural sector were determined by Neubrandenburg University of Applied Sciences. In the rural areas investigated in the project, agricultural enterprises are also energy producers, thus having the potential for flexibilisation of parts of their loads which makes them an important player in the balance between local energy supply and demand.

Against this background, the developed methodology is outlined using the example of an energy system, consisting of a farming business with energy-intensive piglet breeding which operates a biogas plant with connected CHP, and a community with 100 households (see [13]).

The system's only producer is the biogas CHP plant. With the use of a biogas storage system, the plant is operable at 50 to 100 percent of its nominal power. On the consumer side, the households (H0-SLP) and the base load of the farm (heating and cooling) as well as periodic feeding are considered as non-controllable loads. Controllable loads are stirrers in the biogas plant and milling and mixing systems for feed processing. The plants considered in the system are given in Table 1. The biogas plant uses pig manure from the farm and locally available corn silage.

To supply the different consumers, the existing incentive systems result in different marketing options which are given in Table 2.

Apart from customer supply directly from the biogas CHP plant, purchase and sales of energy at the electricity stock exchange is also considered, provided that local prices permit cheaper consumer supply. In addition, surplus energy shall be offered at the stock exchange, when economically beneficial compared to local direct marketing.

Based on economic analysis of different CHP variables in combination with a CHP plant with continuous electrical power of 150 kW, Figure 1 depicts the resulting revenues. The values, which increase with increasing installed CHP power, essentially result from the increasing revenue from market and flexibility premium.

Besides consideration from the economic point of view, analysis also includes the CHP plant's

Table 2: Marketing channels for energy supplied by biogas CHP plant within the analysed system ([7], [8], [9]).

	Plant	Marketing channel	Revenue options
Consumer	Households	DM with market premium	Household electricity price + market premium, saving of electricity tax due to geographical
	Farming business	DM with market premium	Trade electricity price + market premium, saving of electricity tax due to geographical proximity
	Stirrers	Self-consumption	Saving of grid charges and related levies, reduced EEG surcharge
	Stock exchange	DM with market premium	Stock exchange price + market premium

grid-beneficial load-following operation, enabling constant power supply for the exchange with the surrounding system. Since the highest annual surplus is reached with a CHP plant with an installed power of 270 kW, a CHP plant with similar installed power is also assumed for the technical analysis.

Considering the efficiency losses of a CHP plant operating at partial load, this results in a constant annual exit capacity of 19.8 kW. In case of economic-oriented operation, the exchanged power varies from 129 kW (exit capacity) to -18 kW (delivered energy). Without local supply of the consumers and without load management of the flexible plants in the farm, the power of the assumed system delivered simultaneously every quarter of an hour The case study shows that under the previous assumptions, efficient operation in the sense of a smart microgrid of a biogas CHP plant with local direct marketing is feasible, whereby the achievable revenues increase with installed CHP power, since market premium (largest share of revenues) and flexibility premium increase, too. For grid-beneficial operation as well as for direct marketing, power exchange peaks are reduced compared to the reference case (without local energy supply, without load management).

Project Status

During the reporting period, the developed method has been implemented considering various example systems (see [10], [11], [12], [13] and [14]).

Workshops for participating players have been held in participating model communities which were hosted by Ecolog Institut in cooperation with partners from practice. A derivation of detailed applications and targets for the single communities as well as the subsequent implementa-

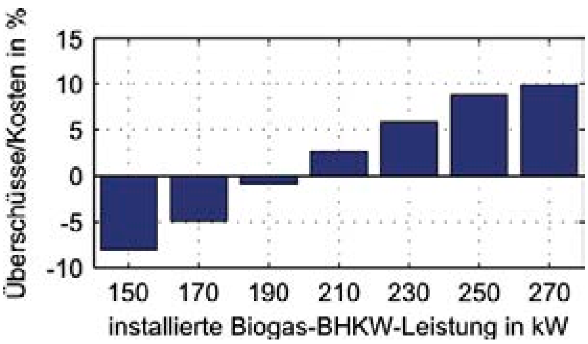

Figure 1: Annual revenues related to annual cost of direct marketing to local customers and purchase and sale at electricity stock exchange.

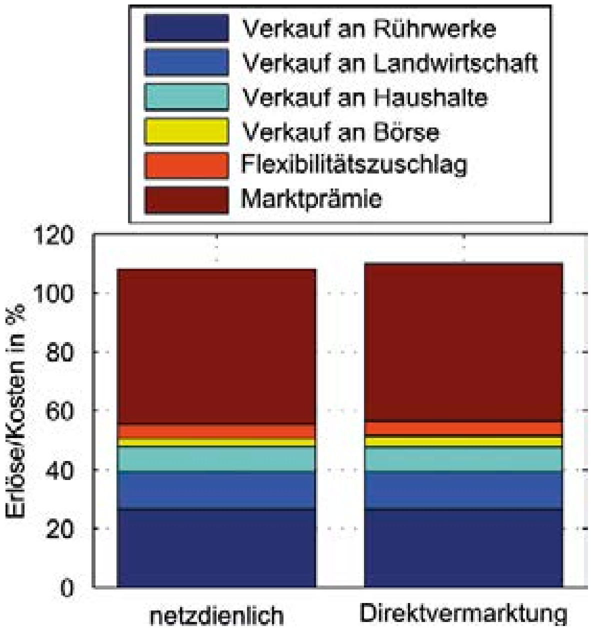

Figure 2: Share of revenues related to cost for grid-beneficial operation and direct marketing for an installed CHP plant power of 270 kW.

tion of the developed method and the adaption of the existing models to the model communities' requirements will be the topic of future work.

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Project partners

Project coordination units
- Ecolog Institut für sozial-ökologische Forschung und Bildung (project coordination)
- Energy Research Centre of Lower Saxony

Participating institutes
- Institute of Electrical Power Engineering and Energy Systems, TU Clausthal
- Neubrandenburg University of Applied Sciences
- Leuphana University of Lüneburg

External partners
- Public utility company of Neustrelitz
- Landeszentrum für erneuerbare Energien Mecklenburg-Vorpommern e.V.
- Energie Ressourcen Agentur Goslar e.V.
- Volkswind Immenrode

Refuelling in the Smart Grid

Problem

Decreasing power plant capacity as a result of nuclear phaseout and shutdown of old coal-fired power plants and the hesitant construction of new, additional large-scale power plants pose a great challenge to the energy supply system. Moreover, flexibilisation of the supply system is necessary because of increasingly steeper residual load gradients. Another question is how to supply inertia as well as primary and secondary reserve power in the future, delivered by large-scale power plants so far.

Objective

The objective of the project is the development and testing of innovative chargers and charging algorithms for electric vehicles as a contribution to dynamic system stability of electric grids.

Approach

Research work focuses on integrating vehicle energy storage systems into electrical energy supply, in order to provide decentralised location-dependent ancillary services.

Furthermore, the use of vehicle storage systems for balancing production and consumption within the balance limits of a customer plant – a so-called "prosumer cell" – is analysed. This requires a communication link from the main meter at the house connection to the vehicle and maybe to the producers, for example a photovoltaic (PV) system or a combined heat and power (CHP) plant, and to other controllable consumers.

Other ongoing and planned projects use electric vehicle storage systems as pure energy storages. In this project, vehicle batteries are analysed with respect to their suitability as "power storages" for the supply of inertia, primary control and further ancillary services.

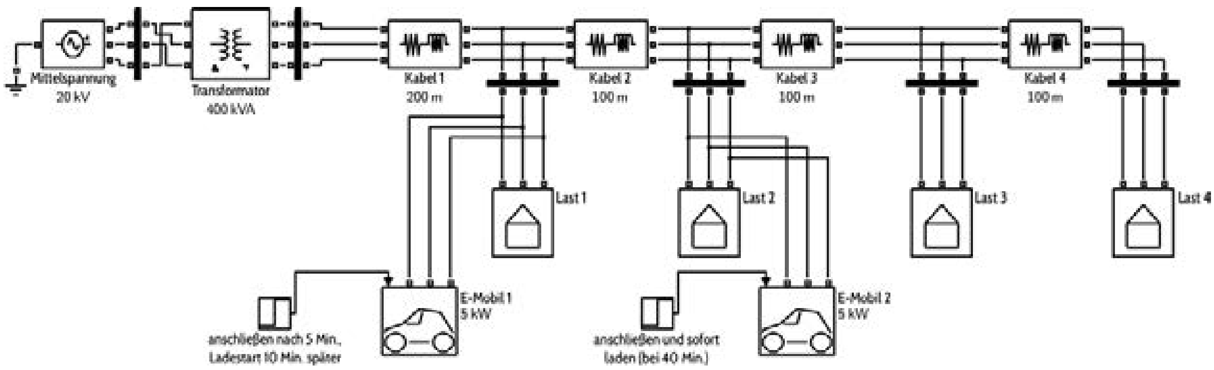

Figure 1: Simplified grid model for analysis of various scenarios with respect to load and production situations as well as connection and charging behaviour of electric vehicles with Matlab/Simulink

Project Data

Project name:
Showcase Electromobility – Refuelling in the Smart Grid

Funded by:
Federal Ministry for Economic Affairs and Energy (BMWi)

Grant number:
16SNI005D

Project duration:
01.01.2013 to 31.12.2015

Project manager:
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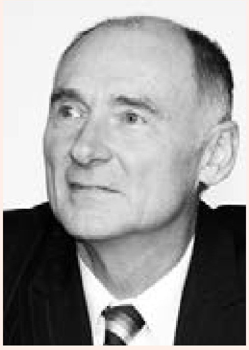

Hans-Peter Beck

Dirk Turschner

Due to different topologies and local states of load, location-specific parameter optimisation is advantageous for parameterising the dynamic reaction of charge controllers to grid events.

As mobile units, electric vehicles are capable of identifying the current state of the local grid area during the grid-connected (plugged-in) phase, thus collecting valuable data for grid providers. The collected data are aggregated in a “power quality map“. In the context of a development towards “Smarter Grids“, the sensor network for grid control becomes more and more dense, thus contributing to a continued high quality of supply.

Within the scope of the project, the aforementioned three functionalities – ancillary services, prosumer cell optimisation and power quality map – are analysed and maybe developed, validated through laboratory setups and integrated into electric vehicles available on the market.

Project Status

The project is in progress. We have applied for an extension of the project by six months until 30.06.2016.

Results

To analyse possible scenarios and develop a smart load management, a simplified grid model is used (Figure 1). With the help of this model, various load and production situations can be simulated dynamically in a branch of the low-voltage grid. Based on the simulation results, the effects of electric vehicle charging can be analysed in detail at different points of the grid.

