Technische Universität Braunschweig

elenia Institute for High Voltage Technology and Power Systems

Annual Report 2020/2021

elenia Institute for High Voltage Technology and Power Systems

Institute for High Voltage Technology
and Power Systems

Annual Report
2020/2021

elenia Institute for High Voltage Technology and Power Systems

elenia

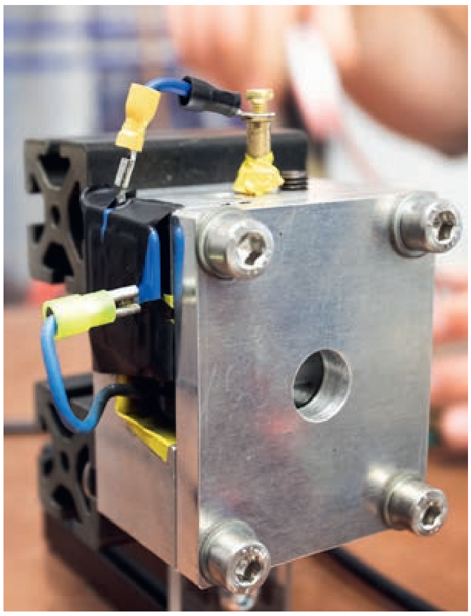
Research Reports

Doctoral Theses

Labs and Workshops

Teaching

Chronology



Foreword

Dear Readers,

After two years, we are reporting as "elenia Institute for High Voltage Technology and Energy Systems" again.

In recent years, the many positive responses have encouraged us to adopt the institute's name, thus preserving the almost century-old tradition and addressing the new challenges posed by systems technology. For the biennial report, we have retained the new format and prepared the wealth of information with the help of an agency. In the annual review, we describe in detail the changes at the institute over the past two years, which were influenced not least by the pandemic.

With this report, we are once again giving an account of our use of funds. Many innovative and fundamental research projects have increased the share of third-party funds. We want to express our sincere thanks to all persons and organizations, the TU, the companies and research institutions, the lecturers, the DFG, the project sponsors, the Federal and State Ministries, and the PTB for the excellent cooperation the support of our work.

Above all, with this report, we are again providing an exchange platform for our dedicated employees to share their ideas and results with the professional world and society. In doing so, we are providing all articles with contacts to facilitate the exchange of ideas. We encourage everyone to use these contacts and engage in more dialogs now that the pandemic seems to be coming to an end.

We are planning a new edition of our symposium for the fall of 2022 so that alumni, friends, and partner companies can meet and exchange ideas in a familiar setting.

We hope you enjoy reading our report and look forward to seeing you again in presence in 2022.

BRAUNSCHWEIG, SEPTEMBER 2021

elenia

Review of the Year

Two years elenia under the influence of the pandemic. In 2020, life changed from one moment to the next, also at our institute.

No more face-to-face lectures and exercises. Virtual meetings with staff and students via the Internet. No more visits to project partners and conferences. It is all the more impressive that the digital world has continued to make many things possible for us and how quickly we have all found our way around the new situation.

Nevertheless, the effort was enormous, and we all reached our limits time and time again. Lectures and exercises had to be rearranged on time in additional work, on weekends and during vacation. The IT system was adapted and expanded. The constant up-to-date information of all employees and students was suddenly the focus.

Some hoped that everything would be back to normal after one semester. However, our researchers from the focus area Infections and Active Substances warned us early on about the waves of infections, which were also publicly in the media.

The long duration of the restrictions has led to many upheavals: Students who are new to the university and have never been able to experience student life, or staff members who find themselves with a virtual institute after being hired. In the last few months, we have all sorely missed the daily life of the institute and the opportunities for personal exchange.

Fortunately, we switched to the new team structure with team leaders in the summer semester of 2020. These thematically replace the previous research groups and now form a flat organizational structure with good organizational support for the researchers by the team leaders. Our proven Project Management Office (PMO) continues to be responsible for the organization of the institute-wide, joint work and the interests of the institute members. Especially in pandemics with the high demand for information, this structure of institute management, team leaders, and PMO has been positively noticeable.

After many decades, the Technical University has requested an update of all institute regulations. We have used this opportunity to present our new organizational structure and future tasks in research and teaching.

Due to the positive response, we have now officially renamed the institute “elenia Institute for High Voltage Technology and Energy Systems.” With the name “High Voltage Technology,” we preserve the almost one-handred-year-old tradition, and with “Energy Systems,” we address the new system-technical challenges in energy supply. In the energy sector, we thus form the cornerstone of our faculty’s strategy: to develop and offer solutions for the significant societal challenges with the possibilities of digitalization.

In the new rules of procedure, we have described our flat organizational structure. The board of directors, which comprises

»To develop and offer solutions for the significant societal challenges with the possibilities of digitalization

representatives of all institute members and will steer the fortunes of elenia in the future, deserves special mention. We have taken much time and worked out these rules of procedure in workshops and coordination processes.

In all communication processes with students and staff, the personal level suffered enormously during the pandemic. Therefore, we have used the summer months to revive our institute events at the working group level while adhering to hygiene rules.

Research topics and the satisfaction of the institute members were on the agenda. Additional digital offers provide group events for new employees to get to know each other, develop research methods, and work out concrete Ph.D. topics. Nevertheless, the intense search for specialists and the pressure to produce results under the challenging conditions of the pandemic has also led some Ph.D. students to leave our institute without a Ph.D. We regret this very much, but understand the motives and wish them good luck in their future life.

For students, we are increasingly offering mentor meetings at the faculty level and a new format together with VDE Braunschweig "Prof.Date" for immersion in the world of science at a university.

We were also able to score points with our infrastructure. The continuous maintenance of the Mühlenpford building and the investments in new laboratories also helped us during this period. Thanks to the far-sighted laboratory space planning when the institute was founded, we could expand laboratory operations further and successfully serve our projects despite hygiene regulations. This also required numerous staff appointments, and we introduced our new institute members to the current line-up. We warmly welcome all of them and wish them much success and joy. Fortunately, Power Engineering also acquired a Juneor Research Group from the Cluster of Excellence funds, strengthening the scientific career path. The future group "Wiring Technologies" will research the possibilities of an electrical wiring system for purely electrically powered aircraft.

We could also continue the high-voltage practical course because safety distances are nothing new for high-voltage technicians. The expansion and installation of new rooms for the electrical engineering workshop, information technology, and additional digital learning workstations for the students came just in time and is urgently needed.

However, our drive for renewal is being held back financially. With the state's financial support for business, we were also made aware early on that the next wave of cuts will hit universities in Lower Saxony again. The global underspending sounds harmless, but it represents a drastic cut in funding as in previous years. The reflex to cut across all areas, even those with a promising future, is unfortunately still present in Lower Saxony.

All in all, the past two years have been essential for the further development of elenia. In addition to the tough constraints, we have also gained many new insights and insights into each other and our relationships. We hope that together we will overcome the pandemic healthy and strengthened. We will continue to work for this and would like to thank all members of the institute, faculty and Technical University for their cohesion and commitment and all individuals for their encouragement and support.

»the next wave of cuts will hit universities in Lower Saxony again

Current Team

Head of the Institute


Prof. Dr.-Ing. M. Kurrat
Managing Director


Prof. Dr.-Ing. B. Engel

Academic Senior Councilor


Dr.-Ing. E. Wilkening

Office Accounting

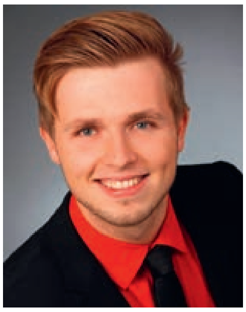

J. Schmidt

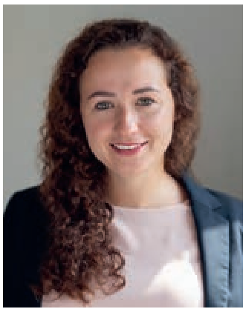

P. Thiele

Office Secretariat


E. Droemer

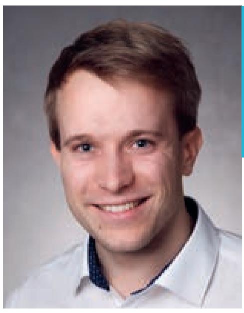
Team Battery Technology


R. Drees
Team leader


L. Hoffmann


New since 2020
F. Katschewitz


New since 2021
T. Jennert


New since 2020
D. Kehl

Team DC Systems and Switching Technologies


M. Hoffmann
Team leader


F. Anspach
Team leader


D. Bösche

L. Claaßen

T. Kopp
Working group leader

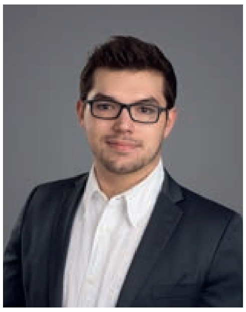
New since 2020

M. R. Lotz

New since 2021

P. Vieth

→ **Team High Voltage-, Plasma- and Vacuumtechnology**



B. Weber
Team leader

E. Peters
Team leader

M. Alija

K. Flügel

T. Meyer

M. Kahn

→ **Team Energy Economics and Energy Management**

New since 2020

F. Klabunde
Team leader

New since 2020

J. Essers

M. Hadlak

L. Kahl

New since 2020

M. Lüdecke

C. Reinhold

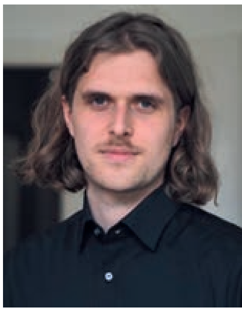
J. Ries

Dr.-Ing. F. Soyck
Working group leader

H. Wagner

New since 2021

C. Wegkamp



New since 2021

J. Studt

New from 09/2021

S. Klöpping

New from 11/2021

E. Nies

→ Team Grid Operation and Grid Planning

Dr.-Ing. J. Wussow
Working group leader

C. Biedermann

New since 2021

W.-Y. Choi

New since 2020

L. Ebbert

New since 2021

T. Garn

New since 2020

N. Gräfer

H. Köppe

G.-L. Di Modica

M. Schuster

New from 10/2021

R. Hermann

→ Team Grid Dynamics and System Stability

E. Rebak
Team leader

New since 2020

M. Qudaih

F. Rauscher

F. Tiedt

B. O. Winter

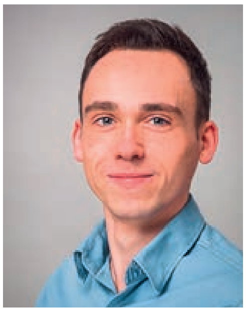
New since 2021

T. Sauer

New since 2021

S. Walujski

→ IT-Department

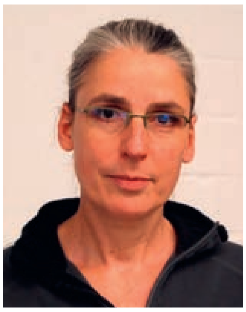


F. Scholz
IT-Manager

New since 2021

L. Oppermann
IT-Administration

→ Mechanical Workshop



K. Rach
Workshop Manager

F. Haake

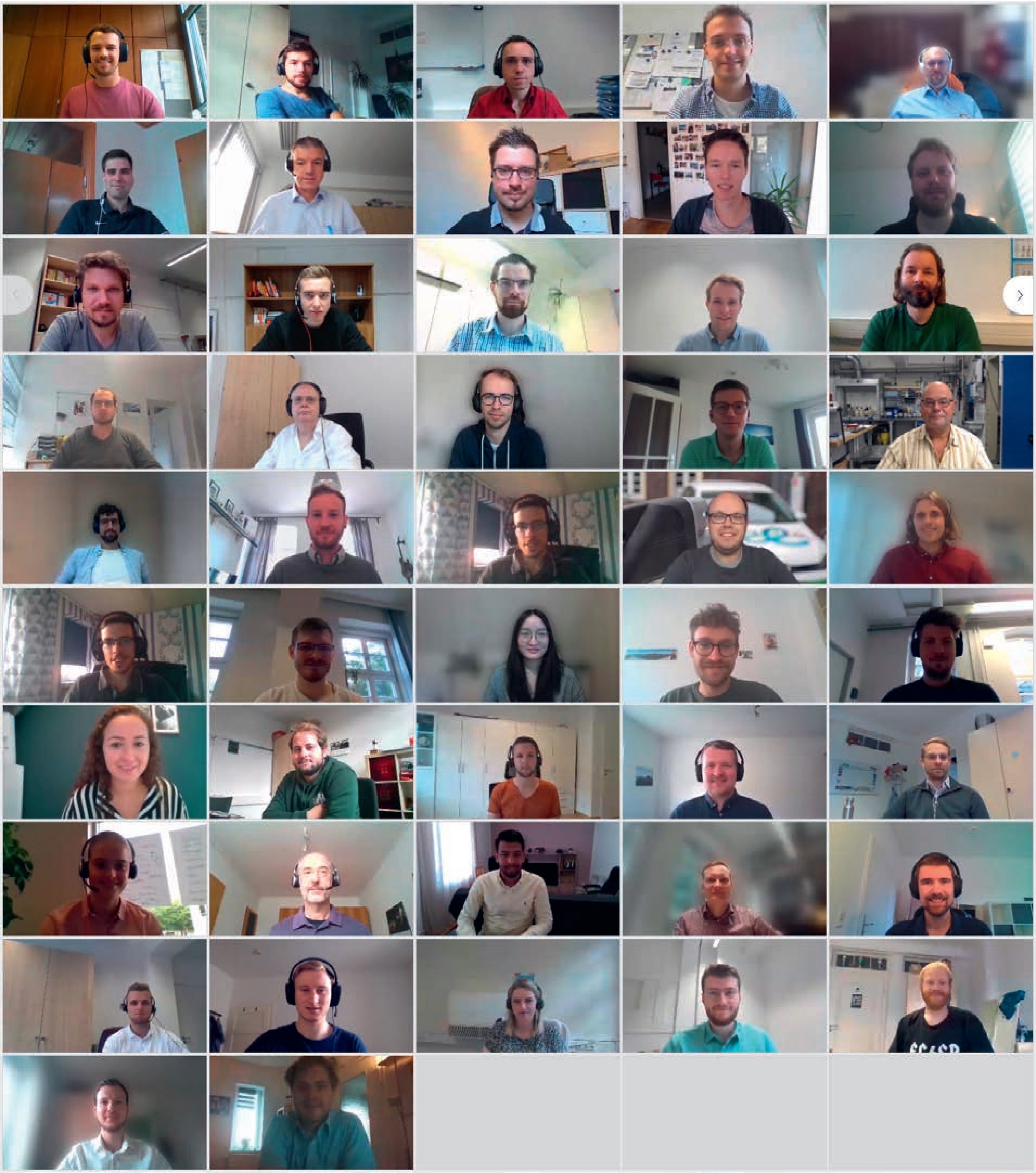
J. Musebrink

C. Narup

→ Electrical Workshop

C. Ryll
Workshop Manager

Status meeting september 2021



Former employees

Thank you so much for your cooperation and all the best on your way.

Julia Brockschmidt (2020), Stefanie Čelan (2020), Jan Hegerfeld (2021), Nicholas Hill (2020), Benjamin Kühn (2020), Sören Meyer (2021), Olga Pronobis (2021), Kerstin Ryll (2020), Carola Schierding (2021), Julia Seidel (2020), Alessa Damrath (2020), Reinhard Meyer (2020), Henrik Herr (2021), Louisa Hoffmann (2021), Fabian Katschewitz (2021), Oliver Landrath (2021), Daniel Kehl (2021)

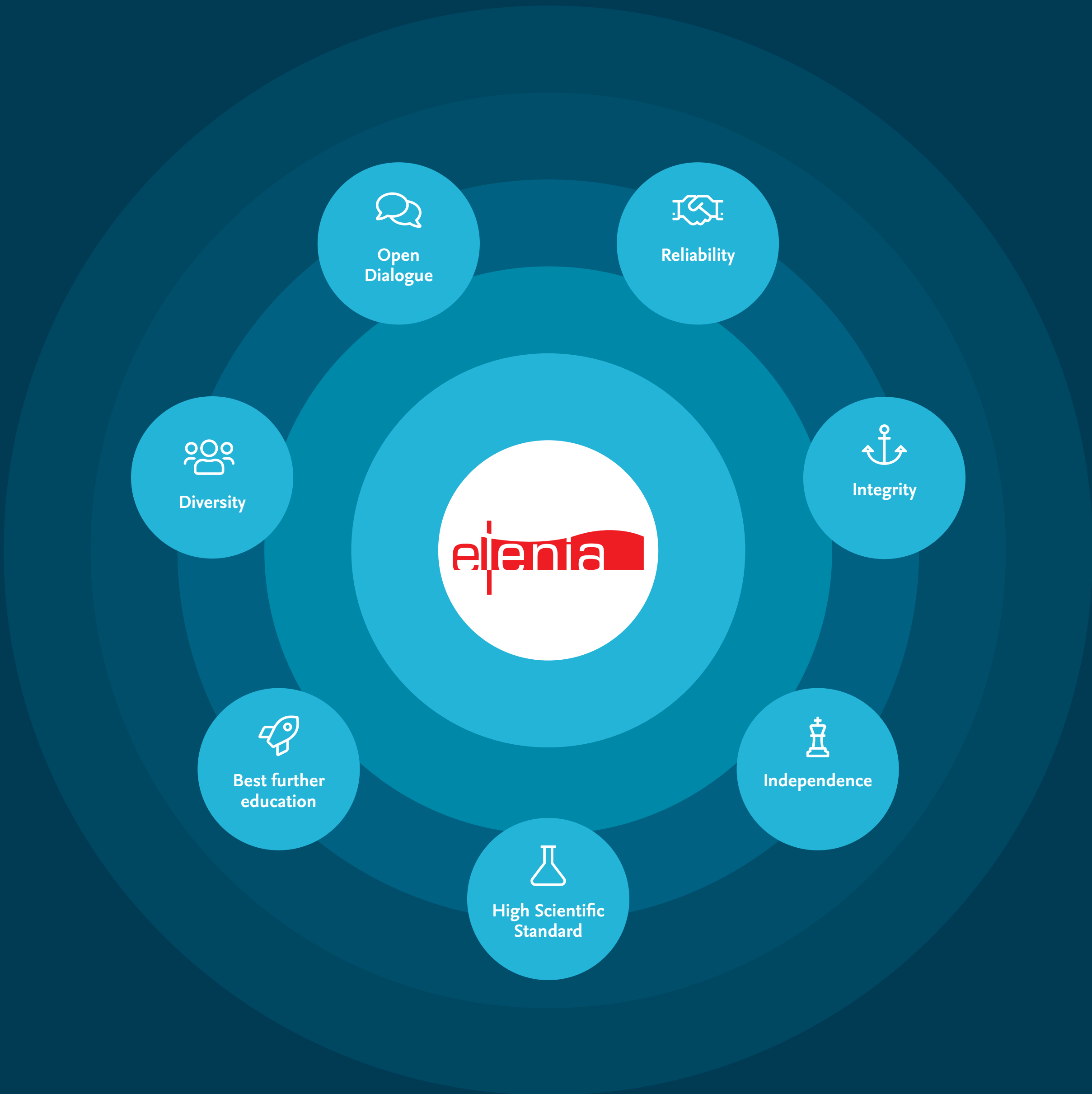
Student assistants 2020/2021

We want to say thank you to our student helpers, thank you very much for your support.

Mariam Al Mostarihi, Dmitry Bardachev, Max Brüggemann, Jonas Biniek, Jens Brüggemann, Ahmed Cherni, Gaseng Chung, Steffen Clausen, Ayan Roy Chowdhury, Serkan Cokgün, Wai-Yee Choi, Fatih Demircan, Julien Essers, Lisa Ermer, Robin Eßling, Lenard Faber, Tarek Fansa, Felten Feldt, Kexin Gao, Joel Gerig, Garsan Gengatharan, Ilja Gitin, Hendrik Grafelmann, Timo Haakert, Nick Hammer, Nils Hartau, Franziska Harstrick, Ahmed Hassanin, Luca Himstedt, Robin Herman, Justin Herdegen, Levin Chee Xian Ho, Ian Oswald Jannasch, Jan Jäger, Maik Kahn, Charu Kabbalagerepura Venkatesh, Abdulbaki Kocabasa, Felix Korff, Gloria Kreft, Andrii Kostrytsia, Julius Kohlhepp, Heiko Köhler, Hendrik Kösjan, Demian Kufeld, Jan Krüger, Chris Lütge, Thanh Mai, Nils Menebröker, Kamyab Moayedi, Behrooz Moeilsiahrodkoloai, Johanna Meier, Navilarekal-Rojgopal, Sönke Niemann, Kai Neumann, Frederike Paul, Christopher Prange, Ann-Katrin Rabe, Alexander Rahn, André Rehbock, Nils Reinköster, Anton Ribel, Felix Reimers, Yifan Shi, Siddharth Singh, Mike Skroch, Lei Song, Julian Studt, Rene Schilling-Johnson, Chris Aaron Schneider, Daniel Swientek, Kevin Schiemenz, Victor Schnell, Julian Schwung, Lia Stücke, Alexandros Themelis, Kenan Torunoglu, Nils Van Ohlen, Kristina von Kölln, Patrick Vieth, Vijesh Vidhani, Stefanie Walujski, Arnold Walker, Julian Wehr, Chao Wei, Meng Wang, Stefan Wever, Emil Weymann, Ji Wu, Zexuan Xu, Till Zeumer, Fanke Zeng, Hejie Zhu, Tianshui Yu

Facts and Figures

Values and goals



"Achieving excellence in research and teaching and actively shaping the future of energy technology"

The years in numbers

People

2 Professores

1 Academic Senior Counselor

3 Staff members of the office

6 Assistant Lecturers

5 Staff members in the Workshops

2 Staff members in IT

49 Research Assistants

93 Student Assistants

Location

Braunschweig (Lower Saxony)
since 1925

Braunschweig
1 University
6 Faculties
84 Courses
120 Institutes
2045 Scientists
18.566 Students

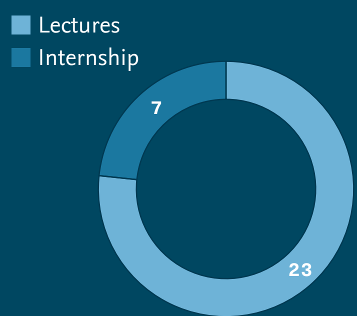
Studentische Arbeiten

Bachelor
16 (2020)
25 (2021)

Master
31 (2020)
33 (2021)

Studies
6 (2020)
4 (2021)

Lehre

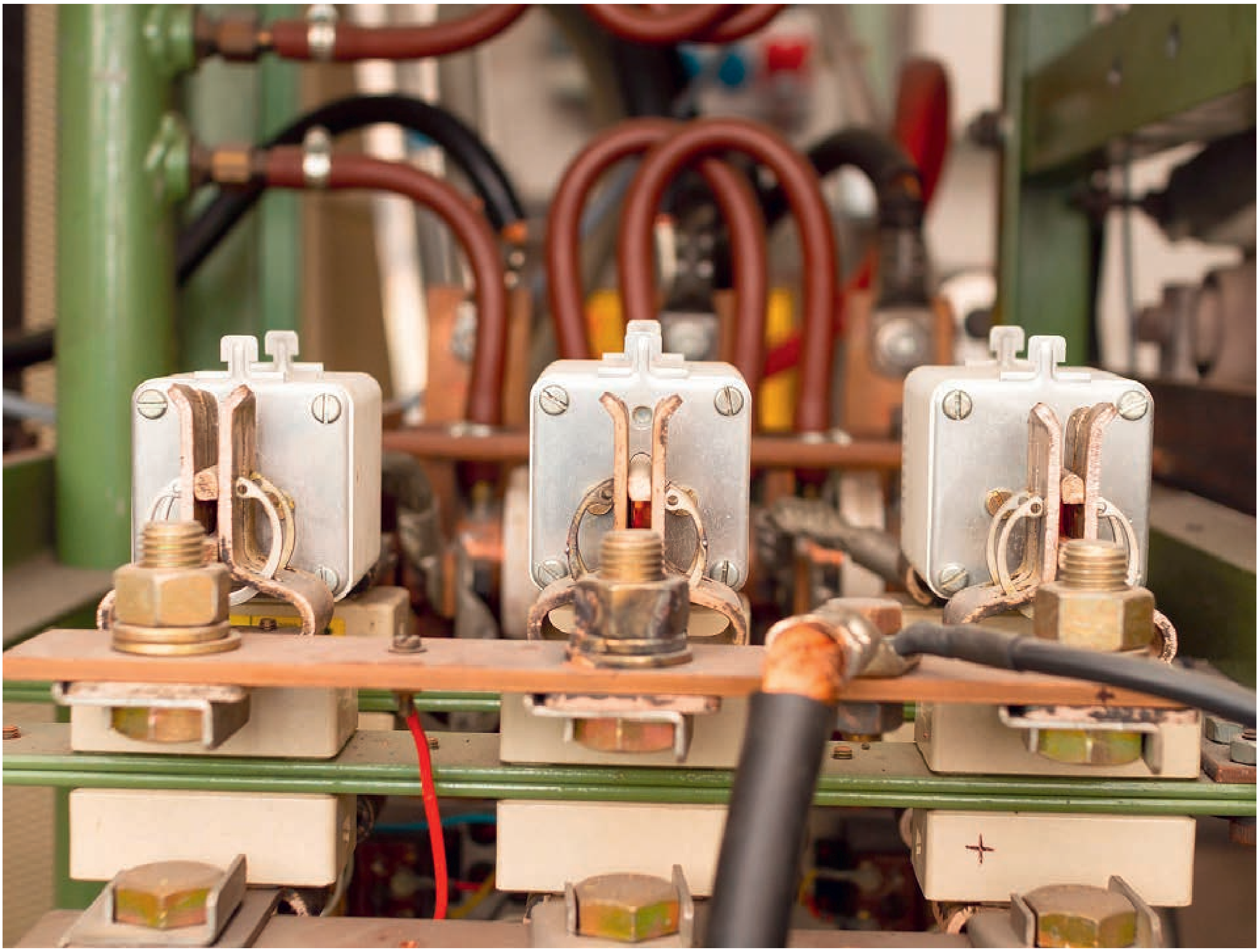


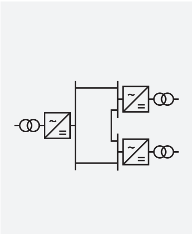
Research Components

Technologies and methods for efficient power supply and reliable operation of innovative AC and DC systems

For the strategies of the city of the future and its mobility at the TU Braunschweig, the technologies of energy engineering must also undergo a change. The elenia supports this change by developing methods for components and their grid integration that meet the requirements of a flexible and climate-friendly energy transmission system. Thereby, our teams investigate different aspects of energy grids from the system level to the components.

At the system level, the focus is on DC systems, their structure and protection system. Insulation systems in the high-voltage electrical system are also investigated. The component level deals with the investigation of medium and high voltage circuit breakers and DC switches. Here, the switching plasma processes are methodically modeled in order to enable further development through the understanding of physical fundamentals. Our motivated teams pursue individual goals depending on the level, which are implemented in projects together with partners in research and industry.



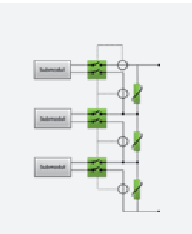


HVDC-Grids

DC-Systems

From the North and South Link transmission lines to industrial production lines and home networks, DC systems are becoming increasingly popular. The meshing with the required intelligent switching and protection systems are the biggest challenges for the establishment of these systems.

The protection systems consisting of sensors and switching devices are elementary for safe DC systems and therefore an essential part of current research projects at elenia. The driving factor is the high efficiency and reliability of power transmission. For the transport of renewable energies, HVDC transmission lines are already the subject of public discussion. Current research is concerned with the optimized design of HVDC networks by means of Model Based Systems Engineering. At elenia, a method is currently being developed that takes into account the requirements of numerous stakeholders for the system. A DC demonstrator system has been set up in the low and medium voltage area. The investigations focus on the efficient characterization of faults in the DC grid by means of Design of Experiments, as well as intelligent protection systems and switching devices. Due to the high transients of DC networks compared to AC, new protection concepts are necessary. Not only the fast fault location, but also the prompt fault elimination is crucial. Therefore, methods are being researched to develop intelligent switching devices that react to the fault condition.



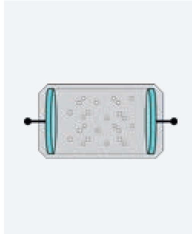
Faultdetection

High voltage and vacuum technology

In the future, decentralized generators, capacitive and inductive reactive power supply, storage facilities and loads will have to be switched on and off automatically. The increase in required switching capacity, automation and thus switching frequency require increased use of circuit-breakers. The vacuum switching principle is ideally suited to these new tasks. The development goals are therefore aimed at improving the switching performance with a long service life and compact design, also against the background of the efforts to replace SF6 switches in the high-voltage level due to the high greenhouse gas potential of SF6. Thus, the switching behavior in vacuum for higher voltages and thus for larger switching gaps becomes the current object of investigation.

Breaker developement

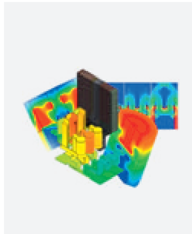
In the high-voltage electrical system, insulating materials are a particular focus of elenia's research. In addition to sustainable production and recyclability at the end of life, new stresses due to the requirements in the field of electromobility must be researched. To this end, elenia is engaged in a lively exchange with PTB and the Institute for Electrical Machines, Traction and Drives (IMAB) with the aim of joint research projects for digitalization in insulating materials research.



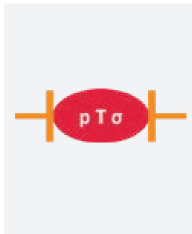
Insulating material characterization

Plasma technology

The safety of the innovative systems depends on the reliability of the individual components and their ability to control the plasmas that occur. Plasma properties are investigated experimentally and simulatively in various requirements at elenia. The plasma simulations support experimental research at the highest level of detail in order to provide material data and to use explanatory approaches for model generation. In the field of lightning protection research, model spark gaps can be investigated as lightning protection devices under surge current stress with connected grid or synthetic circuits. For both DC switchgear and lightning protection devices, the current focus is on the development of model-building methods for describing recovery. In the case of DC switching devices, the focus is on hybrid switches, since they will be able to perform a wide range of tasks as universal switching devices in the future. Method development is based on the combination of experimental and optical high-speed imaging. Here we work together with all teams in an interdisciplinary way to create a basis for processing and analyzing the visual data.



Modelling and Simulation



Plasma behaviour

Technologies and digitalization

For years, elenia has been developing a sound scientific basis for research into energy system components. Here, the demands are changing due to digital development and international communities. Evaluating high-quality results alone is not enough to promote progress and change in energy technology. That is why the focus is constantly evolving. In addition to the existing high-precision measurement technology and the partly unique laboratories, not only components are considered, but also the components in their systems. Thereby, methods of Model Based Systems Engi-

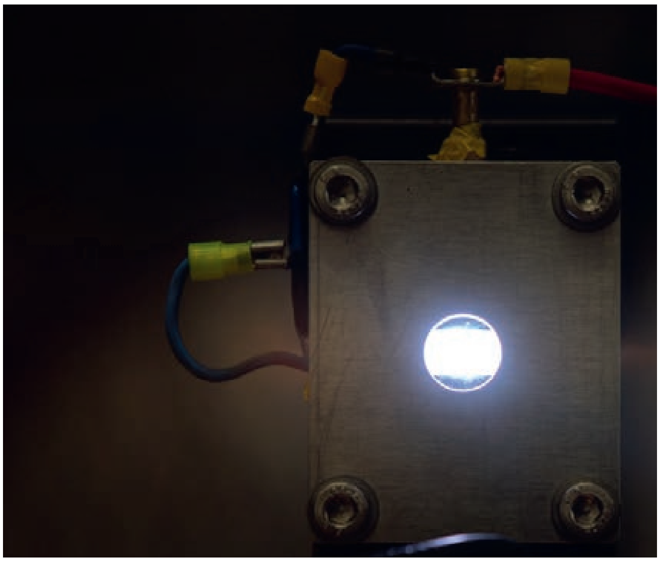


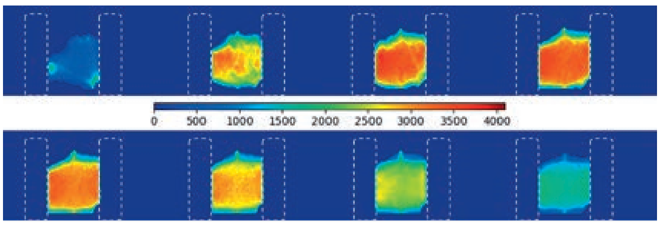
Photo: Max Fuhrmann/TU Braunschweig

neering are applied and laboratories are extended by (power-) hardware-in-the-loop systems.

In this way, we set the basics for requirements management and modeling of our individual application areas. The goal is intelligent data processing from database systems and the transfer into physically based models. These can then be used as prediction or decision models, depending on the application. In the field of DC systems, faults can thus be detected more efficiently using online sensor technology. In switch technology, potential failures can be detected and avoided at an early stage (predictive maintenance). In the field of insulating materials and plasma technology, these models are transferred into a digital twin and thus save development cycles through detailed knowledge-se of the predicted states.

Our image processing algorithm developed at elenia serves as an example of digitization from plasma technology. This allows us to process the data recorded by a high-speed camera deterministically and reproducibly.

Shown here is a selected series of a spark gap model setup recorded during a lightning impulse with a current of 10 kA. The images are optimized by removing noise.



Furthermore, the original black and white images are translated into a color scale corresponding to the digital values. This additional visual possibility of observing switch plasmas offers us many possibilities regarding future data analysis. For example, current paths can be identified by the intense glow in DC switchgear, or a 3D motion profile of plasmas in vacuum switches can be created. In this way, existing description and analysis models can be usefully extended with additional visual data.

The effort is always to develop new models, to verify them by precise measurements and to manage them sustainably. In this way, we combine fundamental energy technology with modern digital systems.