Figure 2 shows a comparison of the simulation results regarding the charging behaviour of two electric vehicles in accordance with the setup depicted in Figure 1. The first simulation (left) assumes charging with constant power (nominal power). The second simulation (right) assumes for both vehicles the new grid-beneficial charging

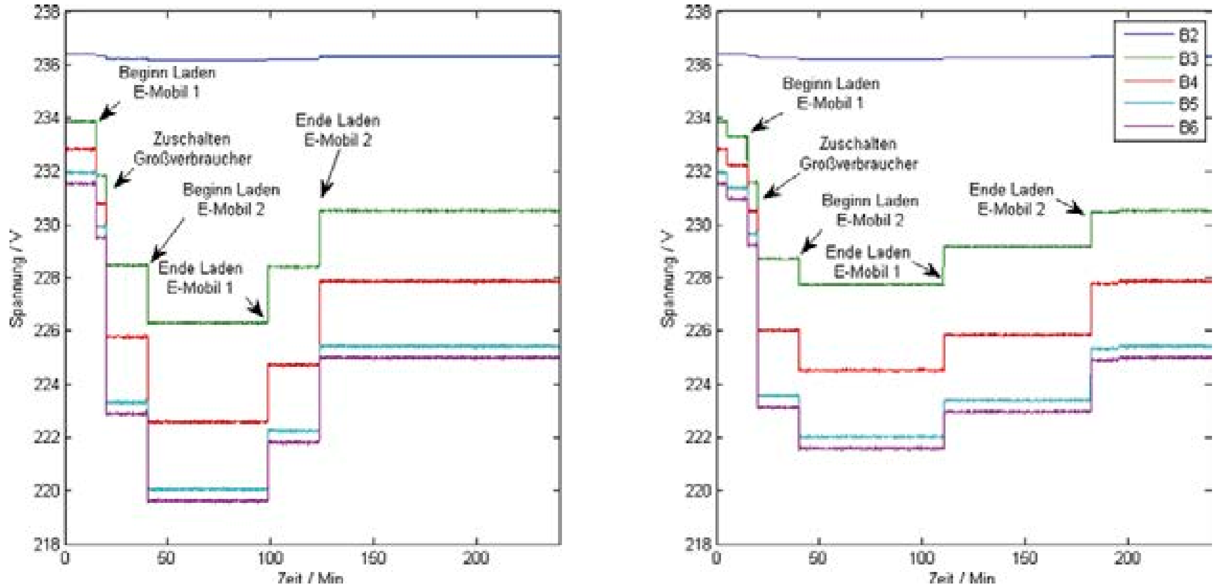

Figure 2: Comparison of simulation results regarding the charging behaviour without (left) and with (right) grid-beneficial charging process according to Figure 1.

process. When comparing the voltage curves, it can be seen that there are less voltage dips in case of the grid-beneficial charging process.

The simulation results (Figure 2) prove that voltage dips can be reduced when using the grid-beneficial charging process. However, this is at the cost of charging time, as shown in Figure 3. It can be seen that charging time of vehicles connected nearer to the end of the grid branch is much longer than for vehicles connected nearer to the start. This is due to the fact that in the simplest case, a constant nominal voltage (for example 230 V) is applied in case of grid-beneficial charging.

In case of a deviation from this nominal voltage, the charging capacity is adapted. For example, it is increased, meaning that charging is accelerated, if the locally measured voltage is above the nominal value. Since the grid voltage is principally location-dependent, i.e. locally different, owing to the voltage drop along the line, the vehicles, which participate in grid stabilisation with the grid-beneficial charging process, will always be treated locally different when regulating to a constant voltage.

In order to avoid that vehicles charged nearer to the end of a grid branch are principally discriminated by longer charging times, it is useful to define local nominal voltages for charging process and control. This is realisable with the power quality map, also developed within the project.

The control of the charger is in accordance with the block diagram presented in Figure 4.

Depending on the frequency and voltage deviations from the preset nominal values (0*,U0*), the charging capacity is increased or decreased compared to the nominal power P0*. Moreover, the nominal power is also adaptable via   P0* to achieve load balance in the prosumer cell.

During operation, parameters highlighted in red in Figure 4 can be controlled via the power quality map. In case there is no connection to the power

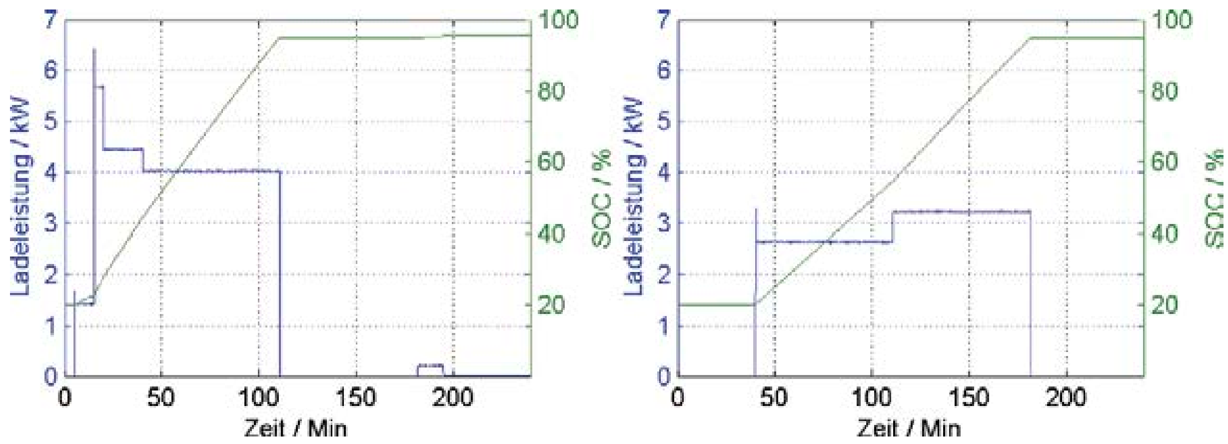

Figure 3: Comparison of simulation results regarding the charging behaviour of vehicle 1 (left) and vehicle 2 (right) using the grid-beneficial charging process according to Figure 1

quality map, the charger operates autonomously, using the preset set of parameters. In this way, the charger's dynamic behaviour and the ability to respond to local grid events is maintained even without online connection.

Data Acquisition and Transmission

To store and visualise the spatially resolved state of the grid and to optimise the parameters of the charging process, power quality map requirements were specified.

For the communication with the power quality map and the data transmission between individual units, individual communication paths and corresponding transmission protocols were specified in cooperation with the project partners.

For an exact fixed measurement of the location-independent grid frequency in the interconnected power system as well as for stationary measurement of the local state of the grid and of the load flow in households and prosumer cells respectively, a measurement box was developed. Figure 5 depicts such a box and the corresponding measurement plot of the state of the grid.

Development and Investigation of Charging Technology

Within the scope of the project, three technical development lines are pursued:

1. According to the principle of the virtual synchronous machine (VISMA), a regenerative charger is developed and constructed for the university-owned test vehicle.
2. In cooperation with FINE Mobile GmbH, supplier of electric vehicles available on the market,

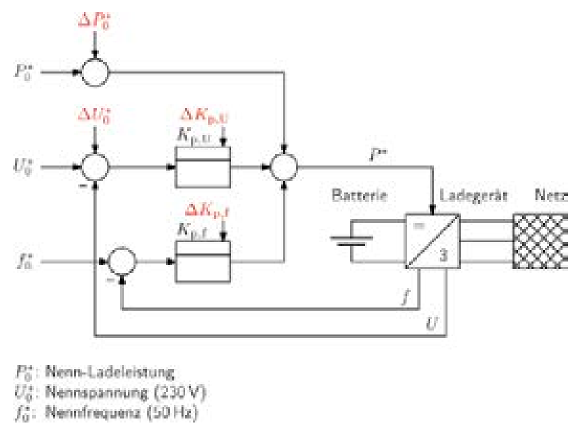

Figure 4: Controller structure of grid-beneficial charging process

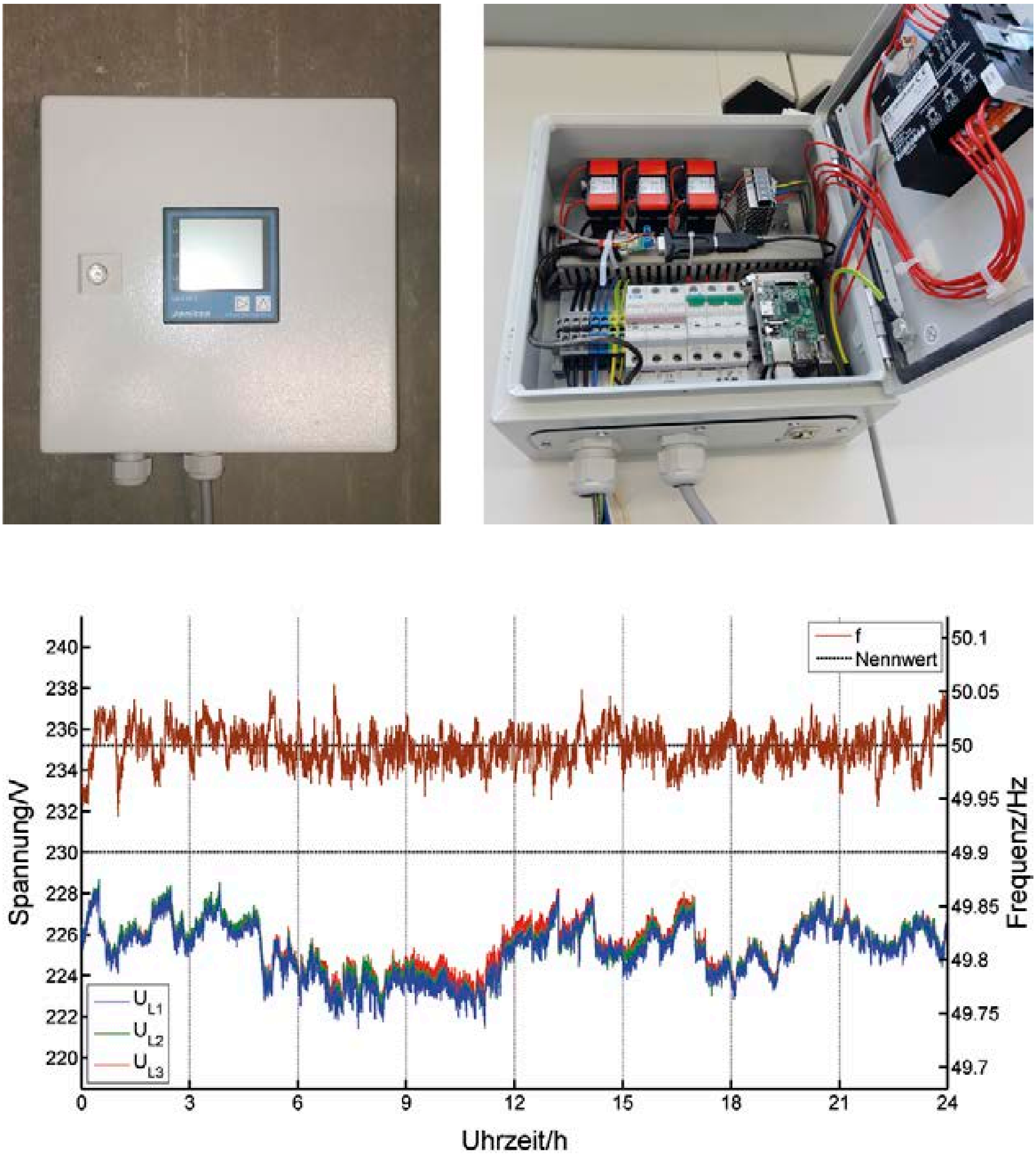

Figure 5: (Top): measurement box developed for stationary monitoring of the state of the grid and for load flow measurement in the prosumer cell with connection to power quality map; (bottom) state of the grid and load flow measured with measurement box

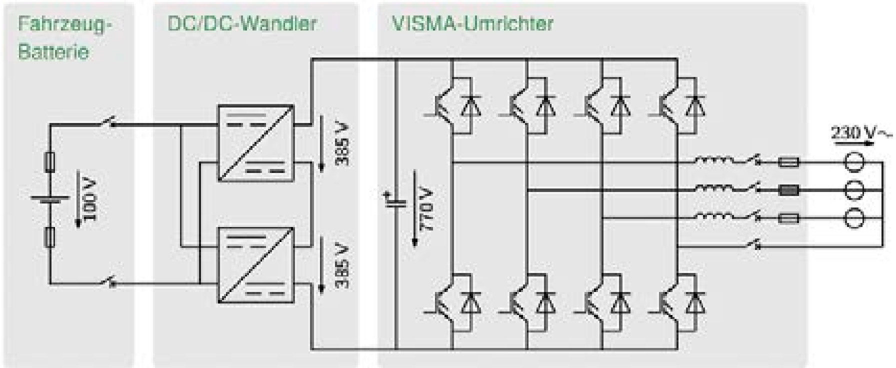

Figure 6: Schematic of VISMA charger for university-owned smart roadster

two vehicles are constructed with specifically modified charging technology for load-dependent charging capacity modulation.