RESEARCH MENTOR

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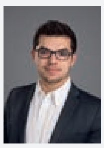
RESEARCH-SUPERVISOR



Benjamin Weber
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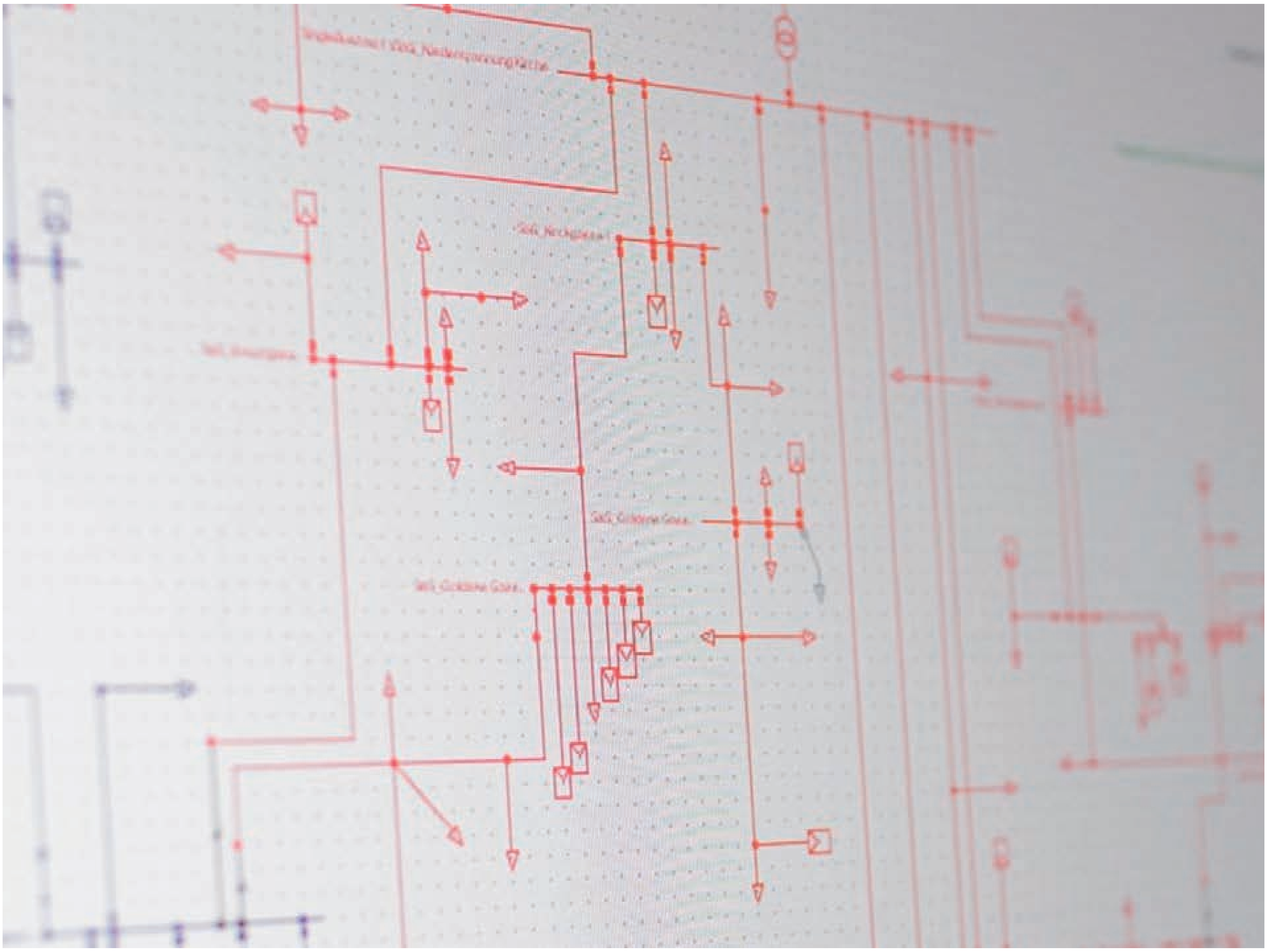
WEBSITE

www.tu-braunschweig.de/en/elenia/research/components-for-power-supply

Research Active Distribution Grid

Innovative technical and economic solutions for reliable grid operation and for flexibility

The energy transition brings with it a multitude of (regulatory) technical and economic challenges, which result in a great need for research. From today's point of view, an intelligent electricity grid that interconnects and controls consumers, generators, storage facilities and grid operating equipment can be seen as a key success factor of the energy transition. This so-called "active distribution grid" is one of three key areas of research at the elenia Institute for High Voltage Technology and Power Systems at TU Braunschweig. It deals with many different topics relating to the future role of the distribution grid. Within the focus area of "Active distribution grid", both technical and economic issues are considered. In this way, elenia is actively involved in shaping the energy transition and developing recommendations for sensible overall concepts. The research area Active Distribution Grid consists of three teams with individual research areas.



Grid dynamics and system stability

The grid dynamics and system stability team consists of five research associates and two laboratory engineers who work on different topics within the team. On the one hand, research is carried out on the integration of voltage source inverters into the distribution grid. In this context, the focus is on the provision of instantaneous reserve and its effect on the superimposed grid levels with the aim of investigating the contribution of these inverter systems to stabilising the supply grid in the event of rapid load fluctuations in grids with a reduced proportion of feed-in from large power plants. On the other hand, the team is working on the question of how components can be used for the provision of flexibility in a grid-friendly and economical manner. Specifically, this involves new types of pumped storage power plants that are used in lowlands. The storage flexibility thus gained leads to the question of how and which ancillary services can be provided as a result?

Furthermore, research is being conducted on the topic of an information and communication technology (ICT) fall-back strategy. Since many decentralised grid participants such as renewable energies, electric vehicles, storage systems and controllable loads will be connected in the distribution grid of the future, an ICT interface is needed to network them together for a fine-granular system structure. The pooled grid participants take over ancillary services that contribute to a secure and stable power supply. But what happens if the ICT of the grid participants fails? Here, it is necessary to develop a suitable fall-back strategy in which they contribute to grid stability even in the event of a communication failure.

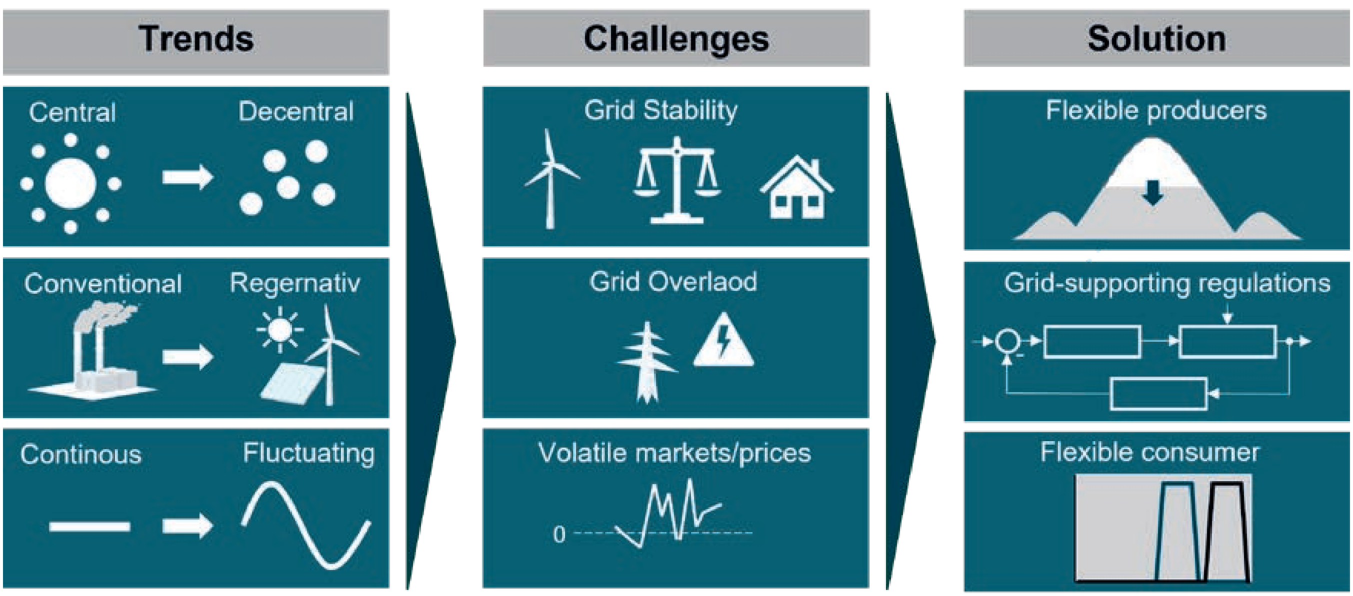
Grid operation and grid planning

The grid operation and grid planning team focuses on voltage stability and voltage quality.

The area of voltage stability includes the decentralised provision of reactive power from individual PV systems or electric vehicles on the basis of grid connection conditions for local voltage stability up to active reactive power management, which includes operating concepts across voltage levels and grid operators.

The research focuses on the integration and active control of inverter-coupled renewable energy systems (RES) within existing reactive power management systems. In the BMWi research project PV-Wind-Symbiosis, it has already been shown that EEAs represent an alternative and supplement to the installation of reactive power compensation systems in reactive power management. The research results show that, in addition to the technical and economic advantages, the active integration of EEAs can also result in economic benefits. The follow-up project Q-Integral focuses on the interface between distribution and transmission grids. For this purpose, the active reactive power management developed at elenia will be adapted to the new requirements of interoperability and supplemented with additional modules such as reactive power forecasting. The aim of subsequent technical and economic investigations using real network models is to formulate recommendations for action with regard to operational and planning aspects of future reactive power management.

In the area of power quality, the team is investigating the effects of increasing penetrations of PV systems, electric vehicles, home storage systems and power-to-heat systems on power quality characteristics such as rapid voltage changes, flicker, harmonics, unbalance, etc. in the low-voltage grid. Based on laboratory measurements of devices such as PV inverters and heat pumps as well as field tests in cooperation with distribution grid operators, we have a broad knowledge regarding unbalances. On the other hand, controls are being developed to maintain the voltage quality in the low-voltage grid even with an increasing number of power electronic components with high nominal power. These controls are first tested in a laboratory environment on freely programmable inverters and subsequently optimised. Later, the controls are implemented in a voltage quality controller, which is tested in a low-voltage grid.



Energy economics and energy management

The "Energy Economics and Energy Management" team consists of ten research associates and two laboratory engineers who are concerned with the economically and technically optimal integration of renewable energies into the current and future energy system. The core of the research is the development and investigation of future business and market models as well as energy management systems in the context of regenerative power generation. Computer-aided simulations, laboratory and field tests can be used to model and evaluate various market and integration concepts and operating strategies. In the institute's own energy management laboratory, fully flexible prosumers can be modelled with the help of a heat pump, charging station, variable loads and generators as well as battery storage units, and conceptualised energy management strategies can be tested thoroughly. In addition, field measurement campaigns will be carried out to provide information about current electricity consumption and generation, and strategies developed in the laboratory will be validated in field tests.

The research competencies of the Energy Economics and Energy Management team include:

- Flexibility provision at component level
- Aggregation and markets for flexibilities
- Forecasting and optimisation methods
- Integration of electric mobility
- Modelling of components
- Energy management at building level
- Multi-use concepts for battery storage

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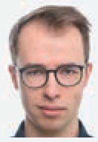
ENERGY ECONOMICS AND ENERGY MANAGEMENT



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Research Electric Mobility

Grid and system integration of battery electric vehicles and battery technology

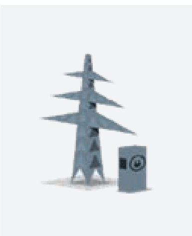
Mobility has become one focus of the strategy process at the TU Braunschweig. The strategic orientation within this subject area is underlined by the first introduction of the course of studies „M. Sc. Electromobility “in winter semester 14/15. The elenia is involved in the implementation with a series of lectures. Through the research infrastructure of the Niedersächsisches Forschungszentrum Fahrzeugtechnik (NFF) and the Battery LabFactory Braunschweig (BLB), elenia is actively integrated in interdisciplinary projects on electromobility research. The competencies are in the areas of charging infrastructure and charging management with the aim of system and grid integration of electric vehicles and battery technology.

Photo: Henrik Herr/TU Braunschweig

Grid and System Integration

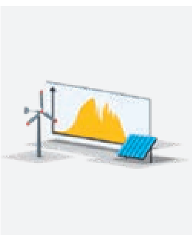
‚Electromobility in Germany in the fast lane‘, was the title of a press release issued by the Federal Motor Transport Authority at the beginning of 2021. Around 200,000 battery electric vehicles were newly registered in 2020. As a result, the total number of vehicles on January 1, 2021, was just under 330,000. In relation to the total number of passenger cars in Germany, this number is still very low. However, the development is exponential. For this reason, we at elenia are addressing a variety of issues related to the future grid and system integration of electric vehicles as well as an active role of electric vehicles. These questions are especially addressed by the team Grid Operation and Grid Planning. Within the framework of the research project LISA4CL (Charging – inductive, fast, autonomous for city logistics, German: Laden – induktiv, schnell, autonom für City Logistik), approaches to generation- and grid-oriented charging are being developed and investigated.

In addition, the electric vehicle is taken into account as an important component in overall system considerations in the team Energy Economics and Energy Management.



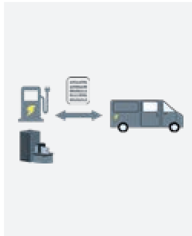
Grid Integration

The research field of grid integration covers the range from simple grid calculations to grid-supporting charging approaches. Within the framework of simulations, low-voltage grids in particular are investigated at elenia with regard to the capacity for electric vehicles. Thereby, experiences regarding charging behavior and energy demand for different scenarios are available. Based on this, approaches for reducing the impact of charging processes on the energy supply grid, which have already been developed in the past, are being further developed.



Generation-oriented Charging

In addition to the grid integration of electric vehicles, elenia is also working on generation-based charging algorithms. These are necessary to control consumption on the basis of decentralized generation. Electric vehicles are particularly suitable for this purpose, since they are large consumers with great flexibility potential. The developed algorithms are tested and validated in simulations, in the laboratory and in real vehicles.



Communication

Communication between electric vehicles, charging infrastructure and a backend plays an important role in the area of grid and system integration. This is necessary, for example, for charging power control for grid support or for the implementation of charging plans in generation-oriented charging.

For research work on electric mobility and related grid issues, elenia has access to a well-equipped infrastructure. In addition to the laboratories, the institute has several charging stations.

Battery Technology

An important research center for battery technology at elenia is the BLB. The research scope covers the entire value-added cycle from material and electrode production to cell manufacturing, system integration and recycling to close the material cycle (see Fig. 1). The BLB combines

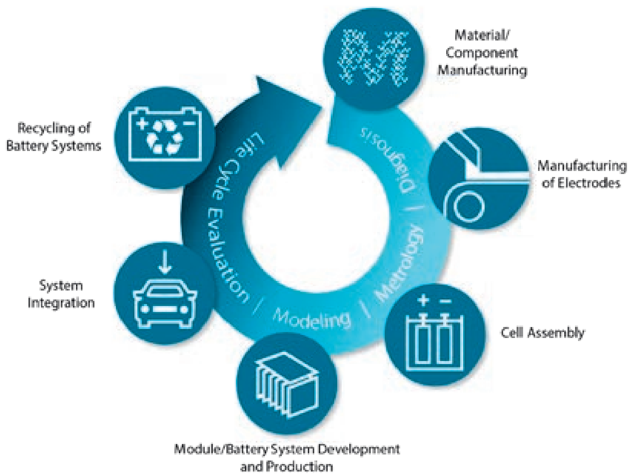


Figure 1: Battery LabFactory Braunschweig (BLB)

the competences of 9 institutes of the TU Braunschweig, the TU Clausthal, the Leibniz Universität Hannover, the Fraunhofer Institute for Surface Engineering and Thin Films IST and the Physikalisch-Technische Bundesanstalt Braunschweig (PTB). This collaboration of a transdisciplinary consortium in a joint lab is unique in the German research landscape.

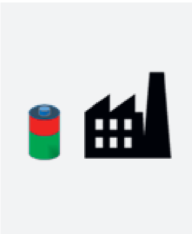
As an active member of the BLB and the institute mainly responsible for formation, aging and characterization, we at elenia are researching relevant topics and expanding our expertise. In cooperation with the PTB, research activities in the field of aging tests on battery modules as well as electrical and thermal safety tests are in focus. The battery technology team deals with a wide range of research topics at cell and module level. The research results obtained are incorporated as current content into the design of teaching. The research fields can be categorized into four areas: Battery production, battery use and aging, battery diagnostics and safety as well as 2nd life and recycling.

Within the production chain of battery cells, formation represents the bottleneck, since this step is time-consuming and therefore cost-intensive. The formation is the final production step and activates the battery cells electrically. Current research activities in the projects DaLion4.0 and FormEL are concerned with the model-based and experimental optimization of the formation process, the identification of sensitive influencing parameters and the determination of quality gates for the evaluation of cell quality.

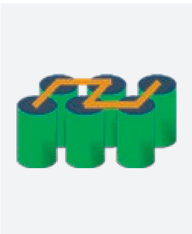
After the formation and thus the BoL (Begin of Life) of the batteries, experimental long-term cyclizations are carried out to characterize the electrochemical performance of the cells in use to draw conclusions about aging mechanisms. The aim of the research project FastChargeLongLife is to develop an aging-adaptive fast-charging strategy that simultaneously ensures a long service life for the battery cells.

Battery diagnostics and safety represent a multifaceted and overarching field of research. In the battery laboratories, various metrological tests are carried out on battery modules and cells in order to evaluate the quality and condition based on parameters. Among other things, the electrical properties are determined by loading with various current and voltage profiles, and the energy properties are determined by constant current loading. By means of current, internal resistance and impedance measurements, the electrical performance as well as the battery state can be determined. In the research project BaSS, investigations are carried out to identify critical thermal and electrical load cases for the classification of safety tests. The experimental work is supported by battery models and thus the electro-thermal battery behavior is simulated in order to develop battery systems and design operating limits. Battery system design with interconnection, cell operation and diagnostic strategies is also part of the research activities.

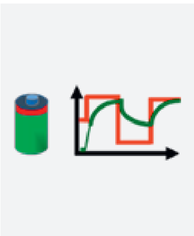
With the help of special methods, such as impedance measurements, the aging history of battery modules can be characterized. The aim of the NetProSum2030 project is to evaluate the modules with regard to their reusability in a 2nd life application.



Battery Production



Battery usage and aging



Battery diagnostics and safety

2nd Life and Recycling

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BATTERY TECHNOLOGY

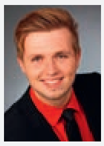

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Photo: Robin Drees/TU Braunschweig

Ways to elenia

Patrick Vieth

My path from student to scientific staff in the Energy Technologies Group

My name is Patrick Vieth, I am 25 years old and I was asked to describe my way to elenia.

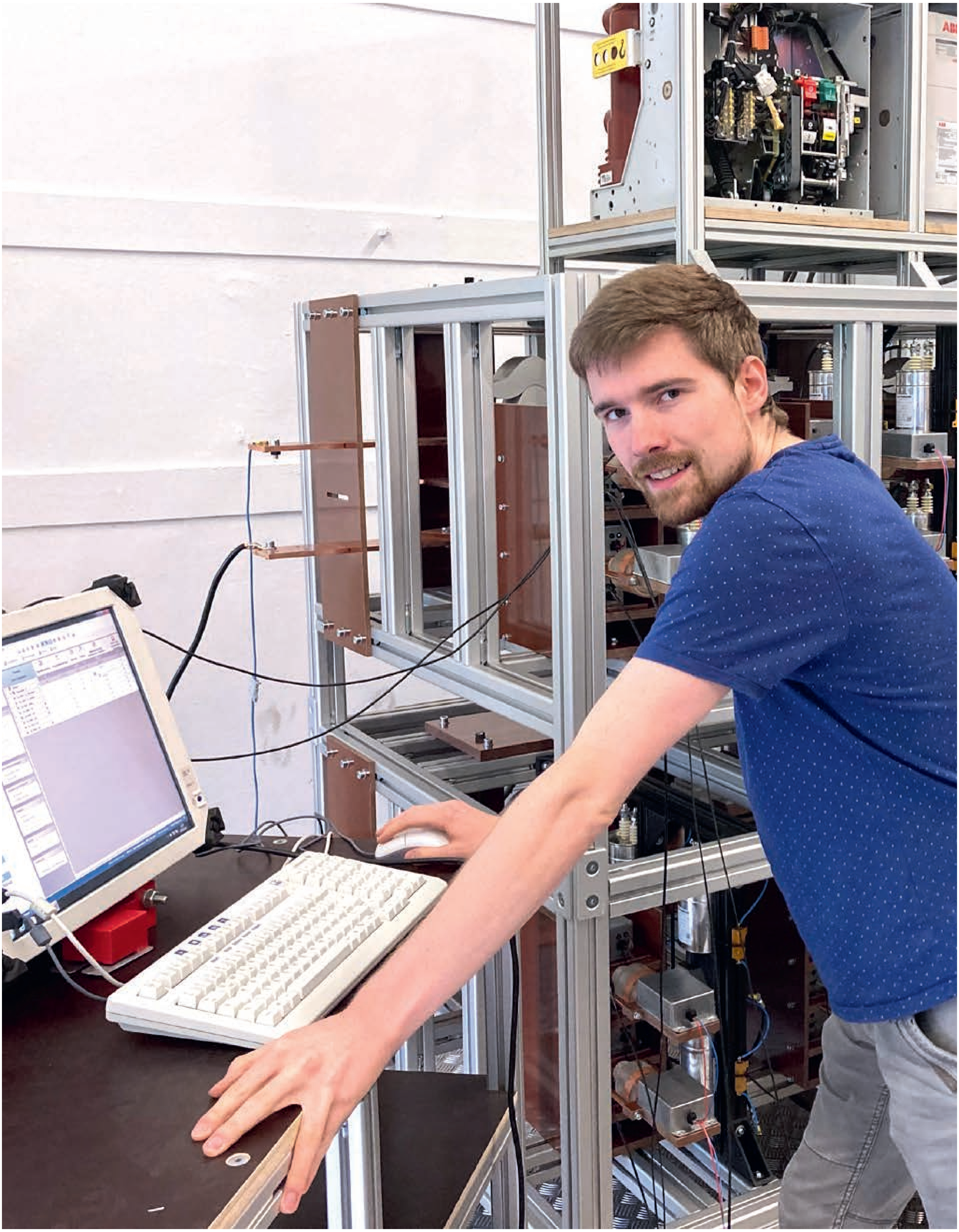
How it all began:
After high school graduation, I started a dual study program at the Osnabrück University of Applied Sciences. Even back then it was all about energy technology. Fortunately, I was able to stay with my company in the power plant sector after my studies and gain my first practical experience there. However, I was aware that I wanted to deepen my knowledge in the context of a master's degree in electrical engineering. That's why I gave my notice for the winter semester of 2018. Because of the appealing courses on offer, I chose the TU Braunschweig.

The time during my master's studies:
In the first semester, I first had to find my way around the new university in the new city. I attended various lectures, registered for a sports course, got to know a few fellow students and slowly found my way around the TU. Towards the end of the first semester, the first phase of exams started. During the oral exam in "Elektrische Energieanlagen I" I came into contact with elenia for the first time. The exam went well and afterwards I was offered a job as a student assistant, which I had to decline due to time constraints.
During the second semester I was able to collect credits diligently, so that I had time for a student assistant position in the coming semester. In addition, I could get to know the lecturers and scientific staff of elenia better during further lectures.
No sooner said than done, and I was hired as a student assistant in the area of switchgear technology. I was warmly welcomed into the team and was able to participate directly in the Christmas party. I set up, carried out and evaluated experiments in the laboratory. This was also one of the first times at the university that I was able to profit from my manual experience from the training. Through the first contact with switchgear, a topic for my master's thesis was also quickly determined.
During the master's thesis, I spent countless hours in the lab discussing the results with the scientific staff. I was also able to get to know the other employees, their working methods and the working environment. Towards the end of the master's thesis, I was then offered further collaboration as a scientific staff.

Review:
Now I am at the institute since the beginning of the year and work on various tasks and exciting projects. It is really what I had imagined and how my colleagues described the job to me beforehand. The job is certainly not for everyone, but by working as a student assistant and writing a thesis at the institute, you can get a good insight into whether employment as a scientific staff is a good fit (for both sides).

Patrick Vieth, M.Sc.
at elenia since February 2021

Photo: Patrick Vieth/TU Braunschweig



Wai-Yee Choi

My path from a full-time student to a part-time employee

Background

During my last years of high school, I needed to decide about the further course of my professional career after school. I had always enjoyed my math and science classes. However, I was also interested in the processes of the economy. Consequently, I decided to study the joint program of Business Administration and Engineering, called "Industrial Engineering". While searching for a suitable university, I discovered that at the TU Braunschweig a specialization is already chosen in the Bachelor program, which appealed to me. So, I finally decided to specialize in electrical engineering as I was already interested in the energy grid and the challenges of integrating sustainable energy sources.

I first got to know elenia trough a basic lecture during my studies. As I already liked the course, I chose to specialize in energy technology in my fourth semester. Thus, I took a specialized course at elenia.

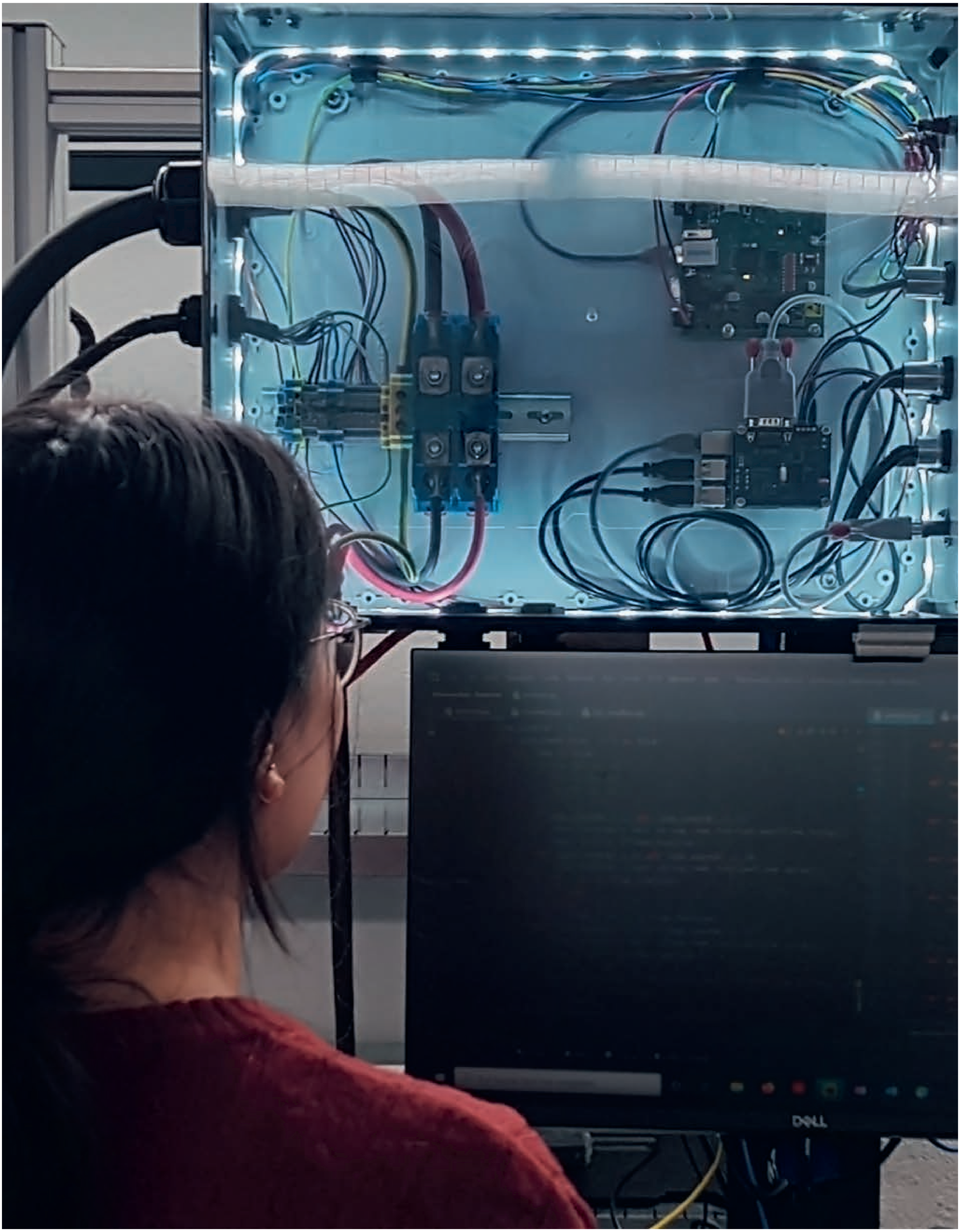
Teamwork at elenia

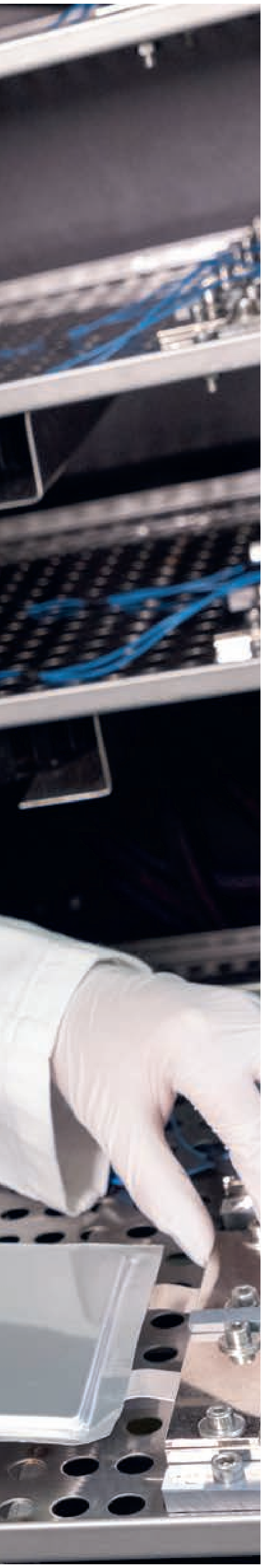
When I was looking for a topic for my bachelor thesis, it was important to me that the assignment would cover the topic of electromobility. Already having a very good impression of elenia from the lectures I attended and knowing that they are always researching highly topical issues, I searched and found a suitable advertisement for a thesis on their website and contacted the responsible supervisor. During the bachelor thesis, a lot of emphasis was already placed on close teamwork. There were weekly meetings to discuss my progress or questions I had. However, I could always contact my supervisor at any time if I had further questions. After my final thesis, I began to work at elenia as a student assistant. In addition, I was allowed to complete my bachelor's industrial internship at the institute, since my original industrial internship was canceled at short notice due to the Covid-19 pandemic. During this time, I worked full-time for six weeks and already got a small insight into the work environment of elenia. In the course of the internship, it was suggested that I work part-time at elenia for about 20 hours a week during my master's degree. Since I liked working at elenia very much and, in addition to that, I wanted to gain practical experience during my studies, I decided to apply as a laboratory engineer.

A deep insight into research field

I finally started working at elenia in February 2021. What I particularly like about the work is the close involvement in the LISA4CL research project. By working together, I was already able to gain a deep insight into research, gather new knowledge and also deepen it, which would not have been possible by my academic studies alone. I was also able to get an impression of the cooperation with other institutes and industrial partners. In addition, I was also able to get to know the work processes that run behind the scenes of "the studies". Among other things, I was allowed to accompany a laboratory experiment from the planning to the execution. Even if the additional working time next to studying may sound demanding at first, the work at elenia is well compatible with the studies due to its high flexibility. I recommend every interested student to take the opportunity to work as a laboratory engineer, because the gained experience is very enriching for the professional as well as the personal development.

Wai-Yee Choi, B.Sc.
at elenia since February 2021





Research Reports

DaLion 4.0

Data mining as the basis of cyber-physical systems in Li-ion-battery production

Project aim

The DaLion 4.0 project aims to map battery production for planning and targeted control in cyber-physical systems in order to make battery cells more efficient and productive. Another focus is on the development of suitable quality management strategies in the context of improved tracking & tracing and the definition of quality gates.

The aim of the research project is to gain a profound understanding of the different steps in the battery cell production chain and to identify mutual relationships between process parameters and the resulting properties of the battery cell product (see Fig. 1). To this purpose, the integration of additional and new measurement technology into the production serves as a basis for data analysis. This knowledge will be used to derive concrete process improvements and to develop strategies for process control. Competitive battery cell production is the focus of the DaLion4.0 project, as it is of paramount importance for the success of electromobility and for Germany as a business location.

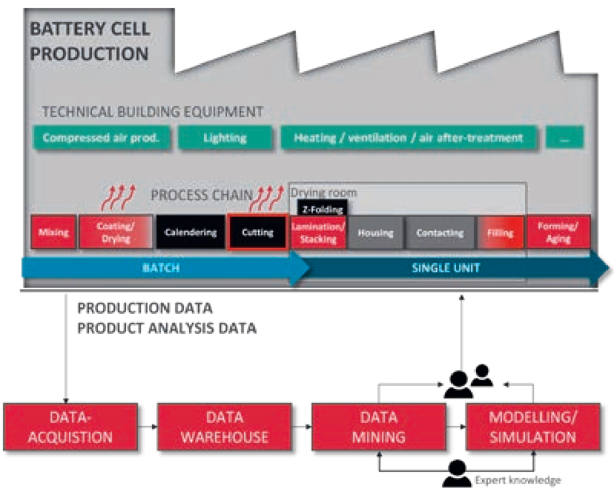


Figure 1: Project overview

Results and Discussion

The focus of research activities at elenia is on formation, which represents a key process in production for the controlled adjustment of battery cell properties. The battery cell is electrically activated by initial charging and discharging cycles. The decomposition products of the electrolyte form surface layers on the electrodes, which influence the characteristics and the long-term and safety behavior of the battery cells. Along the entire production chain, this process step is also the most time-consuming and cost-intensive. Therefore, the aim is to establish a detailed understanding of the process by means of a sensitivity analysis and to derive optimization potential in order to accelerate the formation process while maintaining at least the same cell quality. To this end, experimental parameter studies were first carried out with regard to the electrical parameters on the reference cell NMC 622 I graphite, (large-format pouch cell < 9 Ah, electrode type high-performance cell). A reference formation from the previous project DaLion was defined, which consists of two symmetrical fomation cycles (C/10; C/2) and lasts approx. 24 h. The formation of the cell was performed in the same way as the formation of the reference cell.