3. RegenerativKraftwerke Harz (RKWH) is enhancing their e-drive Audi A2 by a three-phase quick charger with the aim to provide additional support to grid-beneficial charging.

Project partners

Project coordination unit
- TU Clausthal

Participating institutes
- Energy Research Centre of Lower Saxony
- Institute of Electrical Power Engineering and Energy Systems, TU Clausthal
- Institute of Electrical Information Technology, TU Clausthal
- Institute of Computer Science, TU Clausthal

External partners
- Bornemann AG
- Bundesverband Solare Mobilität e.V.
- Forschungsstelle für Energiewirtschaft e.V.
- RegenerativKraftwerke Harz GmbH u. Co. KG

Figure 6 shows the charger's schematic, which is developed for the university-owned test vehicle – a smart roadster equipped with electric drive. The charging converter consists of a bidirectional DC converter on the battery side for adapting the battery voltage of 100 V to the DC link voltage of 700 V and of a voltage source converter/inverter in bridge connection on the grid side.

The grid-supporting design of the corresponding charge controller is independent of the communication with a central management system. For this purpose, the grid parameters "frequency" and "voltage" are evaluated; similar to the primary control of a power plant, the charging capacity is adapted. With an additional, non-obligatory communication link to the power quality map, the control parameters are controllable depending on location and grid parameters, in order to optimise the charging behaviour even more.

Fast Charging of Electric Vehicles

The project "Fast Charging of Electric Vehicles" is investigated by the Energy Research Centre of Lower Saxony in close cooperation with the Fraunhofer Heinrich Hertz Institute in Goslar. The aim is to develop fast-charging algorithms permitting fast but safe charging of vehicle batteries in consideration of temperature. Furthermore, charging stations will be developed and erected, and a business case for service station operators in the era of electromobility will be worked out.

With respect to social acceptance, a widespread problem of electromobility is the range which is mostly assessed as being too low, although in 98.6 percent, most daily trip distances are below 100 km [2][1]. If considering the pure trip distances, the simulation carried out at KIT based on a study [3] reveals that over 80 percent of daily passenger vehicle driving performance is below 125 km, meaning that individual trip distances are even below this distance. Nevertheless, society requires electric vehicles to offer the same range as vehicles with internal combustion engine, as people do not want to put up with restrictions. One possibility to solve this problem is to use larger batteries which would implicate higher prices and in turn lower acceptance. Another option is fast recharging which would reduce society's "fear of range". With the introduction of electromobility, fast charging is therefore a major topic. Some electric vehicle manufacturers offer "fast charging" as add-on option at extra charge, for example advertising "up to 80 percent charge in 30 minutes" or "quick charge in 45 minutes". However, very often the initial state is not defined, and mostly fast charging is only in the range of 20 to 80 percent in 45 minutes, meaning that a full charge would take 1.25 hours, assuming that the first and the last 20 percent would also be realisable in the same period of time, which is normally not the case.

In contrast, this project aims at charging a conventional vehicle battery from 0 to 100 percent in less than 30 minutes. It is realised by the development of novel charging procedures. For this purpose,

Figure 1: Application of fibres on the cells

Figure 2: Battery block with fibres

Project Data

Project name:
Fast Charging of Electric Vehicles

Funded by:
EFRE and MWK

Grant number:
WA3-80127299 / ZW6-80127299

Project duration:
1.2.2012 to 30.10.2014

Project managers:
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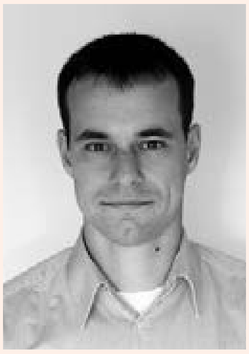

Raoul Heyne

various approaches, such as stage charging, pulse charging and constant temperature charging, are developed, analysed and evaluated.

Such charging procedures require some preparations. One important aspect is to provide additional safety technology for fast charging processes. For this purpose, the project partner Fraunhofer Heinrich Hertz Institute applied fibre-optical sensors, facilitating temperature-field measurements. Due to their size, the sensors can be fitted practically into every battery, leaving the battery's geometry unchanged. In this way, fast charging is possible with nearly all mass-produced batteries. Figures 1 and 2 show batteries equipped with such sensors.

As depicted in Figure 3, complete temperature fields are measurable.

In the course of the project, it became evident that it is not sensible to attach temperature sensors directly to the battery surface, because temperature is measured by fibre elongation and bcause batteries expand, too, depending on their state of charge. This way, temperature measurement is hardly possible. It could be proved that battery expansion is a better safety indicator than temperature. Thus, expansion with temperature compensation will rather be used as indicator in future projects.

With the help of the aforementioned safety and monitoring technology, various charging procedures are then tested. At first, cells, then modules and scooter batteries and finally vehicle batteries are analysed with the newly developed charging procedures.

An excerpt from the results is given in the table in Figure 4.

Charging time is depicted for a charge from 0 to 80 percent and from 0 to 100 percent. It can be seen that many procedures permit charging in less than 30 minutes. The quickest method is constant current constant voltage (CCCV) charging within 0.31 hours, but going along with high

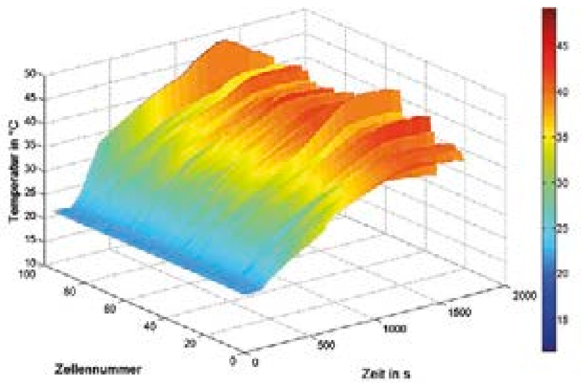

Figure 3: Fast charge temperature curve

temperature rise. The second fastest charging procedure is pulse charging, featuring a lower temperature rise, provided that the cells' maximum charge rate of 4C shall not be exceeded. Another result is that stage charging is the slowest method, but also has the lowest temperature rise in the cells. Compared to charges with low C-rates, this charging procedure is faster featuring the same temperature rise, which is also indicated in literature [4]. With respect to the complete vehicle battery, pulse charging is evaluated as best charging procedure.

Finally, large vehicle batteries are charged using pulse charging. The result of one of the charging processes is presented in Figure 5.

With pulse charging, charging first starts with a constant current of 100 amperes (2.5 C). Proper pulse charging starts as soon as the maximum voltage defined by the cells and the management system is exceeded. However, the amount of current pulses is gradually reduced, in order to prevent the battery management system implemented by the manufacturer from disconnection. In this way, fast charging is realisable with standard batteries including standard management system.

In the course of the project, rapid charging stations for implementing the aforementioned charging procedures are also developed in cooperation with the project partner Power Innovation GmbH. Especially the project partner Wolfsburg AG claims that charging stations have to support at least the CCS standard. As a preceding project of the Showcase Electromobility, its aim is to connect the Harz Mountains via charging stations with the metropolitan region of Lower Saxony.

Ladeverfahren		Ladedauer in h		maximale Temperatur in K	Temperatur-differenz ΔT
		80%	100%		
IU-Ladung	2C	0,40	0,68	310,35	17,2
	3C	0,27	0,38	318,25	25,1
	4C	0,20	0,31	324,55	31,4
	5 C (15,2 V)	0,16	0,31	318,35	25,2
Stufenladung	3C mit 3 Stufen	0,28	0,74	309,35	16,2
	4C mit 3 Stufen	0,32	0,86	311,25	18,1
Pulsladung	2C 850 ms	0,40	0,67	311,15	18
	3C 850 ms	0,27	0,44	318,95	25,8
	4C 500 ms	0,20	0,40	319,15	26
	4C 850 ms	0,20	0,32	322,95	29,8

Figure 4: The table summarises different charging procedures for a complete scooter stack

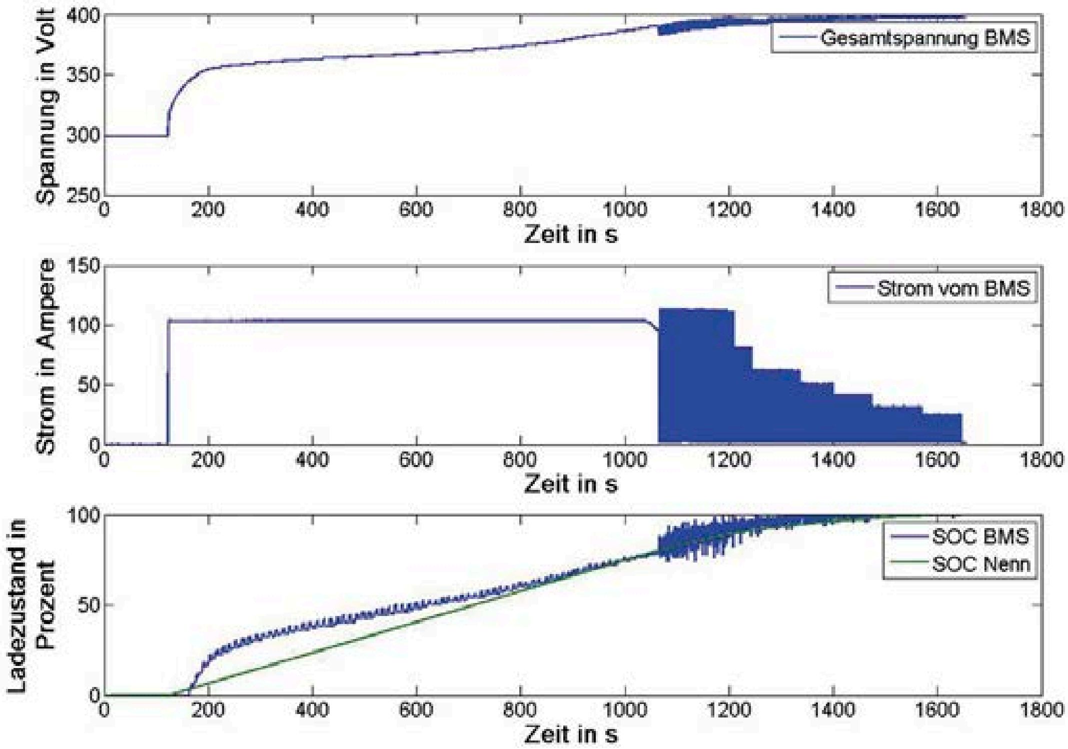

Figure 5: Fast charge of vehicle battery in approx. 27 minutes, until 40Ah are reached.

This a very challenging task. Until the end of the project, the CCS protocol will not be released by automotive industry and the agreed charging station suppliers. As a consequence, we are forced into purchasing standard charging stations which have to be modified by our project partner Power Innovation GmbH. Due to the lacking CCS protocol, just the ChaDeMo protocol is realisable in the vehicles, thus also permitting a standardised charging procedure. The charging stations are rebuilt in the way that they are suitable for CCS, ChaDeMo and direct control. By this means, the charging stations are able to support the developed charging procedures. The only disadvantage is that vehicle batteries have to be connected directly to the station without standardised adapter, which requires some rebuild time. Due to the rather political negotiations with the aim to obtain the CCS charging protocol, the erection of the charging stations is delayed, having the consequence that in the course of the project, no long-term research on the effects of charging procedures on battery lifetime can be conducted under real conditions. But towards the end of the project, there will be a publication of KIT [5], explaining that occasional fast charging prolongs battery lifetime, meaning that fast charging is not only detrimental to batteries. Thus, it can be expected that long-term application of the charging procedures developed within the project does not necessarily lead to battery life reduction, but instead to battery life extension.

Another basic problem of fast charging is the provision of large amounts of electrical power required for the fast charging process. This is not possible everywhere, in particular not in private households. For this reason, the project partner Jochen Schreiber, operator of two Aral service stations, has been brought in the project. Service stations normally have a larger power connection, mostly needed for their car wash plants, which is suitable for supplying fast charging stations. The project has also been initiated by the service station operator's question about the future of service stations in the era of electromobility? One possible answer could be to erect fast charging stations at service stations, facilitating charging within 30 minutes. Such a model matches very well the business case for service stations developed within the project, especially since the service stations' major sales are in their shops [6], so that a longer duration of stay of customers could have a positive effect. In the course of the project, the staff of the service station has been trained to be able to manage the charging stations and help drivers of electric vehicles. In this context, the project partner WVI Professor Wermuth Verkehrsforschung und Infrastrukturplanung GmbH has analysed the impact on infrastructure and the integration of charging stations into it.

All in all, the project aims could be achieved, and the project has generated a lot of media attention (Figure 6).

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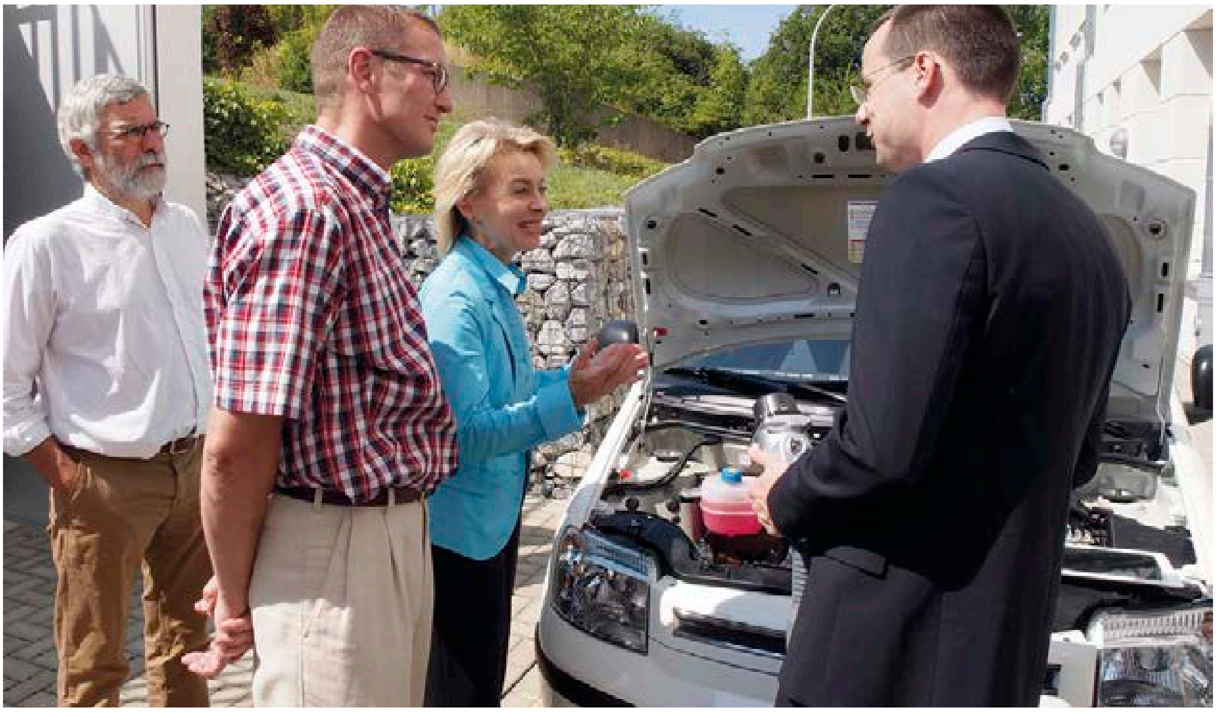

Figure 6: Communication exchange with the German Federal Minister Ursula von der Leyen at EFZN in Goslar

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Project partners

Project coordination unit

– Energy Research Centre of Lower Saxony

External partners

– Fraunhofer Heinrich Hertz Institute Goslar
– Jochen Schreiber (Aral service station operator)
– E-Wolf GmbH
– WVI Professor Dr. Wermuth
– Verkehrsforschung und Infrastrukturplanung GmbH
– Power Innovation GmbH
– Wolfsburg AG

Active Vibration Damping in Drive Trains with Planetary Gears and Input Observation Using the Example of Wind Load

Problem

Wind turbines require high reliability and operational safety. However, drive train failures are still very often responsible for plant breakdowns.

Besides a static and a quasi-static part, loads occurring during operation and consequently the local stress imposed on the components also consist of a large dynamic part which is due to wind load, wind gusts and certain unanticipated events.

Objective

The aim of the project is to develop an additional control for active vibration damping in drive trains. This is done exemplarily for a wind turbine. The controller is designed in the way that it is applicable to various common generator concepts with field-oriented control (synchronous machine, doubly-fed induction machine with full converter).

Considerably better results are expectable, if the drive train's shaft torques are known, since they respond highly dynamically to load changes. In drive trains with a gearbox with high gear ratio, as is typical for wind turbines, it is very time-consuming to measure such a high torque reliably at the slowly rotating shaft. For this reason, the project focuses on a dynamic observation of torque.

State of the Art

The Institute of Electrical Power Engineering and Energy Systems (IEE) has already been researching on active vibration damping in drive trains for a long time. In drive trains with electrical three-phase machine, damping is principally possible via a field-oriented control of the machine.

Damping can either be realised by adaption of the existing control concept or by means of an additional controller.

In wind turbines, vibration damping is either achieved by blade pitch control, i.e. the adjust-

Project Data

Project manager:
Dr.-Ing. Dirk Turschner

Project coordinator:
Dipl.-Ing. Nikola Ell


Dirk Turschner


Nikola Ell

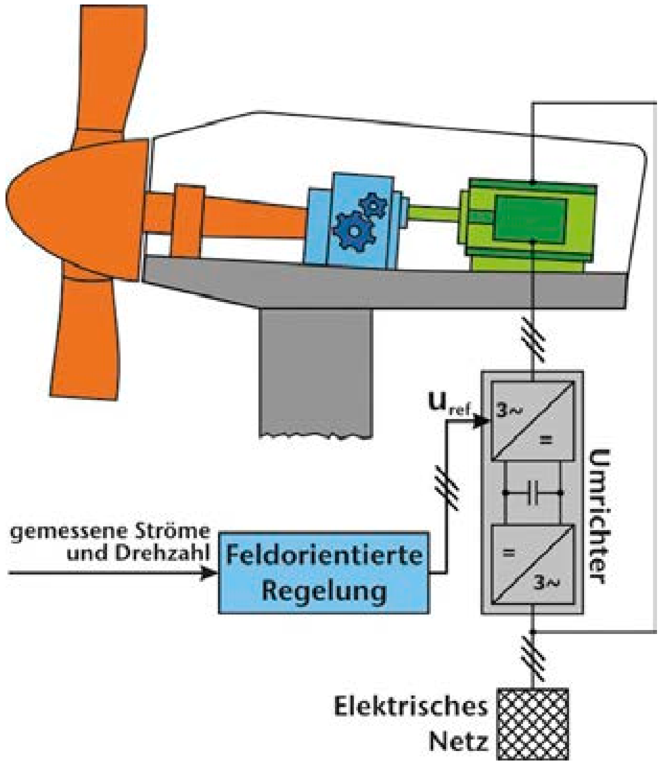

Figure 1: Principle structure of a wind turbine with doubly-fed induction motor and gearbox

ment of the rotor blade, or by field-oriented control of the generator. Nowadays, active vibration damping in wind turbines is often realised by feedforward speed control, i.e. by feeding the measured generator speed back. This way, good vibration damping results are already achievable.

The method serves as a reference throughout the project.

In drive trains with a gearbox with high gear ratio, it is particularly complicated to measure such high drive shaft torques accurately. There exist torque transducers which are capable of measuring such high torques. However, these complex custom-made devices are expensive and prone to error in case of rough weather conditions.

Approach

First, the controller and observer design is realised exemplarily in a simulation, involving generator, mechanical components and control system. This is done with the software Matlab/Simulink.

Next, the results are to be validated on a test bench, modelling the drive train of a wind turbine including doubly-fed induction motor and all important mechanical and electrical component parts of such a plant on a smaller scale. The plant is depicted schematically in Figure 1, the test bench itself in Figure 2. Wind load is simulated by a high-torque motor.