Figure 2 shows the comparison of the reference fomation with two developed dual-current (DC) protocols with respect to the characteristics relative discharge capacity (SoH) and C-rate performance. The fomation protocols of the DC variants differ in the 1st cycle. With 03 DC, charging takes place with C/10 up to 3.6 V and then

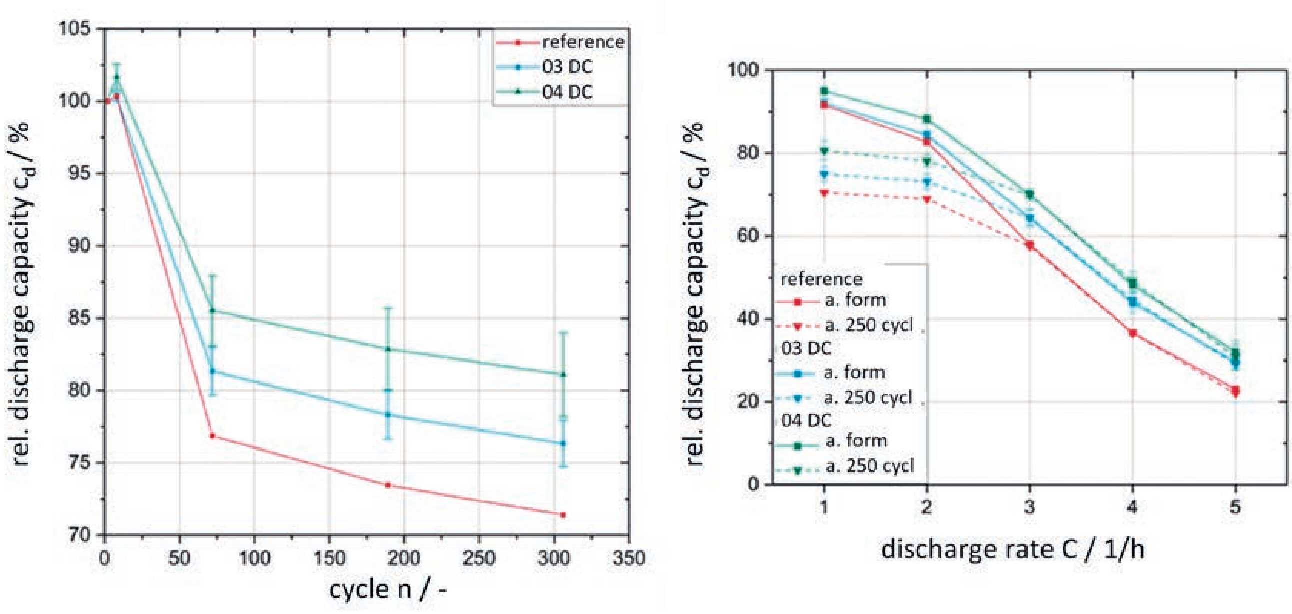


Figure 2: Comparison of dual-current (DC) fomation variations in terms of relative discharge capacity at C/10 relative to rated capacity after fomation (left) and relative discharge capacity from C rate test after formation and after 250 cycles (right).

with 1C until the final charge voltage of 4.2 V is reached. Complete discharge takes place at C/2. The 04 DC variant differs only by an increased charge rate of C/5 in the low voltage range of the full cell. If the process time is compared with the reference formation, a time reduction of approx. 15 % (03 DC) or even just under 50 % (04 DC) can be achieved. Regarding their energetic properties, it can be stated that the nominal capacity after fomation is 3 % (compare 03 DC) to 6 % (04 DC) higher for the reference. After the first characterization sequence, which consists of a sym. C rate test up to 5C and 50 cycles with 2C (cyclization), the usable capacity decreases rapidly in all three measurement series. The cells are deliberately heavily stressed in order to be able to quickly evaluate the parameter study in the formation. After 300 cycles, the SoH of the DC variations is 76 % (03 DC) and 81 % (04 DC), whereas the reference cell has a SoH of 71 %. The faster aging of the reference can be attributed to different SEI compositions, which favor long-term stability.

The C-rate test is performed symmetrically at five different C-rates immediately after formation and after 250 cycles to evaluate the electrical performance of the cells. The cells formed by the DC method have a higher discharge capacity at the same C-rate compared to the reference after formation and after 250 cycles. It can be seen that the cells formed at a higher C-rate also have better C-rate stability in the higher range. Overall, with the dual-current process, a fomation strategy was developed that significantly reduces the process time and achieves a comparable cell performance to the reference.

Outlook

In the last half-year of the project, the already started experimentally based investigation on the formation of the new high-energy electrode type will be finalized and compared with the results of the high-performance cells. The experimental investigations will finally be correlated with the simulations as well as the post-mortem analyses for the characterization of the SEI structure and composition by means of SEM and Raman spectroscopy of the project partners in order to exclude lithium plating. Thus, a model-based concept for the identification of cell-specific optimal fomation procedures is developed and implemented, which reacts quickly to new electrode structures and cell chemistries.

PROJECT NAME

DaLion 4.0

PROJECT RUNTIME

January 2019 – December 2021

PROJECT LOGO

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Photo: Battery LabFactory Braunschweig

FormEL

Determination of process-quality relationships of the Formation and End-of-Line test for function-integrated overall process optimization

Project goals
The aim of the FormEL research project is to optimize and combine the final production steps (formation and quality testing) of lithium-ion battery cells. The first charging and discharging cycles of a lithium-ion battery (formation) have a decisive influence on the performance, aging and safety of the battery cell. During the first charge cycle, the electrolyte is decomposed due to the low anode potential and forms the solid electrolyte interphase (SEI), which protects the electrolyte from further decomposition. To ensure a homogeneous SEI layer, several formation cycles are performed. These forming cycles can last up to 48 h. This is followed by the end-of-line test (EOL-Test) to quantify the capacity, internal resistance and self-discharge. The self-discharge test in particular lasts up to 30 days in order to be able to make reliable statements about the cell quality.

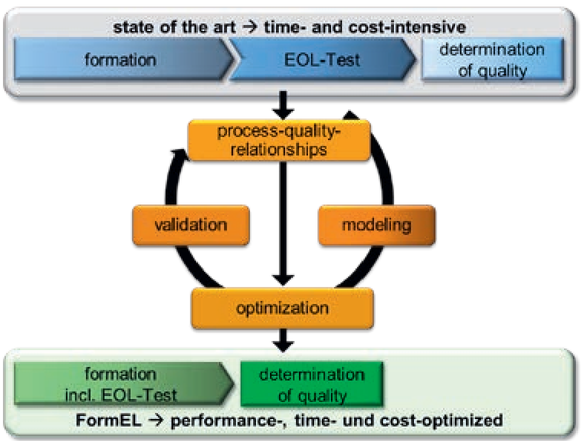

Figure 1: Project overview

The project will determine the interactions between the formation procedure and the EOL-Test in relation to the resulting and diagnosed cell quality. These process-quality relationships will be used to develop detailed models and optimizations of the two process steps, with the goal of single functionally integrated merged step. Optimized formation including EOL-Test is expected to increase cell quality and reduce both process time and cost (see Figure 1).

Results to date
At the start of the project, a reference procedure for the formation and EOL-Test was first defined. The forming procedure takes about 21 h and consists of a 0.05 C charge and 1 C discharge followed by degassing. The EOL test is based on the standard on IEC 62660 and takes about 31 days, of which 28 days are due to the self-discharge test. The remaining 2 days consist of several capacity tests and pulse current tests to determine the internal resistance at different states of charge. Based on these reference procedures, initial experimental variations have already been performed to reduce the process time without compromising the quality or diagnostic performance of the EOL-Test. The elenia focuses on fast charging methods that avoid lithium plating (Li-Plating). Li-Plating is the result of an undesirable side reaction of the negative electrode when the charging current is too high. Li-Plating reduces the available capacity and can evoke internal short circuits. Therefore, care must be taken not to cause Li-Plating during formation.

With the help of model-based methods and simulation models, promising optimization results have already been achieved. Using special small-format 3-electrode cells, the voltage of the negative electrode is monitored and always kept above 20 mV in order to avoid Li-Plating. In particular, Li-Plating is favored at voltages below 0 V of the negative electrodes. In contrast to a state of the art CCCV

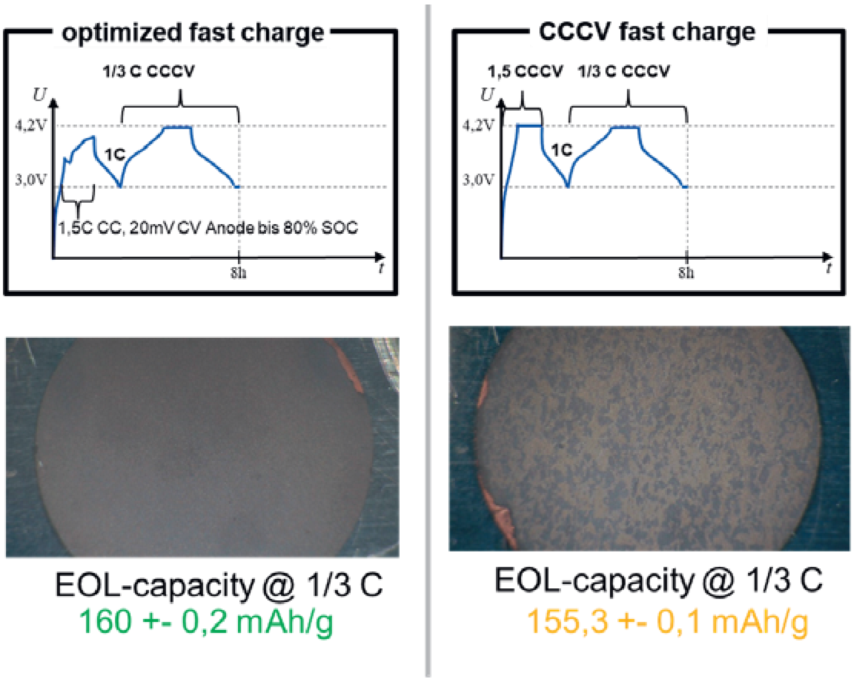

Figure 2: Left: optimized fast charge without Li-Plating. Right: CCCV fast charge with Li-Plating.

Graphics: Robin Drees

charge (constant current, constant voltage), a higher capacity could be achieved without causing Li plating for the same formation time (8 h) (see Figure 2). After formation, so-called post-mortem analyses were performed to determine whether Li plating had occurred. For this purpose, the cells are opened under an inert gas atmosphere. Subsequently, the negative electrodes are examined by microscopy.

Outlook

Further experimental and simulative sensitivity analyses will be performed in an attempt to reduce the process time even further. In parallel to these investigations, elements of the EOL-Test will be integrated into the formation procedure in order to reduce the overall process time. Synergies between optimized formation procedures and EOL-Tests will be used to develop a functionally integrated process. For example, defined current pulses or relaxation processes from the EOL-Test can be integrated into the formation procedure. The resulting characteristics of the voltage curve can be correlated with simulation models to determine cell properties (e.g. internal resistance or self-discharge) or to diagnose production defects. Function integration is expected to reduce process time by at least 30 % compared to the sum of the reference forming procedure and EOL reference testing.

In the further course of the project, various optimized procedures will be transferred to large-format pouch cells. The special feature of large-format cells is that several electrodes are stacked on top of each other. This makes it particularly difficult to wet the electrodes evenly with the electrolyte. Poorly wetted areas lead to inhomogeneous current density distributions, which favor Li-Plating. Therefore, with the help of different temperature cycles and mechanical pressure, an attempt will be made to realize wetting as uniformly as possible. Furthermore, the developed methods are also applied to different material systems (e.g. different active materials, electrolytes or separators) in order to determine differences between the properties of these material systems.

PROJECT NAME

FormEL

PROJECT RUNTIME

August 2020 – Juli 2023

PROJECT LOGO

FormEL

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SUPPORTED BY

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aufgrund eines Beschlusses des Deutschen Bundestages

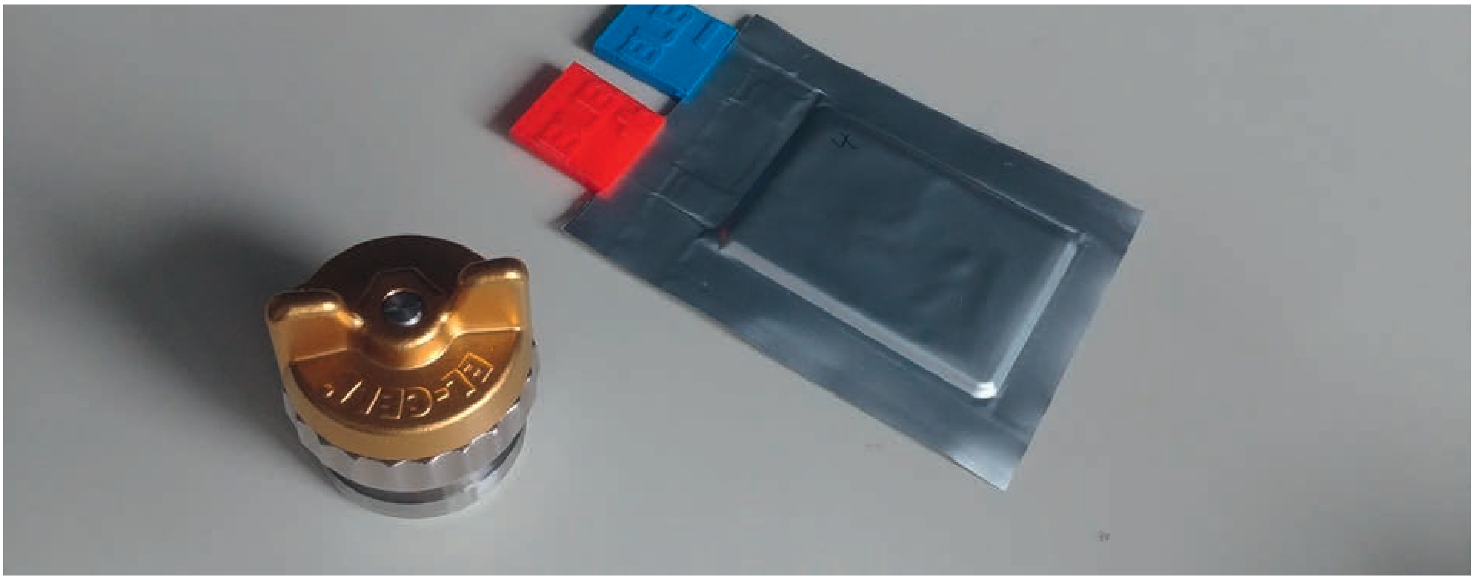

Photo: Fabian Katschewitz/TU Braunschweig

Adaptive Fast Charging Strategies

Model-based evaluation of the operating limits of different cell systems for the design of ageing-adaptive fast charging

Motivation

A multitude of factors influences consumer acceptance of electromobility. The terms cost, energy efficiency, safety, sustainability, range and performance come up again and again in this context. In addition, a long service life of lithium-ion battery cells as well as a short charging time of these in operation is decisive for the success of electric vehicles. The requirements for fast charging capability come from the respective application, but are often limited by the material system and cell design. In addition, the cell properties deteriorate due to battery ageing. Fast charging procedures in particular can lead to accelerated ageing. Therefore, the operating limits are often designed very pessimistically in order to avoid safety-critical processes and accelerated ageing processes such as lithium plating. A promising alternative is the determination of age-dependent operating limits for the corresponding adjustment of the fast charging strategy. However, this approach is associated with challenges because an age-related adjustment of the operating limits depends on states of the material and cell system that cannot be measured directly.

Project objective

The project FastChargeLongLife addresses this challenge and develops a methodology for the model-based evaluation of different cell material systems with regard to the maximum charge operating limits depending on the ageing state. For this

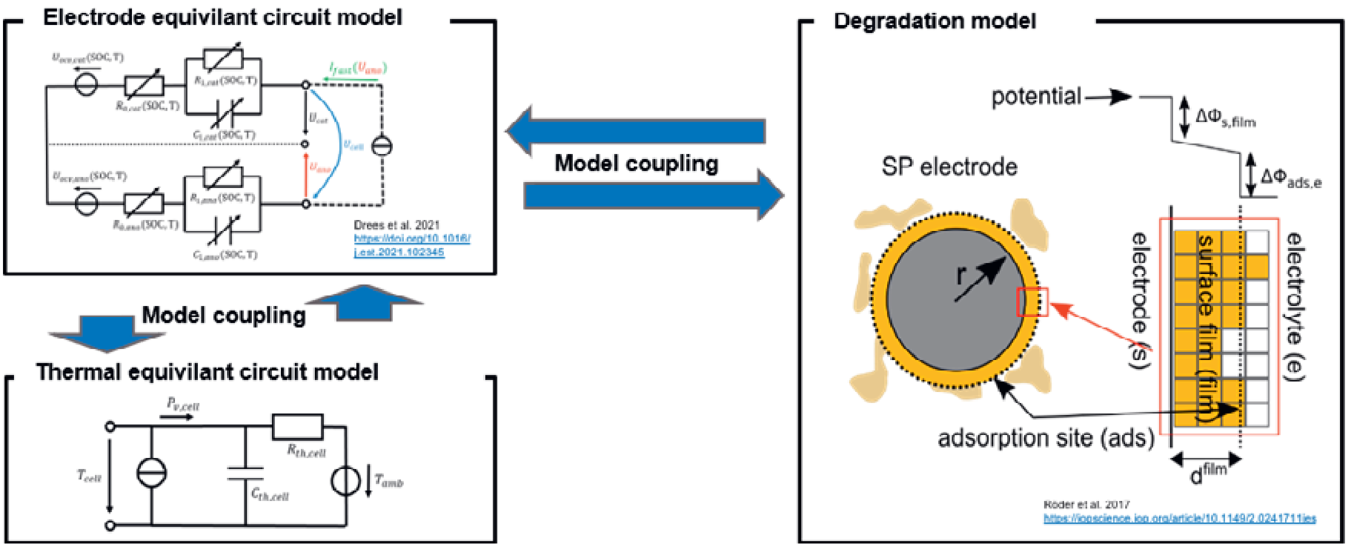

Figure 1: Model coupling of electr-thermal and physico-chemical models

purpose, a coupled modelling approach is used, which combines real-time equivalent circuit models and detailed physico-chemical degradation models (cf. Fig. 1). Due to the age-dependent and continuous model parameterisation during the entire utilisation phase, fast charging strategies can be adapted in order to adequately consider material-related changes in the cell properties during ageing. In addition, this holistic approach makes it possible to establish a direct link between given application profiles and the cell design. Thus, this model-based methodology is suitable for accelerated requirements assessment with regard to fast charging strategies for different cell material systems along the entire utilisation phase in 1st- and 2nd-use. A model-based scalability of the material data is provided in order to transfer the model parameters from small cell formats in 3-electrode format to large-format pouch cells. On the basis of the model-based determined operating limits, ageing-adaptive fast-charging strategies are derived, which avoid safety-critical degradation effects. This is done for different cell material systems, which can then be compared with each other with regard to the age-dependent fast charging capability. The optimised fast charging strategies should improve the charging time and service life by at least 10 % compared to state-of-the-art fast charging strategies without age-dependent adaptation.