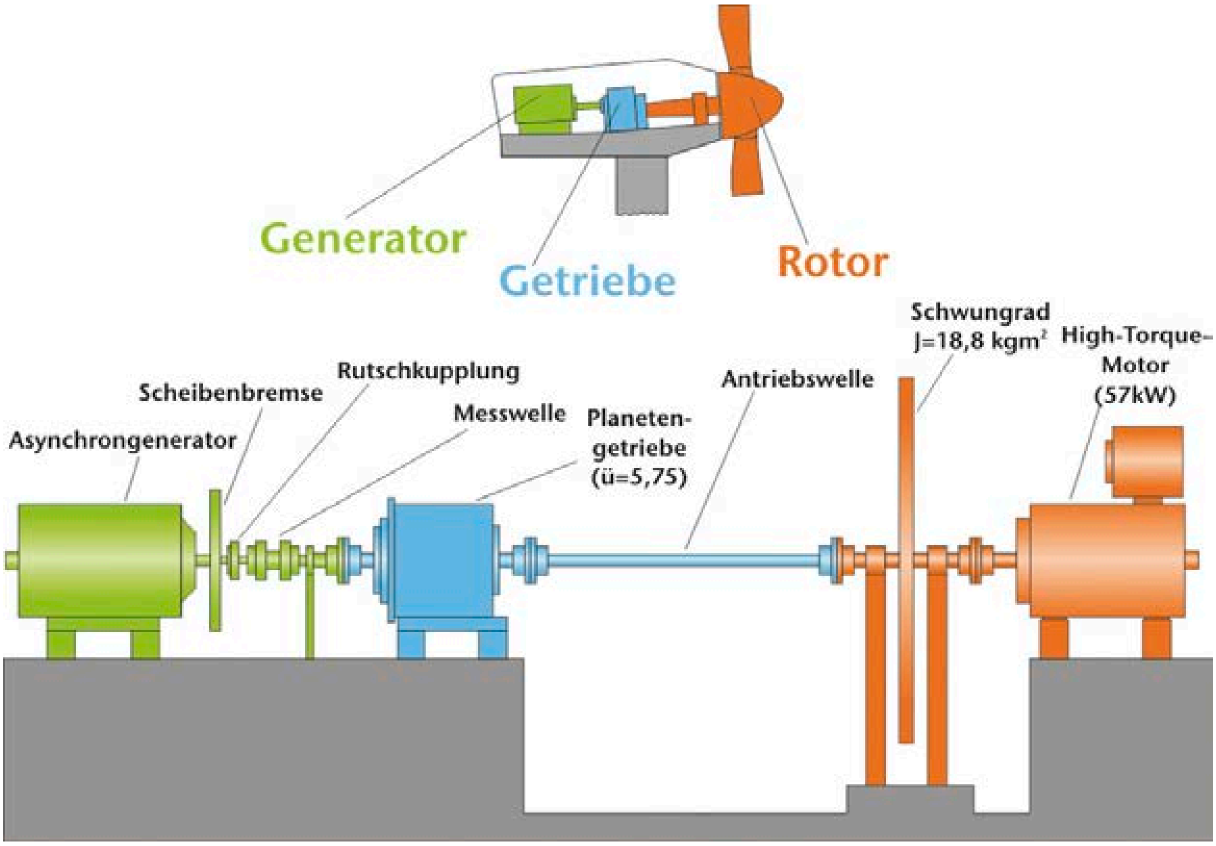

Figure 2: Schematic diagram of the test bench for modelling the drive train of a wind turbine at IEE

Project Status

The model required for the controller and observer design was implemented and tested with Matlab/Simulink.

The methods for observation and active vibration damping were tested on the model by simulations, achieving good results. For this purpose, the "control for lifetime enhancement of drive trains" (RELA) was developed which determines a corrective speed setpoint for speed control, superimposing the initial setpoint and thus reducing torsional vibrations in the drive train. The controller is based on the idea of reducing vibrational stress by rotational acceleration control.

The results prove that active vibration damping in the drive train works very well. Figure 3 shows the difference torque of the gear shafts vs. time. This difference imposes load on the gearbox and all drive elements. The blue curve depicts the behaviour without, the red curve with RELA control. Below, the load collectives determined by rainflow counting are depicted for both cases. The reduced vibrational stress in the drive train is clearly visible.

After modification of the test bench, it is presently put into service. In the next step, the developed concepts will be implemented and tested on the test bench.

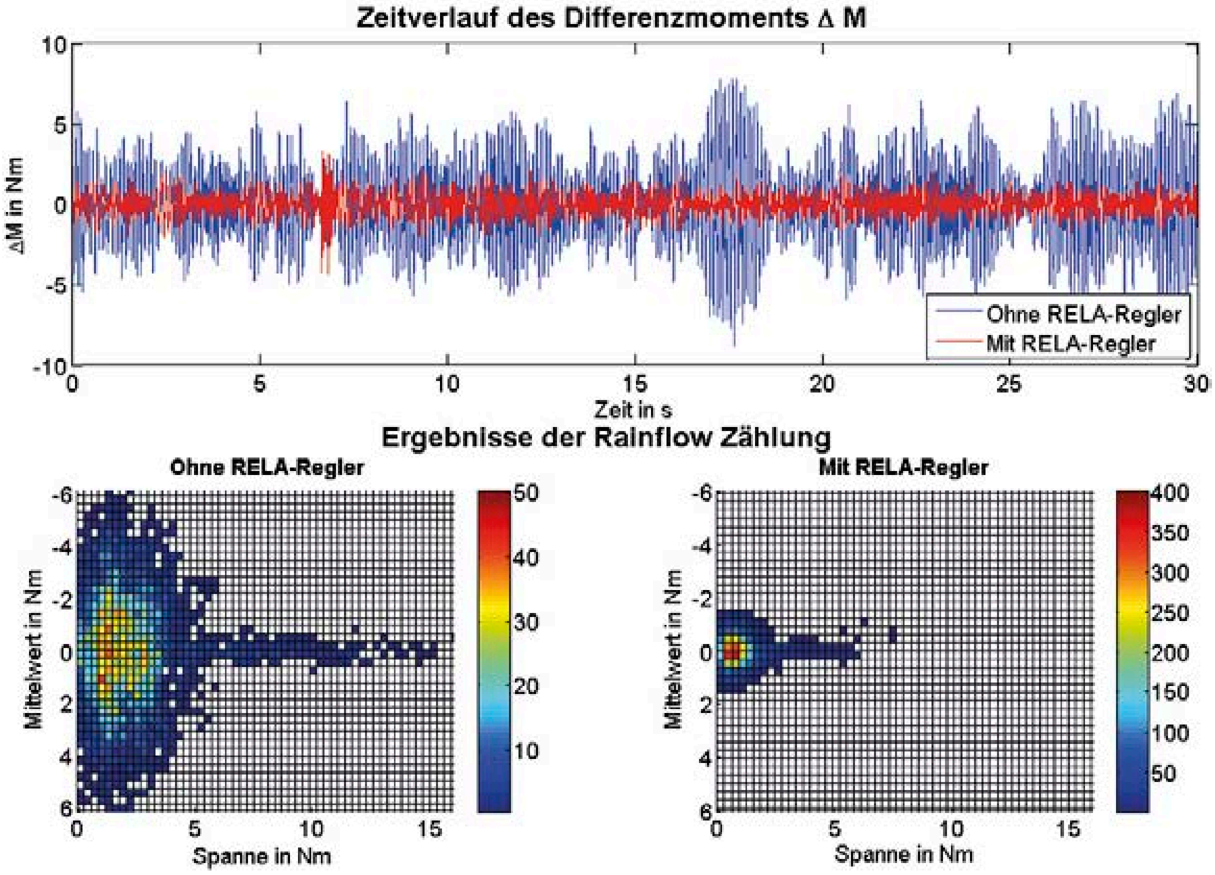

Figure 3: Top: Difference torque of gear shafts vs. time, imposed on gearbox, without (blue) and with (red) "control for lifetime enhancement of drive trains" (RELA).

Bottom: Rainflow counting results of difference torque with and without RELA controller. The number of vibrations with the corresponding value is depicted in colour.

Direct Heat to Electricity Conversion in Thermoelectric Energy Systems (Thermoelectricity)

Problem

Process-related waste heat produced in various energy-intensive processes, like in steel and glass production as well as in industrial bakeries, is often released unused into the atmosphere. With the help of thermoelectric generators, heat can be directly converted into electricity. Thermoelectric waste heat recovery could be a means to reduce primary energy consumption and thus be a major contribution to climate protection.

Objective

Within the scope of the project, the overall efficiency of thermoelectric waste heat recovery is to be determined and improved with available components under realistic conditions.

For this purpose, a multi-chamber calorimeter is constructed for measuring the thermal efficiency of the conversion process. Efficiency improvement shall be realised by use of an adapted converter with maximum power point tracking (MPPT). Exemplarily, an electrical circuit is to be developed which converts the output of a thermoelectric module network into maximum electrical output power. Moreover, the long-term goal is to develop thermoelectric high-temperature generators.

Higher temperature differences lead to increased Carnot efficiency and thus to increased efficien-

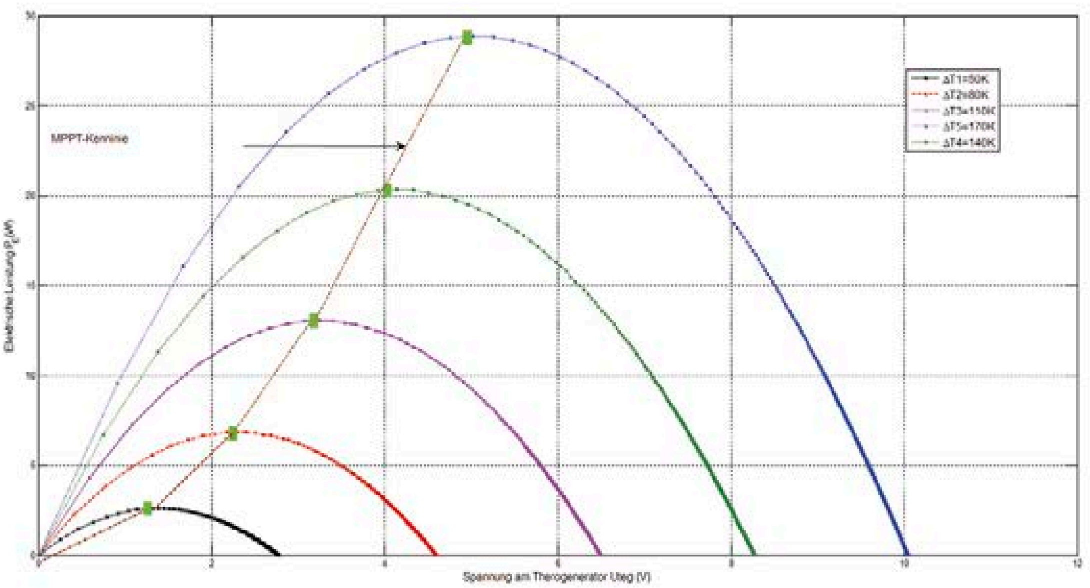

Figure 1: Calculated power characteristic of thermoelectric generator for different temperature differences

Project Data

Project name:
Direct Heat to Electricity Conversion in Thermoelectric Energy Systems (Thermoelectricity)

Funded by:
German Research Foundation (DFG)

Grant number:
BE 1496/16-1; BE 1496/16-2 (Fortsetzungsvorhaben)

Project duration:
01.09.2011 to 28.02.2016

Project manager:
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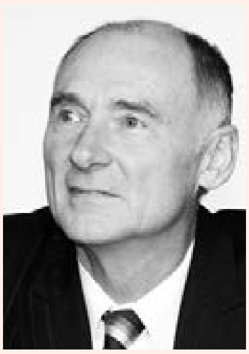

Hans-Peter Beck

Abdelhamid Bentaleb

cy of TE conversion. Conventional solder joints are only able to withstand frequent temperature changes to a limited extent. Especially in case of higher temperature differences, novel pressure sintering techniques with considerably improved thermal fatigue resistance have to be applied.

State of the Art

Bismuth telluride is the most commonly used thermoelectric material in thermoelectric generators. Nearly all commercially available thermoelectric generators are made of this semiconductor material. The achieved ZT value (the figure of merit indicating thermoelectric efficiency) is around unity between room temperature and 100 degree Celsius. An important aspect of thermoelectric energy conversion is the fact that efficiency is not only scaled with the semiconductor's properties, but above all with the thermodynamic Carnot efficiency. If Carnot efficiency is low (meaning small temperature differences), thermoelectric efficiency is low, too. In scientific studies, this correlation is often neglected. Acceptable efficiencies are only possible with high temperature differences. But at this point, many TE modules reach their limits. In most cases, conventional TE materials are only usable at temperatures below approx. 250 degree Celsius, and joining techniques are based on conventional solder technology which additionally limits the temperature range available. TE modules, which are especially subjected to temperature cycling, are often affected by errors, for example due to adhesive fracture of the solder metallisation at the semiconductor.

Since the output voltage of the thermoelectric modules varies with temperature difference, it is necessary to introduce a transformer circuit between TEG and load for power correction (the simulated power characteristic of a thermoelectric generator is depicted in Figure 1). An important factor, when designing the TEG circuit, is the arrangement of the thermoelectric modules. Since power applications require more than one module, module arrangement may either be in series, in parallel or in parallel chains.

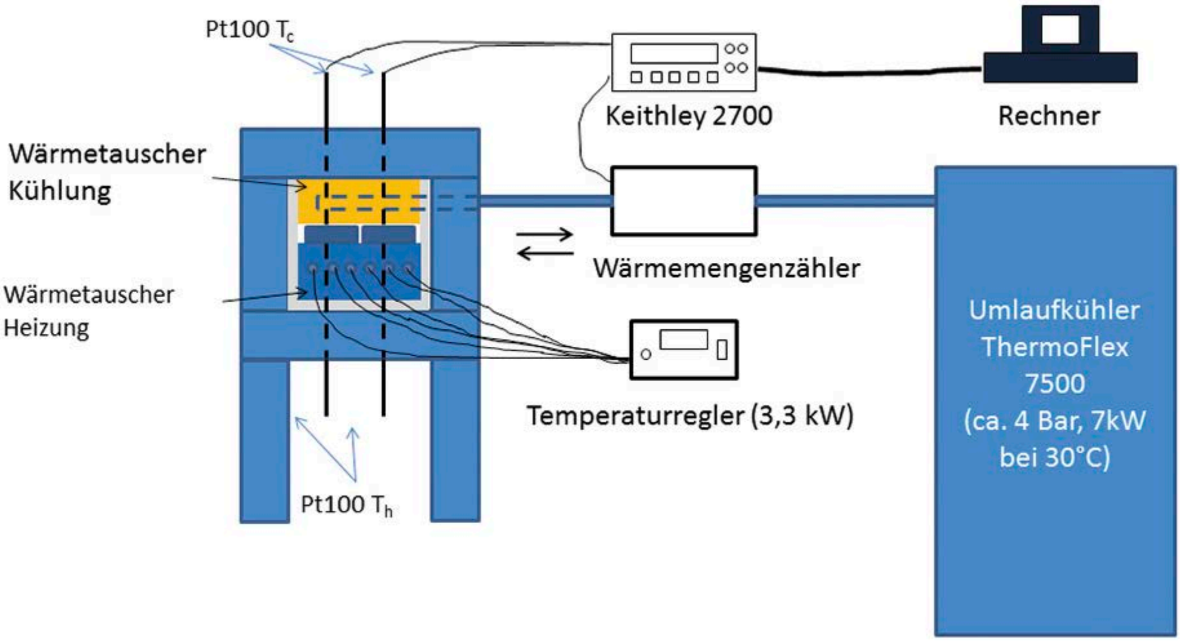

Figure 2: Schematic layout of the calorimeter

Experience gained from other fields of electrical power engineering can be introduced in the circuit design and module arrangement. For example, experience gained in photovoltaic and fuel cell technology, also requiring multiple series of cells for power adaption, are very helpful. However, the interconnection of many thermoelectric modules has the disadvantage that the effective temperature difference is not equal at all modules, leading to differences in power and internal resistance and consequently to mismatch. This drawback shall be overcome by investigating a so-called “distributed MPPT“.

During the last years, efficiency of electronic voltage converters could be increased more and more due to miniaturisation and device integration. Moreover, a reduction of the forward resistance in power semiconductors has contributed to this improvement. Further improvements, for example by active compensation of switching losses, will be the topic of future research work.

Approach

A new joining technique is tested for the development of high-temperature generators. The method relies on sintering of nanoporous silver layers at relatively low temperatures of about 250 degree Celsius and at pressures up to 30 MPa. The result is a compact silver layer in between two joining partners, featuring excellent electronic, thermal and mechanical properties, meanwhile also applied as solder replacement in the production of power electronic devices. Since the melting point of silver is above 900 degree Celsius, the joint is capable of withstanding process temperatures above 250 degree Celsius.

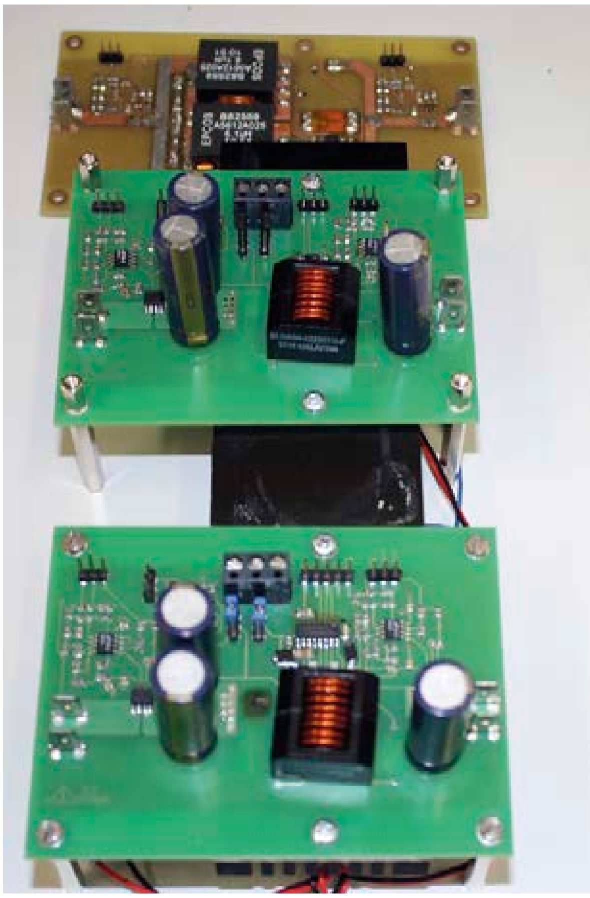

Figure 3: (Left) two-phase synchronous boost converter, (middle) full-bridge buck-boost converter, (right) full-bridge buck-boost converter with other gate driver and adjustable dead time

For power conditioning, an efficient converter (buck-boost converter) is developed.

Research includes aspects considering efficiency increase (e.g. active compensation of losses, device dimensioning and design, polyphase circuits). For maximum power efficiency, maximum dynamic MPPT efficiency has to be achieved, requiring the development and testing of a stable control algorithm of the converter.

In the test series, precisely controlled temperature differences are applied to the modules. This is realised by use of a multi-chamber calorimeter, including heat source module network, heatsink and adequate measurement instrumentation.

By this means, it is possible to measure the heat flow taken in by the thermoelectric generator, the temperature difference and the quantity of heat leaving the system. Thus, it is possible to determine thermoelectric generator efficiency.

Project Status

For the test procedure, a multi-chamber calorimeter was set up, permitting adjustment of various temperature differences and precise measurement of the heat quantity flowing in and out. The schematic chamber layout is presented in Figure 2.

For comparison and optimisation reasons, power conditioning is realised by a DC/DC converter using various topologies. Figure 3 presents the schematic of three tested circuits.

A two-phase synchronous converter with 70W nominal power per thermoelectric generator unit at different operating temperatures (T=Th–Tc=50K...200K) was identified as the most energy-efficient circuit concept.

Table 1 summarises the converter efficiency measured for various input power levels.

For the control, various MPP tracking methods were developed and implemented. Operating point adjustment is done with a model-based calculation of measured temperature difference or via power gradient tracking over time. The step size changing the converter's duty cycle is variable, in order to improve the system's dynamic behaviour in case of load changes. Figure 4 depicts the measured dynamic MPPT efficiency for two tested MPPT methods.

The thermoelectric network consisting of 12 modules set up in the multi-chamber calorimeter was connected to the input of the (MPPT-controlled) converter, yielding an electrical output power of approx. 136 W at a temperature difference of 200 K.

Table 1:

P_input (W)	30	40	50	60	70	80	90
Efficiency (%)	96,41	96,47	96,96	97,11	97,21	97,1	97,04

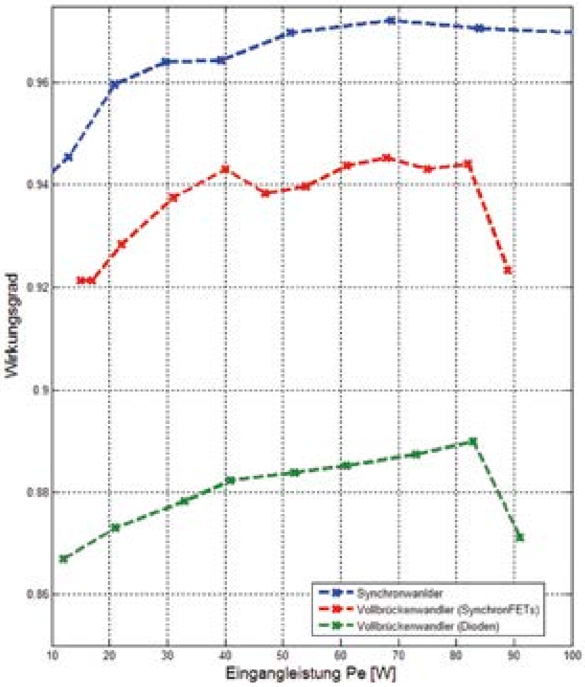

Figure 4: Dynamic MPPT efficiency of the converter in case of load cycling

Project partners

Project coordination unit
– Energy Research Centre of Lower Saxony

Participating institutes
– Institute of Semiconductor Technology, TU Braunschweig
– Institute of Electrical Power Engineering and Energy Systems, TU Clausthal

Development Towards a Joint Scientific Institution and Presentation of the Energy Research Hubs

3

The New Structure of EFZN as Joint Scientific Institution of the Universities of Braunschweig, Clausthal, Göttingen, Hannover and Oldenburg with Effect from 01.01.2016

Based on a proposal approved by the Federal Government of Lower Saxony and in accordance with the initial Statutes of EFZN of 12 December 2006, EFZN was founded as "scientific institution of TU Clausthal in cooperation with the universities of Braunschweig, Göttingen, Hannover and Oldenburg". In § 1, para. 2 of the statutes of 2006, the cooperation partners already agreed that in the medium term, the organisational structure of EFZN was to be turned into a Joint Institution of the universities involved. By the end of October 2010, the EFZN Managing Board and the Chairman of the Board of Trustees jointly initiated the "WG Organisation Development" and gradually developed the key points for further discussions with the Presidential Executive Committees of the partner universities and the Ministry of Science and Culture of Lower Saxony (MWK). The aforementioned key points were incorporated in the "Framework Agreement on the establishment of the joint scientific institution Energy Research Centre of Lower Saxony", which became effective on 16.06.2015 by signature of all presidents of the partner universities of EFZN.

Since then, EFZN is a joint scientific institution of the universities of Braunschweig, Clausthal, Göttingen, Hannover and Oldenburg. Since October 2015, it is headed by the Managing Board with equal representation of its members (one member per cooperation partner). The Branch Office, a central unit of EFZN located in Goslar, supports the Managing Board with the management of the ongoing business.

In order to ensure continuous coordination with the presidential executive committees of the partner universities and MWK concerning fundamental issues (for example, the focus of Lower Saxony's cross-locational research strategy; budget planning of the federal state funds granted to EFZN), a Board of Trustees was established. Moreover, the Board of Trustees appointed a Scientific Advisory Board, advising the Managing Board on all scientific and organisational questions.