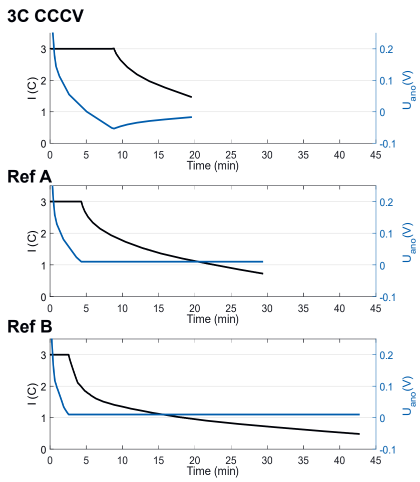

Figure 2: Comparison between three fast charging strategies

Design of the reference fast charging strategies

The design of state-of-the-art reference fast charging strategies for different cell material systems serves as the basis for a later age-dependent optimisation of the fast charging strategies. The basis for the reference fast charging strategies is provided by an electrode equivalent circuit model developed at the institute, which considers the electrodes separately from each other and thus enables the anode voltage to be controlled. By setting a minimum anode voltage above 0 V during fast charging, lithium plating can be avoided and accelerated ageing can be reduced. For parameterisation and validation of the model, various characterisation procedures such as capacity tests, current interrupt tests at different states of charge (SOC) and C-rate tests are applied to small-format cells in 3-electrode format. The cell type is a PAT cell from EL-Cell GmbH with approx. 8 mAh and a lithium reference electrode on the separator, which allows the electrode potentials to be determined. Depending on the specification of the maximum charging current, the minimum anode voltage and the SOC to be achieved after fast charging, the model specifies a corresponding charging strategy. In total, two reference fast charging strategies are defined for each cell material system. The first charging strategy (Ref A) results for a charge from 0 to 80 % SOC, a minimum anode voltage of 10 mV and a maximum charging current of 3C. The second reference charging strategy (Ref B) is also based on these boundary conditions, but is dimensioned on the basis of a 50 % higher internal resistance of the cell. The three line diagrams (cf. fig. 2) show the cell and anode voltage curve for a measured fast charge with 3C CCCV (maximum cell voltage = 4.2V) as well as for the simulated profiles Ref A and Ref B. The cell material system considered is based on the cell chemistry NMC622/G, and the ambient temperature is 20 °C. With 3C CCCV fast charging, the charging time is 19 min, but the anode voltage drops to as low as 50 mV, which causes lithium plating during charging and significantly accelerates cell ageing when cycling with this charging strategy. Ref A and Ref B have charging times of 29 min and 42 min, respectively, while at the same time avoiding lithium plating and thus slower cell ageing. Initial cycling tests with subsequent cell characterisation tests and post-mortem analyses have already confirmed the conclusions regarding the ageing behaviour. As a next step, the reference fast charging strategies will be designed for further cell systems in order to be able to analyse the significance of the cell system dependence on charging operation limits.

PROJECT NAME

FastChargeLongLife

PROJECT RUNTIME

October 2020 – September 2023

PROJECT LOGO

BattNutzung FastChargeLongLife

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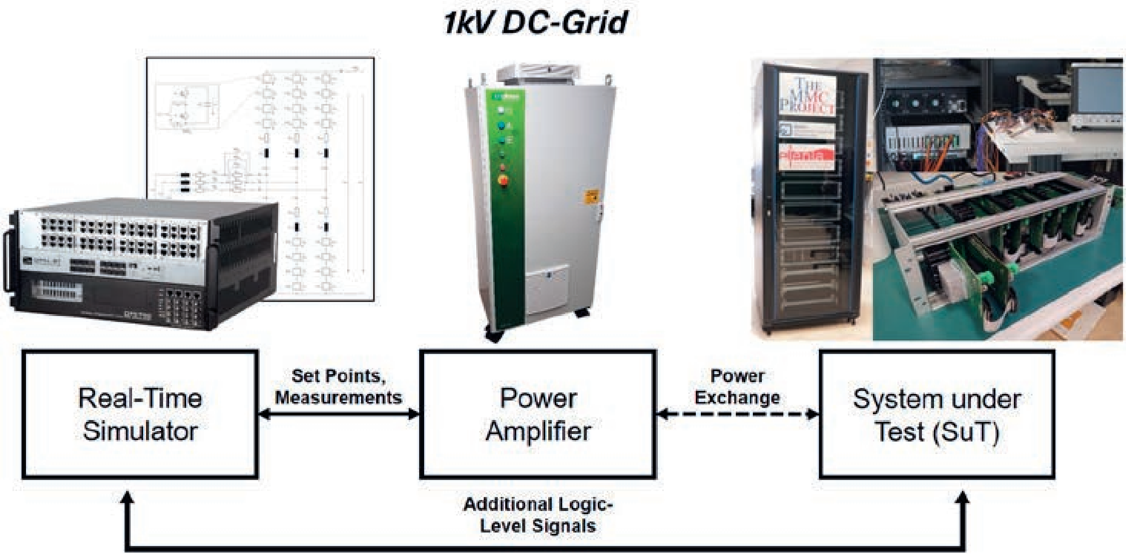


Photo: opal-rt.com, Frederik Anspach/TU Braunschweig

Future DC-Grids

DC multi-voltage level demonstrator for grid characterisation, development of protection systems and intelligent technologies

Introduction

In addition to DC transmission (HVDC), other applications for DC technology are currently emerging and will continue to do so in the future. These include, above all, server farms, industrial networks, transmission networks and building networks. In the research project Smart Modular Switchgear II (SMS II), the topics of protection technology, switchgear and network behaviour are being worked on. A demonstration grid with several voltage levels is being set up to research future DC grid structures. This can be used to simulate various grid topologies. The developed protection technology and the switching devices are tested on this structure. The repercussions of the network dynamics on the switching behaviour and the fault detection are determined in the course of this. The demonstration network is to be understood as a bidirectional transmission function between protection technology and switching device. In future, a PHiL laboratory will be set up on a scaled-up scale for the investigation of extended DC grid structures.

Status of project

The SMS-II project is planned to run for four years. The third year of the project will be completed this year. In the first half of the project (2019-2020), various questions and developments in the field of 1 kV were dealt with:

1.) Testing of 1 kV hybrid switches
2.) Design, verification and validation of a simulation for a DC-DC converter with dual active bridge
3.) Selection and qualification of a suitable measuring device for investigating the emitted EMC disturbances of a DC network
4.) Design, calibration and implementation of the 1 kV voltage sensors
5.) Installation, commissioning, electrical measurement and characterisation of various operating cases of the 1 kV DC demonstration network
6.) Connection of the 380 V SMS-I DC network
7.) Construction of a system test stund for verification of the protection system
8.) Validation of the protection system for two voltage levels in the demonstration grid (380 V, 1 kV)

In the second half of the project (2021-2022), the focus will be on expanding the demonstration grid and upgrading all peripherals for the 3 kV level. In the third year of the project, the following goals have been achieved so far:

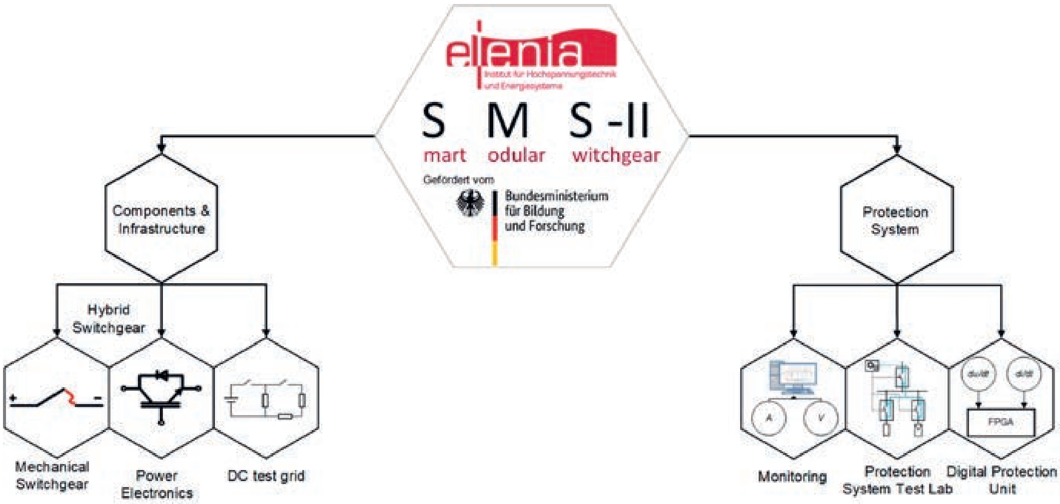
1.) Definition of switching device topologies for MVDC networks
2.) Definition of an MVDC network topology by means of simulation-based preliminary investigations
3.) Design, construction and investigation of a 3 kV hybrid switching device

The construction of the 3 kV grid and the adaptation of the measurement technology will be completed by the end of the project.

The findings of the fulfilled sub-areas of work are explained in more detail in the following sub-sections.

Protection System Design

Throughout the project so far, a modular protection system for the identification, localization, classification and selective clearing of current faults in DC networks at nominal voltages of up to 1 kV has been investigated and continuously developed. Different network topologies were considered, which, for example, also result from different voltage levels and coupling by means of DC-DC converters. The concept of the protection system is based on the permanent monitoring of the system status through voltage and current sensors, which



are installed within the switching devices used in the network.

The data from the sensors are collected in a protection unit before further, derived variables are calculated from the measured values via an FPGA controller. The implemented protection algorithm´s decisions are based on the measured and calculated values. Depending on the dynamic load changes in the demonstration network, different evaluations of the current network status are made by the protection unit and, if necessary, instructions are passed on to the switching devices in the form of switching commands in order to carry out the fault clearing as selectively as possible.

The decentralized application of the protection algorithm on distributed controllers was a major milestone in the first half of the project. Later on, the system will also be further developed for use in the 3 kV level.

Test grid

The multi-voltage level DC demonstrator has a modular and bidirectional design (Table 1). All network structures can be generated by means of a variable plug-in system. For the qualification of the mentioned protection system for the higher voltage levels, a requirements analysis is necessary. For this purpose, selected system states are investigated in order to carry out an efficient (design of experiments) parameterisation of the protection system. The aim is not to parameterise the protection system for a specific network structure, but rather to develop a method that allows the protection system to be efficiently adjusted to various network topologies.

Parameter	Value
Voltage Level	380 V, 1000 V, 3000 V
Power	220 kW
Grid Topologies	Industrial grids, server-farms, power supply residential buildings
Typ of Switchgear	Hybrid
Load Polarity	Bidirectional
Loads	Ohmic, inductive, capacitiv, electronic
Connection to other network entities	Bidirectiona connection the AC-Grid

Tabel 1: Characteristics of the test grid

Power-Hardware-in-the-Loop

With Power-Hardware-in-the-Loop (PHiL), additional DC grid sections and components can be deployed on real-time simulators. A power amplifier serves as the interface, so that simulated voltages and currents are converted to signals of high power, power exchange between the real-time simulation and the demonstrator. It is then possible to analyse interactions between the demonstrator and the modelled elements. This flexibility enhances the number of observable operational states and faults, so that the performance of the demonstrator can be validated with additional configurations.

Summary

The current state of research already allows a comprehensive analysis of future DC grid structures. Due to the consideration of switchgear technology and sensor technology in the system analysis, a wide range of interactions between grid components is already considered. The view into the future is oriented, the applicability of the research results in higher grid levels is to be investigated by means of power hardware in the loop on a scaled scale.

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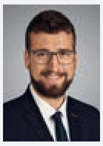

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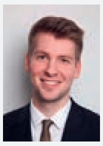

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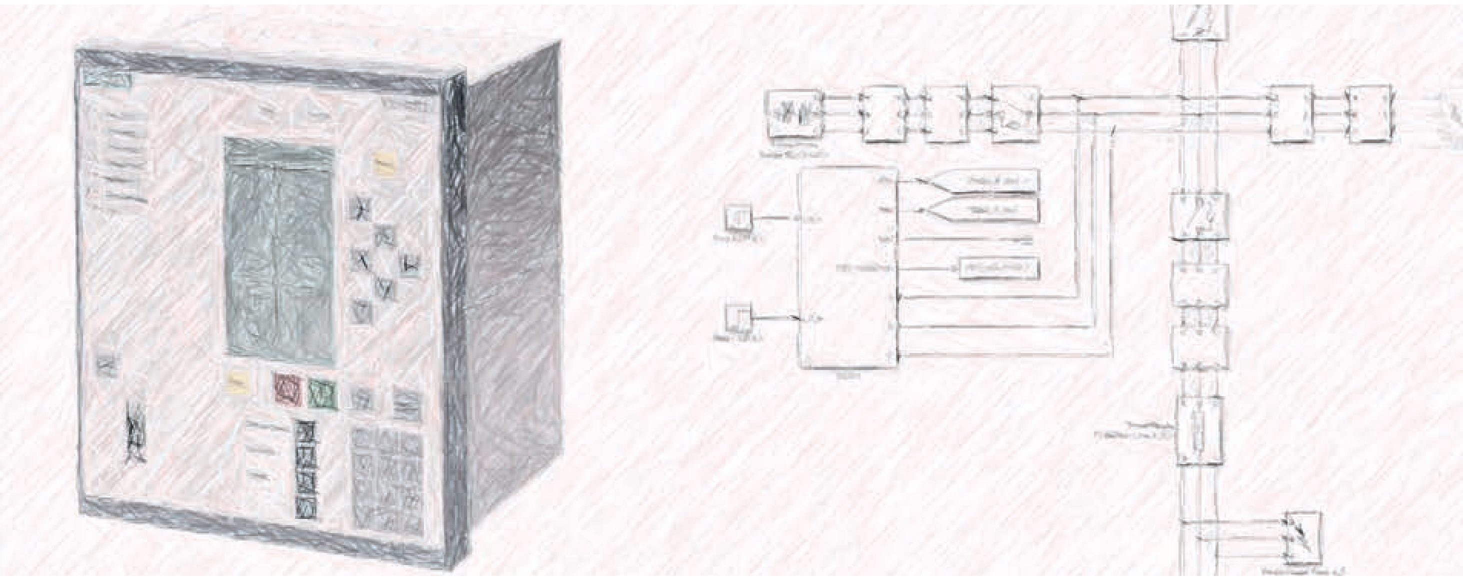

Protection in Distribution Grids

Model-based system engineering for the design of protection systems for inverter-dominated distribution grids of the future

The increasing renewables infeed into the distribution grid through inverter-based systems has a severe impact on the functionality of conventionally deployed protection systems. Within the joint research project SiNED – "Ancillary Services for Reliable Power Grids in Times of Progressive German Energiewende and Digital Transformation", this impact is analysed in detail to further develop the existing protection systems, so that safe and reliable grid operation and provision of ancillary services is ensured.

Emerging Challenges for Protection Systems

Conventional protection systems are designed to function properly for grid configurations with typical down-stream power-flow direction. The integration of inverter-based Distributed Energy Resources (DER) into the distribution grid leads to a change of the power-flow direction. Varying short-circuit current levels and infeed locations, as well as the inverter characteristics, negatively influence the selectivity and tripping time of protection systems, causing loss of coordination or even false tripping.

Scope of the Project

In this project, the challenges that are imposed on conventional protection systems are being analysed in a simulative manner using reference grids, to define requirements for modern protection systems in grids with inverter-based DER, ensuring safe and reliable operation. These requirements build the foundation for the development of protection systems and algorithms with Model-Based Systems Engineering (MBSE). The next step is then the verification and validation using the same reference grids.

MBSE for Protection System Design

A protection system is a complex system with many requirements, interfaces and design options, which makes MBSE a valuable tool for the development of protection systems. Especially with the change to a grid characterised by renewable and decentralised energy generation based on power electronics, the protection system needs to be adapted. The MBSE methodology is based on the V-model presented in Figure 1.