One particular goal of EFZN is to improve the importance and reputation of energy research in Lower Saxony as a whole on the national as well as on the international level. In accordance with the Framework Agreement, future tasks especially include:

- initiation and implementation of primarily cross-locational joint third-party funded projects,
- strategic coordination of the joint energy research strategy in Lower Saxony,
- nationwide and international marketing for energy research in Lower Saxony,
- establishment of centralised research infrastructure like the Battery and Sensor Test Centre in Goslar and the Drilling Simulator Celle.

Under the auspices of EFZN, the advanced cooperation of the five university sites involved is based on a systemic, transdisciplinary research approach and on the development of a joint content-related overall concept, also with the aim to shape the profile of future energy research in Lower Saxony.

Members of the Managing Board and speakers of the energy research hubs: top row from left Professor Carsten Agert (Oldenburg), Professor Axel Mertens (Hannover) and Professor Michael Kurrat (Braunschweig); bottom row from left Professor Jutta Geldermann (Göttingen) and Professor Hans-Peter Beck (Clausthal).

In accordance with the Framework Agreement, independent "energy research hubs" are established by the cooperation partners at the respective locations. Own research priorities (presented below) are coordinated and bundled at EFZN, in order to pursue a joint energy research strategy. For this purpose, a location profile was developed for each of the five "energy research hubs" (intra-university, interdisciplinary research groups), considering the following main criteria: system relevance and scientific benefits with respect to energy transition, economic and social relevance, synergy and cooperation potential among EFZN locations based on existing quantitative and qualitative expertise in natural and engineering sciences as well as in humanities, economics and social sciences.

Energy Research Hub of Technische Universität Braunschweig

Organisation

The Energy Research Hub Braunschweig (EFK BS) consists of 26 institutes of different disciplines from five faculties of TU Braunschweig in cooperation with the Automotive Research Centre of Lower Saxony (NFF), the Battery LabFactory Braunschweig (BLB), the Laboratory for Emerging Nanometrology (LENA) and the Physikalisch-Technische Bundesanstalt (PTB). Joint research is done on the entire value chain of energy generation, energy transport and energy utilisation. At EFK BS, a speaker team consisting of three professors (Professor Michael Kurrat, Professor Frank Eggert, Professor Ulrike Krewer) is the highest decision-making body.

Moreover, a coordination unit consisting of two employees of the Institute of High-Voltage Technology and Electrical Power Systems (Dipl.-Ing. Fridolin Muuß, Dipl.-Ing. Hauke Loges) assumes all the coordination work within EFK BS (schedule coordination, recording, communication with partners, coordination of proposals). Together with the members of EFK consisting of professors and employees, they currently represent the core of EFK BS.

Research Topics

The research topics of EFK Braunschweig are presented in the graphic below. Each topic is handled

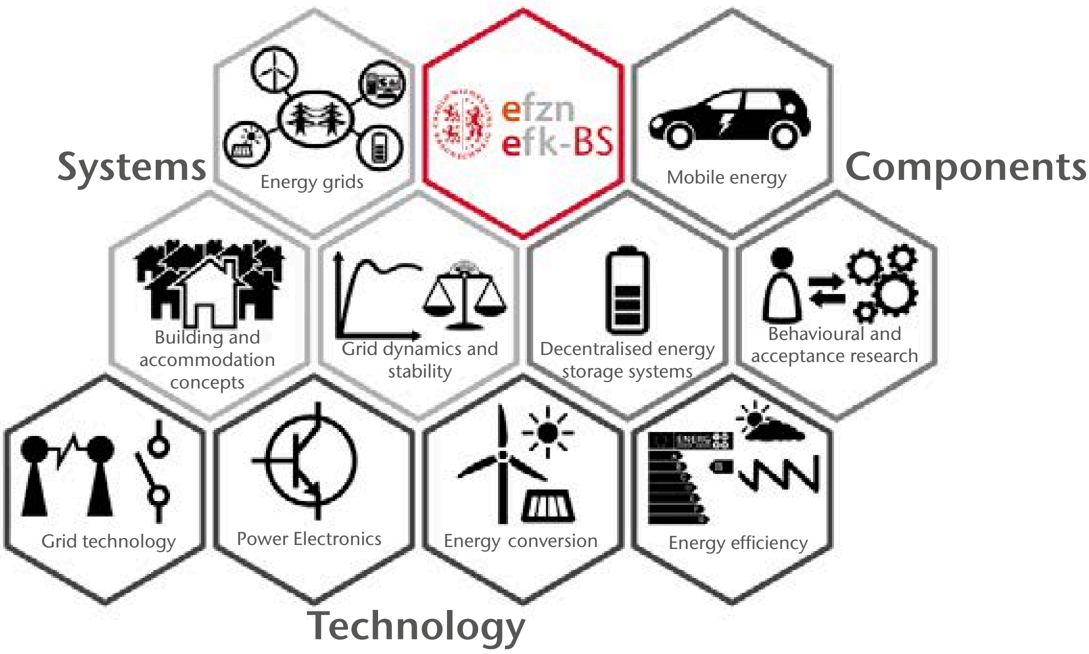

Figure 1: Research topics at EFK Braunschweig.

by several member institutes and employees within the scope of various research projects.

Within EFK, the research priorities have been selected so as to be able to contribute to the energy generation and energy utilisation chain of the future. A further aim of EFK BS is to gain a stronger profile in the field of "Smart Decentralised Energy Systems and Storages". In this context, the motto "small, scalable, smart" characterises the overall concept for future projects. EFK BS is already involved in two interdisciplinary EFK projects ("NEDS" and "SmartNord-iQ"). For the future, EFK Braunschweig strives for further joint cross-locational research projects in cooperation with partners of other EFKs.

Dipl.-Ing. Hauke Loges and Dipl.-Ing. Fridolin Muuß are the contact persons for EFK coordination/cluster management and support of the joint research at EFZN.

Research Hub Data

Name: Energy Research Hub Braunschweig (EFK BS)

Speakers:
Prof. Dr.-Ing. Michael Kurrat
Prof. Dr. Frank Eggert
Prof. Dr.-Ing. Ulrike Krewer

Contact/Coordination:
Dipl.-Ing. Hauke Loges,
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Dipl.-Ing. Fridolin Muuß,
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Technische Universität Braunschweig

Energy Research Hub of Technische Universität Clausthal

Organisation

The Energy Research Centre of TU Clausthal (EFZ TUC) was founded in October 2005. As scientific research association, the target is to concentrate and develop application-oriented fundamental research in the energy and materials sector and to establish the new discipline “Energy Sciences” in research and academic education. In cooperation with the non-university partners CUTEC, Fraunhofer HHI-FS and LIAG, scientists of TU Clausthal are able to make substantial contributions to energy research based on the existing competencies in research and academic education in the fields of energy, materials and resources, especially in the disciplines “Geotechnical Engineering”, “Mining and Petroleum Engineering“, “Energy Process Engineering“, “Chemical Technologies and Batteries“, “Energy Systems“, “Energy Economics“ and “Energy Law“, “Geo Informatics“ and “Energy and Material Physics“, since from today’s point of view, these fields are mapping the knowledge and generation of knowledge for the relevant areas of the existing energy system in research and education with about 20 professors and 200 employees. Until 31.12.2015, the activities at EFZ and EFZN have been more or less the same.

Research Topics

With the planned strategic cooperation via the established EFZ of TU Clausthal, the aim is to consolidate and enhance the high competencies in the field of sustainable energy systems (energy storage and energy storage systems). EFZ’s role is to consolidate the thinking and work processes stimulated by the technical and scientific spectrum of the disciplines involved and to further enhance

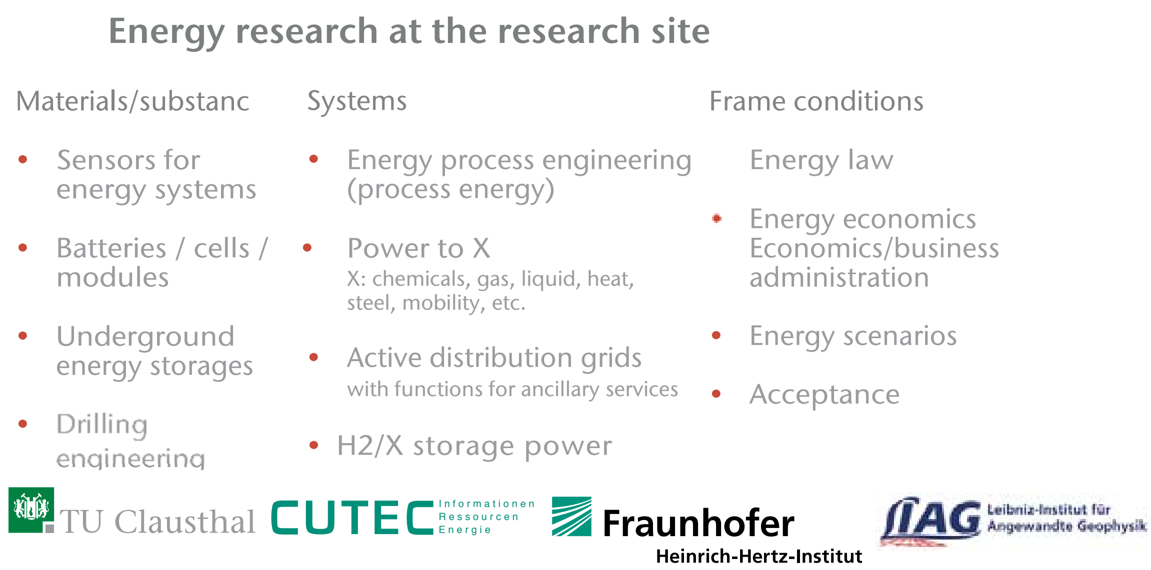

Fig. Future energy cluster development at the research sites in Clausthal/Goslar (cf. target/performance agreement, 2015)

them through strategy-forming joint projects and in accordance with the priority theme "Sustainable Energy Systems" with the research topic "Renewable Storage Power Stations" as defined by the TUC master plan and the target and performance agreement derived from it. Medium-term key research areas will include topics, such as safety of geological and geotechnical systems, power to X and hydrogen storage power stations with corresponding system technology.

With the established cooperation at EFZ of TU Clausthal, stipulated in the target and performance agreement approved by the TUC's Presidential Executive Committee, future work will cover, additionally to fundamental research topics (energy and material sciences), also application-oriented fundamental research along the entire energy value chain within the EFZN research association.

Research Hub Data

Name:
Energy Research Centre of
TU Clausthal (EFZ TUC)

Speakers:
Prof. Dr.-Ing. Hans-Peter Beck
Prof. Dr. Leonhard Ganzer
Prof. Dr. rer. nat. Wolfgang Schade

Contact/Coordination:
Dr. Jens-Peter Springmann,
jpspringmann@tu-clausthal.de

TU Clausthal

Energy Research Hub of Georg-August-Universität Göttingen

Organisation of the Energy Research Hub

In Göttingen, energy research is done through fundamental research in the fields of energy transformation at surfaces, renewable resources as well as geosciences and social sciences. Energy research in the respective disciplines is embedded into institute and faculty structures as well as in joint research projects conducted within the scope of a Research Training Group and a Collaborative Research Centre. By working in a network, Göttingen wants to bundle its energy research at EFZN and complement EFZN's energy topics with respect to fundamental sciences.