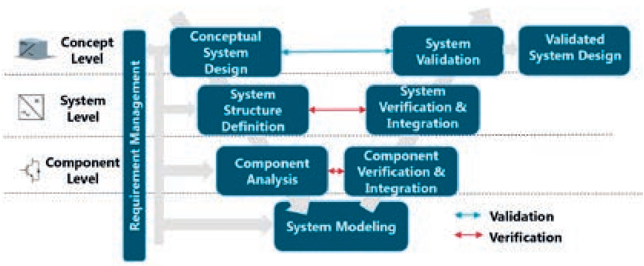

Figure 1: V-Model for the Development of a Protection System Using MBSE

Different design levels ensure a structured procedure and a systematic implementation of the originally defined requirements. The conceptual design describes the system goal, the boundary conditions and the system structure, the expected behaviour and the functionality. This is transferred to the system level in the next step, where the most suitable protection system structure is determined based on an evaluation methodology. Verification and validation are crucial in MBSE to ensure that the system is designed according to the requirements and that the correct system design is developed. Various design elements such as the location of a protection device, the presence of a central protection unit and the communication mode were used to define the system structure. In addition, the criteria listed in Figure 2 were utilised. These criteria together with the criteria weighting resulted in the most suitable protection system

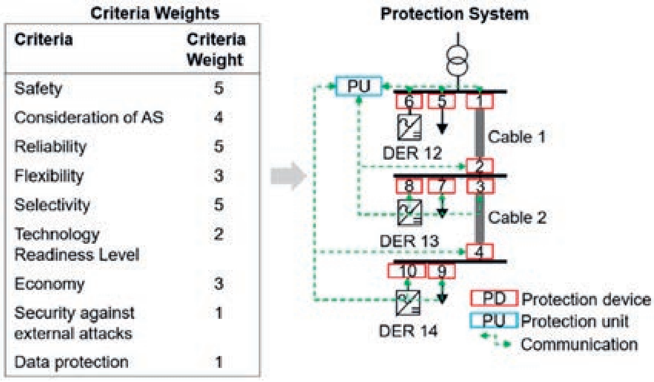

Figure 2: Criteria Weights (1: low impact to 5: high impact) and Protection System Design

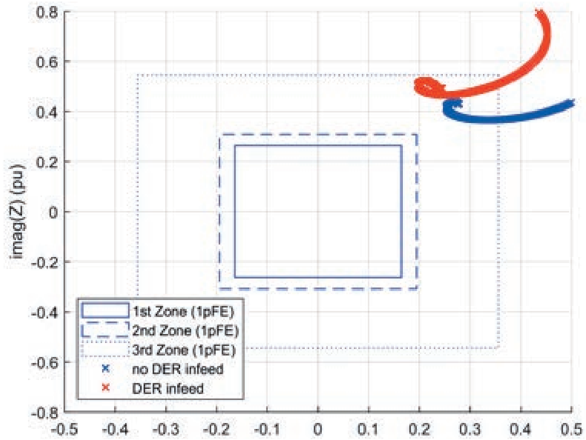

Figure 3: Impedance Error Measurement caused by DER infeed

design. The system structure of this protection system is shown in Figure 2. Once the system structure has been identified, the next step is to add further details to the protection system design at component level according to the V-model before proceeding with system modelling and validation.

Reference Grid Definition

The reference grid that serves as a basis is a simplified excerpt of a German medium voltage grid. It is implemented in MATLAB/ Simulink. The protective functions that are considered are overcurrent and distance protection. Regarding the DER, they will be modelled with their inverter dynamics and characteristics compliant with VDE AR N 4110, including fault-ride through and reactive current infeed capabilities. At each node, the maximum permittable infeed is calculated to parametrize the DER.

Analysis of Fault Scenarios

Infeed location, kind of fault and fault location are combined in order to define fault scenarios. These are being simulated and evaluated. The comparison between protection system functionality with and without DER infeed is of special interest. It can be analysed which effects negatively influence the functionality when DER are incorporated into the grid.

Evaluation

The evaluation of the performed simulations of fault scenarios shows that the functionality of protection systems is negatively influenced by different aspects. It is possible that the overcurrent protection lacks selectivity if non-directional devices are used. Additionally, the tripping time can be higher, especially for devices with time characteristics. The functionality of distance protection is mostly influenced by error measurements, leading to over- or underreach, and increasing the tripping time. Loss of coordination or false tripping can also be observed. Figure 3 shows an example of error measurements for a single-pole-to-ground fault.

Outlook

In the following, the results of the fault scenario simulations will be further analysed to define requirements for the development of modern protection systems and algorithms. The design of a suitable protection system will be expanded to the component level to implement the overall design and validate it with simulations of the reference grid.

PROJECT NAME

SiNED

PROJECT RUNTIME

November 2019 – October 2022

PROJECT LOGO

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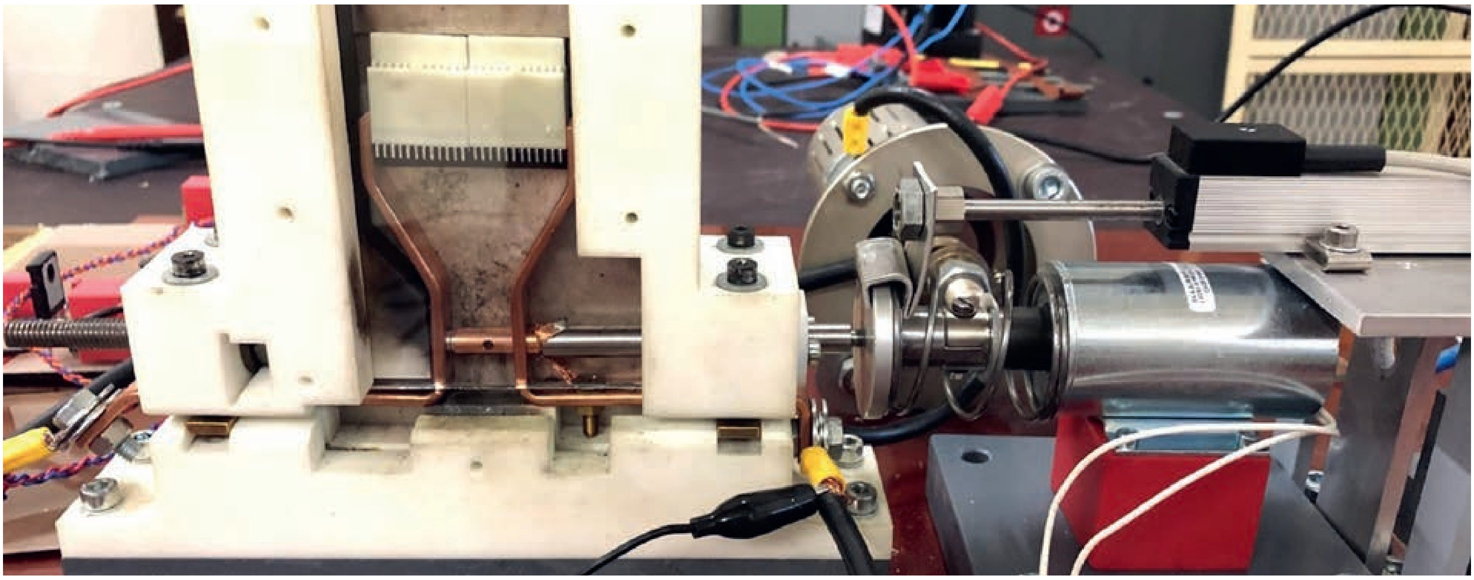


Photo and Graphics: Patrick Vieth/TU Braunschweig

Universal Power Switch

Investigation and optimization of hybrid circuit breaker

The share of direct current networks is increasing more and more. Areas of application include electrical systems in electric vehicles, ships and aircraft. The energy transition is expected to lead to a further increase in the use of renewable energies such as photovoltaic systems, battery storage or the grid connection of offshore wind farms. In order to be able to safely clear faults in these grid structures, suitable circuit breakers are indispensable. For the development of suitable, cost-effective circuit breakers, the combination of state-of-the-art power semiconductors and mechanical protective switching devices in a hybrid circuit breaker is a technologically promising solution. Hybrid circuit breakers combine the advantages of mechanical switching devices and power semiconductors in one device and can be used for both DC and AC applications. A hybrid circuit breaker is being developed in a joint project between industry and science in UPS – Universal Power Switch.

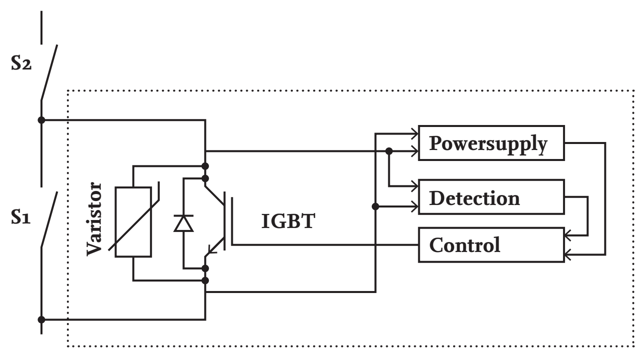
Switchgear testing

For stable and safe grid operation, circuit breakers are required that can switch off nominal, overload and short-circuit cases within a few milliseconds. Based on previous investigations, hybrid circuit breakers have proven to be a suitable and superior technology to conventional switchgear. The function of the hybrid circuit breaker is verified and validated in our institute's own test fields (see laboratory report: DC test field).

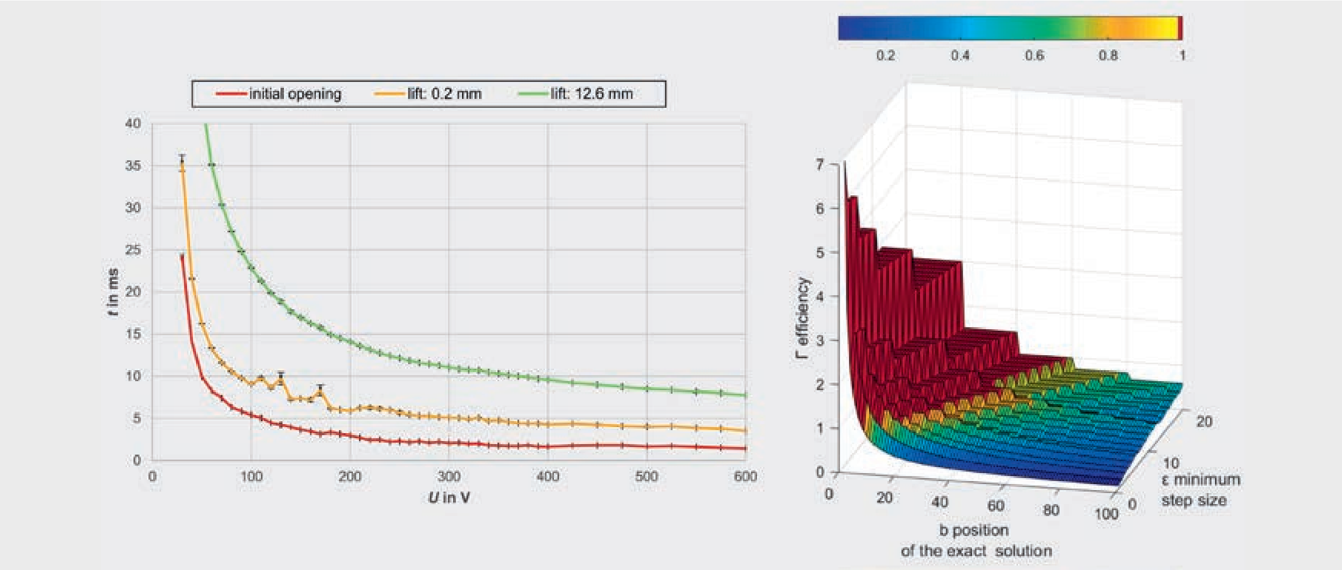
The hybrid circuit breaker being investigated in the project consists of a pneumatically driven mechanical switching device. An electronic switching device which consists of IGBTs with control electronics and a varistor are connected in parallel (see figure). In the past two project years, the investigations with the hybrid switching device for the low-voltage DC range have been deepened. Various optimization potentials have been investigated and evaluated. In particular, the switching phases during the switch-off process have been analyzed in various publications. The greatest influence on the switch-off time is shown by the switching delay time and the movement speed of the contacts. Both parameters depend on the actuator used. It has also been shown, that there is optimization potential in the duty cycle of the IGBTs. It must be matched to the switch-off behavior of the hybrid circuit breaker. This can be optimized by adapting the electronics. The implementation of the optimization potential is described below.

Adjustment of the mechanics

Both the contact speed and the delay time are influenced by the pneumatic drive. The drive speed was already increased in the model switch by using a latch. However, this also resulted in a higher drive delay time. A change in the drive concept is therefore currently being investigated. Due to the high speed, Thomson coil actuators are being investigated as a possible concept for hybrid circuit breakers. The actuators are already researched in applications in the HVDC sector. Due to the low availability and high costs, an attempt was made to transfer the principle of Thomson-Coil actuators to other electromagnetic drive concepts. The basic function of a Thomson-Coil actuator is based on the short-term overloading of



Circuit diagram of the hybrid circuit breaker



Left: Opening behavior of the solenoid actuator; Right: Efficiency (blue) of interval bisection vs. linear method

a magnetic drive to generate high forces. Studies on various actuators show, that solenoids can achieve significant speed increases by electrically overloading them. Based on this experience, a 24 V linear solenoid with a maximum dielectric strength of 1000 V was investigated. The drive voltage was incrementally increased to 600 V and the opening behavior recorded (see figure above). The higher the drive voltage is set, the lower the delay time and the higher the movement speed is. The solenoid is thermally stressed in pulse mode, but the Curie temperature is not reached. The applicability of the Thomson coil principle to solenoid actuators was demonstrated. Drive delay times have been reduced from about 28 ms with latched pneumatics to 1.5 ms. The average speed has been doubled.

Adjustments of the electronics

In addition to drive optimization, optimization of the conducting time of the IGBTs was also identified as a targetable improvement. The conducting time of the IGBTs is influenced by the dielectric strength of the switching path after the arc is extinguished. The exact relationships are being investigated at elenia as part of several dissertations and are currently not yet fully clarified. If the conducting time of the IGBTs is selected too short, the arc will reignite. If the time is selected too long, the thermal load on the power semiconductors increases and the switch-off time increases. To enable rapid determination of the optimum duty cycle, new methods, such as the interval bisection method, have been used. This allows a sufficient accurate determination of the minimum necessary conducting time of the electronics by shortened experimental investigations (see figure above). The switch-off time for ohmic-inductive overload cases up to 600 A could be reduced to an average of 6 ms. In the event of a short circuit, the mechanical switching device can switch currents of up to 3 kA. The function of the switching device can thus be ensured for all operating ranges. In combination with the protection system developed in the SMS-II project, faults can be detected and switched off within 7 ms. With completion of the test field developed in the project, higher operating limits can be determined and tested.

PROJECT NAME

Universal Power Switch

PROJECT RUNTIME

July 2016 – December 2021

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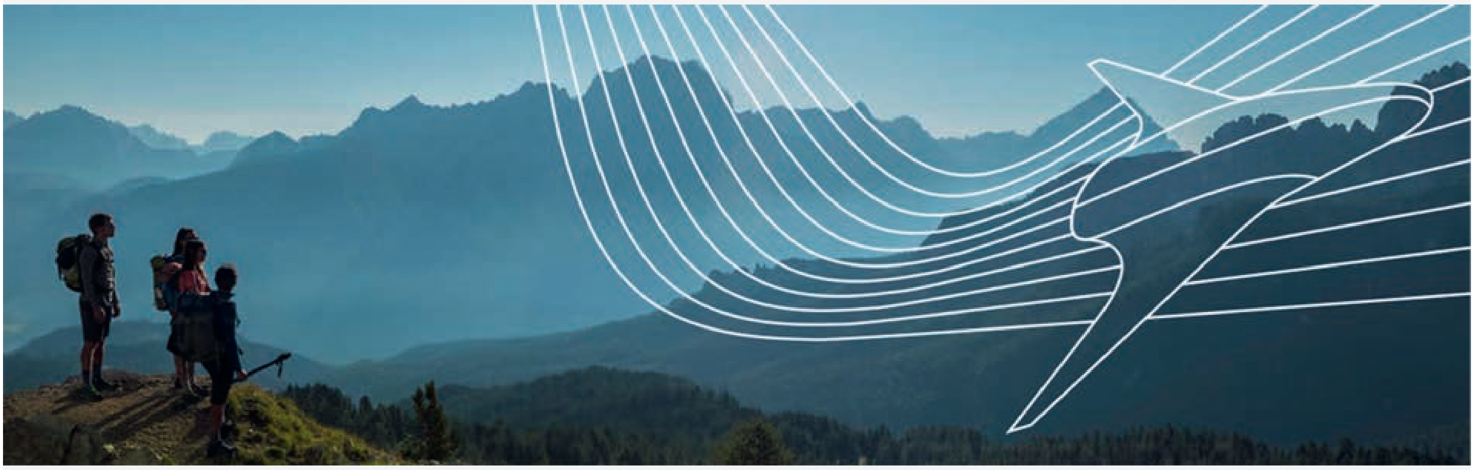


Graphics: SE²A/TU Braunschweig

SE²A

Sustainable and energy-efficient aviation

Since 2019, elenia actively participates in the cluster of excellence SE²A – EXC 2163 (Sustainable and Energy-Efficient Avia-tion). In this project, a multitude of institutes of the TU Braunschweig, the LUH, the DLR, the HBK and the PTB work together to proactively shape a new era of air traffic.