Research Topics of the Energy Research Hub

Energy research topics pursued in Göttingen are the result of long-term activities of various institutions on site. The aim of their individual contributions to energy research is to take up and complement topics dealt with at EFZN individually, seen from the side of fundamental research by covering a broad spectrum of themes and approaches. It is not planned to bundle Göttingen's individual energy research projects thematically.

In the field of molecular and material sciences, energy conversion processes and dynamic processes at surfaces are investigated on the molecular level. In this field, Professor Alec Wodtke (Humboldt Professor at the Faculty of Chemistry and at the MPI for Biophysical Chemistry) is responsible for research on chemistry of surface processes, among others regarding heterogeneous catalysts and photo catalysts, photovoltaics and fuel cells. The focus of his research is on energy conversion at interfaces using state-of-the-art laser, molecular beam and ultrahigh vacuum technology. Research is embedded in the International Centre for Advanced Studies of Energy Conversion (ICASEC) as well as in the DFG-funded Collaborative Research Centre (CRC 1073) "Atomic Scale Control of Energy Conversion", joining working groups of the Faculty of Chemistry and Physics regarding energy conversion under the responsibility of Professor Christian Joos.

The energetic utilisation of renewable agricultural and forestry resources requires the consideration and maintenance of economic, ecological and social standards. Taking the example of the sugar beet, the Institute of Sugar Beet Research of Universität Göttingen, headed by Professor Bernward Märländer, is doing research on the sugar beet's potential for energy recovery, in order to overcome the strong focus on corn whose locally high concentration of cultivation has a lot of ecological disadvantages and often has low social acceptance. Based on the evaluation of the performance potential of sugar beets for the energetic utilisation, specific breeding goals shall be derived. Production system requirements are determined including economic aspects, and a technology assessment is made considering ecological as well as economic aspects in the context of a sustainable development. Further participants involved in this research topic are Professor Ludwig Theuvsen (Faculty of Agricultural Sciences), Professor Johannes Isselstein (Centre of Biodiversity and Sustainable Land Use) as well as Professor Hans Ruppert of the Interdisciplinary Centre for Sustainable Development and Professor Norbert Lamersdorf (Faculty of Forest Sciences and Forest Ecology). The comprehensive approach aims at formulating recommendations for a sustainable biomass cultivation. The project offers very favourable networking conditions for all work-

ing groups involved with respect to production-related, economic and ecological topics.

Energy research in the field of geo-reservoir hydrogeology is coordinated by Professor Martin Sauter (Faculty of Geoscience and Geography). In applied geology, flow, heat and material transport in deep geo-reservoirs is investigated with the aim to quantify their fluid storage capacity (hydrocarbons, CO_2, et cetera) as well as their energy content (heat) and to predict future system states under operational conditions of use. In this context, the behaviour of large-scale fractured rock samples shall be investigated under reservoir conditions (up to 200 degree Celsius, 120 MPa) on a large-scale triaxial press; the respective proposal for the large-scale research facility (investment volume of about two million euros) is currently in the decision phase.

The term "Socio-Scientific Energy Research" comprises cross-cutting research in the fields of law, economic and social sciences. One major topic of the researchers in Göttingen is interdisciplinary research on decentralised renewable energy production, as in the DFG-funded Research Training Group 1703: "Resource Efficiency in Interorganisational Networks" headed by Professor Jutta Geldermann (Faculty of Economic Sciences). Potentials for joint research projects at EFZN are seen as to their complementarity of expertise, considering besides agricultural, engineering and scientific aspects primarily socio-scientific, psychological, economic and legal issues.

The scientists involved are Professor Lutz Kolbe (Business Information Systems), Professor Kilian Bizer (Institutional Economics, Environmental and Local Economics), Dr. Rüdiger Mautz (Social Research, Industrial Sociology) as well as Professor Thomas Mann and Professor Peter-Tobias Stoll who are responsible for Public Law and Business Law, respectively.

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GEORG-AUGUST-UNIVERSITÄT
GÖTTINGEN

Energy Research Hub of Leibniz Universität Hannover

Organisation

The interdisciplinary "Leibniz Research Centre Energy 2050" (LiFE 2050) unites 26 professors and more than 300 Ph.D. students and researchers of Leibniz Universität Hannover (LUH), including the Institute for Solar Energy Research Hamelin (ISFH) associated to LUH. A six-member executive board, headed by an elected board speaker, is coordinating all tasks. The office of LiFE 2050 is supporting all the processes for acquisition of joint research projects, creation of interdisciplinary networks and implementation of projects with services and tools. Moreover, the office is responsible for the research centre's public image.

Research Topics

The aim of LiFE 2050 is to make research contributions for a sustainable, affordable and reliable energy system. Moreover, the energy system must also be environmentally friendly and above all reduce greenhouse gases. In this context, the focus is on the transformation process of a system with large conventional power generating systems towards a system with many small decentralised generating systems based on renewable energies. Research work at LiFE 2050 is based on efficient research lines in the field of engineering and applied sciences (see Figure 1), complemented by cross-cutting topics related to economics, law and environmental planning.

Wind energy research addresses the entire wind turbine, ranging from foundation, (offshore) wave loads, support structures and their materials, to aeroelastics, rotor blades, transmissions, bearings and generators to power electronic energy conversion and grid integration, including efficiency and financing. The research group also comprises the circle of FORWIND Hannover. Excellent infrastructure is provided by the Test Centre for Support Structures, the Generator-Converter Lab, the Large Wave Channel and other large-scale research facilities. The key areas of solar energy research include crystalline Si photovoltaics, low-temperature solar thermal energy and development of decentralised solar power systems for the generation of electricity and thermal power. In this respect, interactions between solar and non-solar components like storages and heat pumps are of particular importance. These topics are investigated by ISFH in cooperation with institutes from electrical engineering, mechanical engineering and physics.

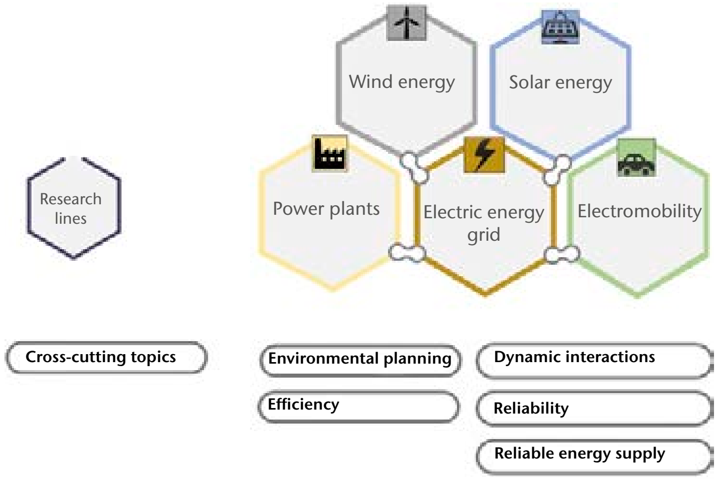

Figure 1: Research lines and cross-cutting topics of LiFE 2050

In this research field, comprehensive experimental potential is offered by the experimental facilities of ISFH and LNQE (Laboratory of Nano and Quantum Engineering).

Flexibility and efficiency enhancement are the main goals with respect to thermal power plants. Research is jointly conducted by the Institutes of Thermodynamics, Technical Combustion, Turbomachinery, Power Plant Technology, Materials Sciences, Dynamics and Vibration Research, Electrical Machines and Information Systems. The new research building “Dynamics of Energy Conversion” and the respective large-scale facilities have been approved successfully; its completion is scheduled for 2019.

The electricity grid is investigated by five disciplines of power engineering, complemented by economics and environmental planning. The major research target is to ensure stability of the electric grid, also in view of the increasing share of renewable energies and decentralisation. Among others, this is supported by the Chairs for Electric Power Engineering, Power Electronics and Electric Energy Storage Systems.

In the field of electromobility, research focuses above all on (electric and hybrid) drive trains including transmission, on grid integration as well as on car sharing and urban logistics. These research activities are largely integrated into NFF.

Nearly all members of LiFE 2050 are already working in joint research projects dealing with the aforementioned topics. Furthermore, there exist various projects which are conducted with cooperation partners of the EFZN research association, as for example

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Leibniz Universität Hannover

Energy Research Hub of Universität Oldenburg

Organisation

With more than 30 years of successful history, energy research at Oldenburg is meanwhile conducted by a core group of about 30 professors and approx. 300 researchers. Since 2008, the research consortium "ENERiO" (Energy Research in Oldenburg, www.enerio.de) has been serving as an important interdisciplinary cooperation platform with respect to energy research at Oldenburg. At the same time, it represents the organisational form of the EFZN research hub.

Research Topics

Energy research at Oldenburg unites university as well as non-university players (coming from institutes associated to the University or to FhG). The content structure as well as the range of topics are given in the Figure below. The nine fields of research, assigned to the three pillars "Materials", "Systems" and "Organisation", are characterised by high research strength and staffing level, thus ensuring comprehensive cooperativeness nationwide, also with respect to relevant joint EFZN projects.

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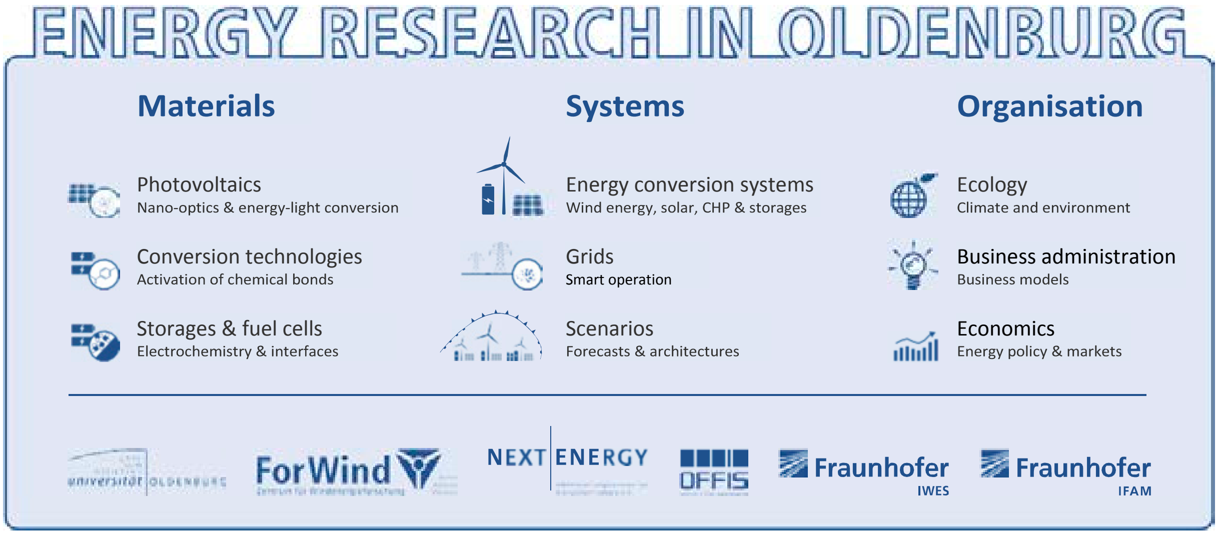

Structure of energy research at Oldenburg. It consists of three pillars with regard to contents and is jointly addressed by the University and external institutes and FhG project groups associated to the University.

Editorial Notes

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