In principle, the SE²A cluster is divided into three main research areas:

- ICA A Assessment of the Air Transport System
- ICA B Flight Physics and Vehicle Systems
- ICA C Energy Storage and Conversion

In ICA C, elenia, together with IMAB from Braunschweig and IAL from Hannover, is researching in the working group "C4.2 – Power Supply System for All Electric Aircraft" how we can succeed in providing an electrical wiring system for an All Electric Aircraft. In particular, ICA C 4.2 is focusing on the fundamentals of converters, power electronics, switchgear and insulation systems.

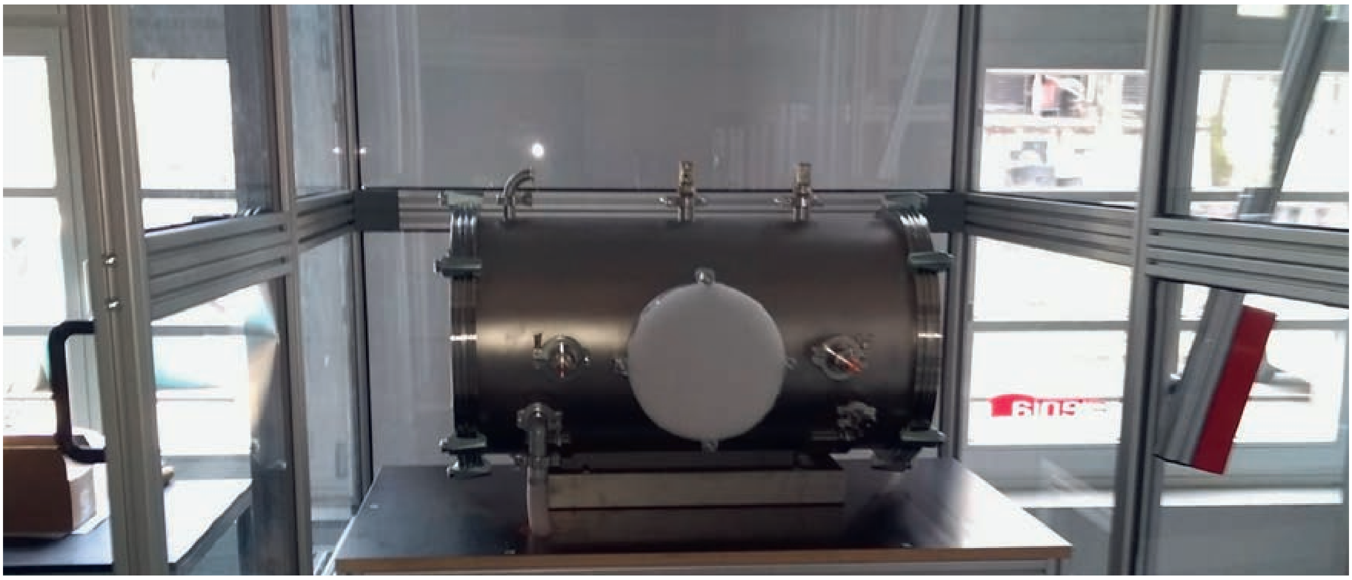
Structure of the Cluster

Therefore, we obtained an overview of the necessary technical and normative boundary conditions in the beginning. The environmental conditions in avionics, especially pressure and temperature, pose technological challenges for systems with high supply voltages. In concepts such as All Electric Aircraft, higher supply voltages are a basic requirement for operability, since the mass of the wiring system must be kept as low as possible. The findings from the requirements were jointly published by the entire working group C 4.2 in an extensive discussion in the multidisciplinary open access journal "IEEE Access", Figure 2. Here elenia went into more detail on the requirements for switchgear and supply lines for all-electric aircraft, among other research questions.

The development of completely new aircraft technologies is only possible in a methodically very well-structured research project. Conventional research and development strategies that focus in detail on the respective component must be integrated into the overall project via Systems Engineering. We have to be able to react to changing requirements from different stakeholders in the research process, which is why we have recently started using the Model Based Systems Engineering approach. For other partners, we provide gravimetric and volumetric models for cable and switchgear to support other system design processes.

For research purposes, a low-pressure chamber has been developed, which enables us to investigate geometries and components in a large volume at pressures (down to 1 mbar) that are significant for avionics using current high-voltage methods (impulse voltage, DC and AC test methods with voltages up to 10 kV), Figure 3.

The technology in and around the test chamber is currently being automated so that predefined tests can be run automatically at different distances, ambient pressures, voltages and voltage forms. The focus of the planned investigations is on basic geometry arrangements with a low measurement uncertainty as well as different PCB arrangements in order to qualify them for higher voltages

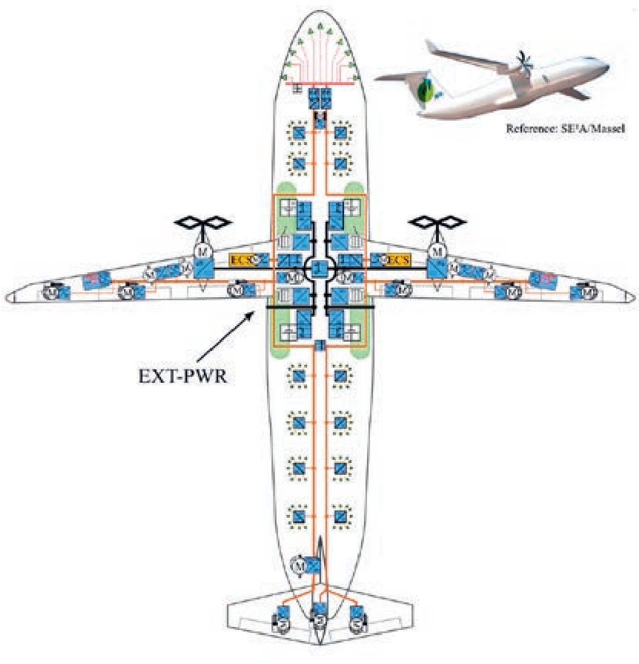


Low pressure chamber for high voltage tests Photo: Tobias Hartmut Kopp/TU Braunschweig

and lower pressures. In this sub-project, elenia is cooperating with IMAB from Braunschweig.

In addition, elenia is developing and investigating possible new electrical wiring topologies with colleagues from the Clausthal University of Technology. By combining model-based systems engineering with electrotechnical simulation software, load flows and transient fault cases occurring in different topologies are investigated. The results provide important parameters for the definition of requirements for components. The design of the components, together with the definition of possible system architectures, forms the basis for the development of a suitable electrical system design for all-electric aircrafts.

Through the described research activities, elenia hopes to contribute to the implementation of the EU strategy Flight-path 2050.



First design of a wiring system for an AEA (~30 × 30 m)
Graphic: Hendrik Schefer/TU Braunschweig

PROJECT NAME

Sustainable and Energy-Efficient Aviation

PROJECT RUNTIME

January 2019 – December 2025

PROJECT LOGO

SE²A

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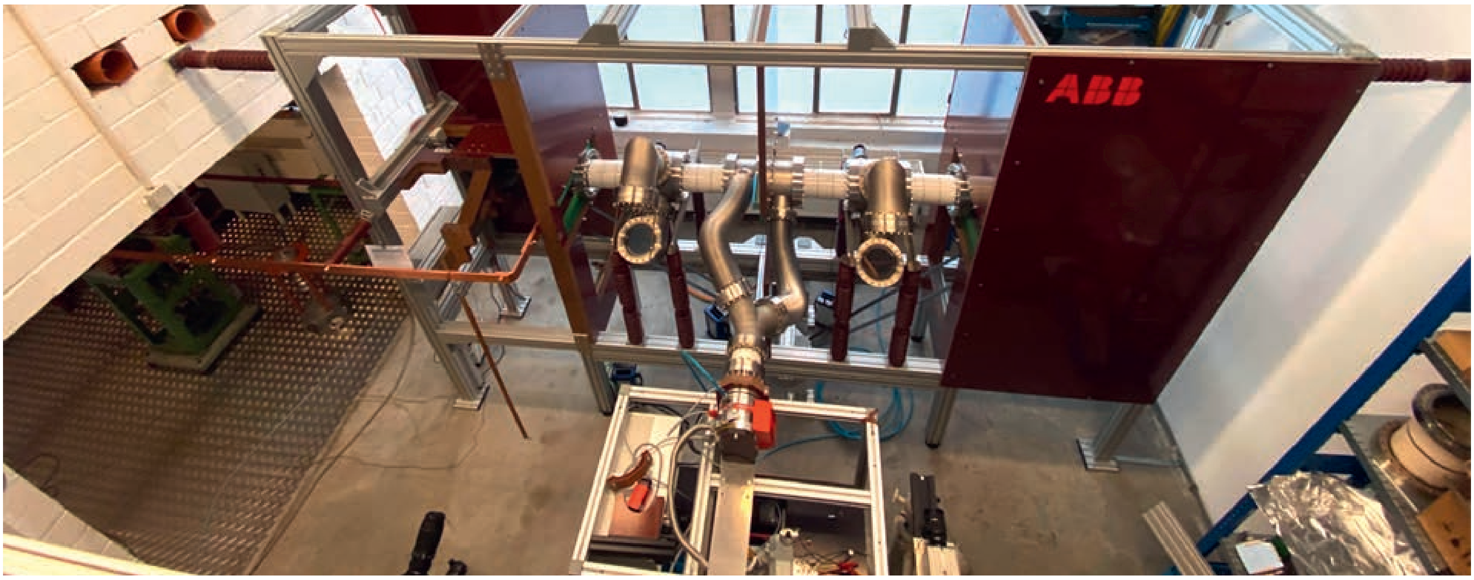


High Voltage Vacuum Breaker

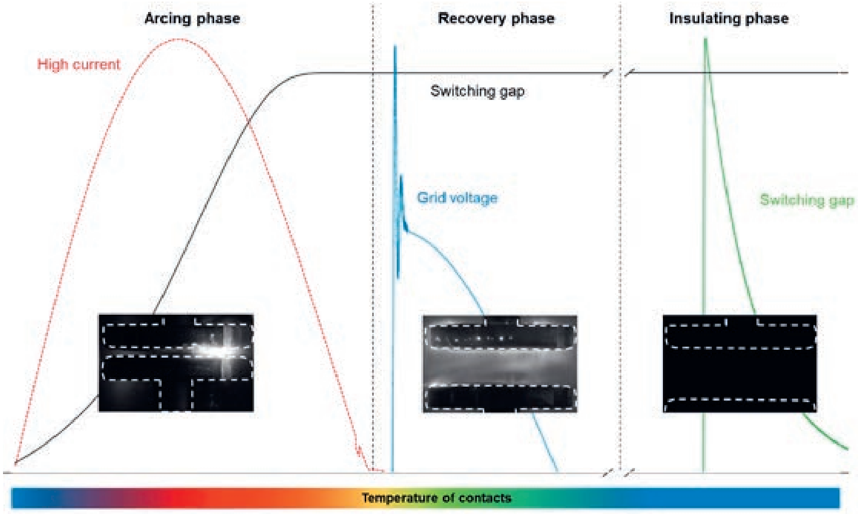
Eco-friendly solutions for circuit breakers in power transmission

In order to be able to use vacuum circuit breakers not only in the medium-voltage range but also in the high-voltage range, various approaches are being pursued: One is the use of long switching gaps and the other is the series connection of several vacuum circuit breakers. In order to make energy transmission more sustainable, vacuum circuit breakers are to be used to remove greenhouse gases from the grids while at the same time saving energy through lower contact resistances. The relevant processes are being systematically investigated in the projects on vacuum circuit breakers at elenia. In order to be usable in the high-voltage range, a circuit breaker must reliably disconnect short-circuit currents in extreme cases and withstand the following grid voltage. The open switching path must also ensure galvanic isolation during lightning impulse stresses. These loads, divided by phase, are shown in the figure. The isolation can start at any time at grid frequency. The separation is successful as soon as the conductive connection of burning contact material is extinguished at the next current zero crossing. The recovering switching gap with the still heated contacts must hold the applied mains voltage without allowing a breakdown. The open switch with cold contacts must maintain its insulating state even during a lightning strike.

Investigation during the arcing phase
To disconnect rated or short-circuit currents, a moving contact is removed from a fixed contact via a drive. The short-circuit case represents the greatest possible load and is therefore used for testing in the research context. The required distance from the contact separation to the safe galvanic separation is reached within 10 ms. The increasing distance is shown in the figure. During separation, a conductive connection is created by melting the contact surface, which is extinguished in the next zero crossing. To improve the switching performance of a vacuum switch, the energy of this conductive plasma must be distributed as simultaneously as possible; not only at known distances (15 mm), but also at larger distances up to 30 mm. In order to better understand the distribution of the energy, elaborate optical observations by high-speed camera are used and combined with automated optical evaluation methods. Based on the findings of this arc phase, the goal is to transfer contacts that are loaded as optimally as possible into the re-strengthening process.

Description of the recovery
After the current zero crossing and the extinction of the plasma, the switching gap will regain its dielectric strength. This phase is characterized by the previous high-current phase, in which the vacuum arc generates conductive particles in the switching gap by contact erosion. These conductive particles are exhausted to the cathode and anode during the recovery phase. This suction mechanism is caused by a rapidly increasing recovery voltage. The flow of the particles is visualized by a post-current measurement. The elenia investigates the plasma behavior in the recovery phase by methodical evaluation procedures using statistical experimental designs. From post-current measurements, models are developed that describe the plasma and can be verified by optical investigations. The aim is to enable a description of the plasma behavior and to use this knowledge to generate a successful switch-off for higher voltage levels, thus initiating a successful insulating phase. Further switching technologies like a series connection of vacuum circuit breakers can be investigated with this model.

Investigation of electrical strength
The approach of a modular series connection of vacuum circuit breakers offers some advantages, especially for large voltage loads. However, when installing a series connection of several vacuum circuit breakers, e.g. in a switching system, the voltage distribution across the individual vacuum circuit breakers is influenced by the spatial proximity of earthed surfaces such as shut-



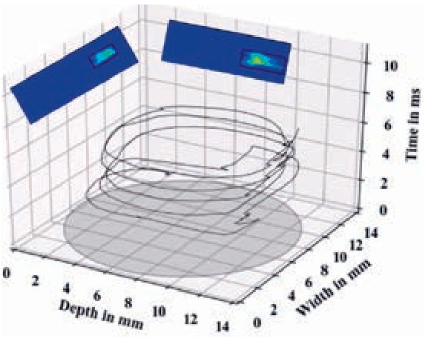
Requirements for circuit breakers during and after opening operations (a.u.)

off grids or enclosures. To ensure symmetrical voltage distribution despite this influence, a shielding and control arrangement has been developed which shields external fields and controls the switching gaps symmetrically by capacitively coupling the shields to each other and to the metal vapor condensation shields of the vacuum circuit breakers.

The shield arrangement consists of three aluminum shields fabricated in the institute's own workshop. The upper and lower shields are rotationally symmetrical cylinders closed on one side with an outer diameter of 21 cm. The middle screen consists of a rotationally symmetrical cylinder with an attached base ring. For the external insulation of the shielding arrangement, vacuum is used as in the interior of the circuit breaker. For this purpose, the installation takes place in the vacuum recipient in the high-voltage hall. A pump combination of rotary vane and turbomolecular pump enables tests in the pressure range of 10^5 mbar at voltages up to 400 kV. The tests with lightning impulse voltage according to the up-and-down method can be recorded in high resolution with the transient recorder. In addition to investigating the electrical strength of the double-break with shielding configuration, symmetry is important for assessing the voltage distribution. For this purpose, the development of a measurement system for the potential of the isolated center shield is the focus of the practical activity. The system, which consists of a Zaengl divider integrated into the test object, enables the detection of partial breakdowns in the shielding arrangement and double interruption. In this project, simulations and practical tests are combined to optimize the shielding arrangement.

Award

During ISDEIV 2020, the contributions of vacuum technology were followed with great interest. This was recognized by the organizers with the **Best Video Award** for the work of Benjamin Weber.



Reconstructed arc movement

PROJECT NAME

MoLiboA

PROJECT RUNTIME

January 2019 – December 2021

PROJECT PARTNER

HST TU Darmstadt

SUPPORTED BY

DFG Deutsche Forschungsgemeinschaft

PROJECT NAME

EUDo & EUlaS

PROJECT RUNTIME

EUDo: Jan. 2021 – Dez. 2022
EUlaS: Jan. 2020 – Dez. 2022

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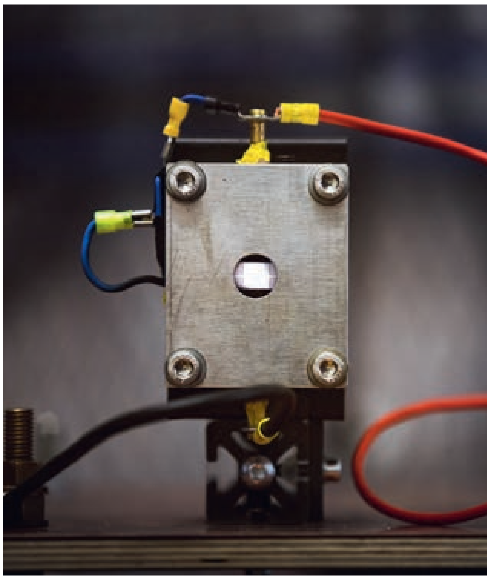

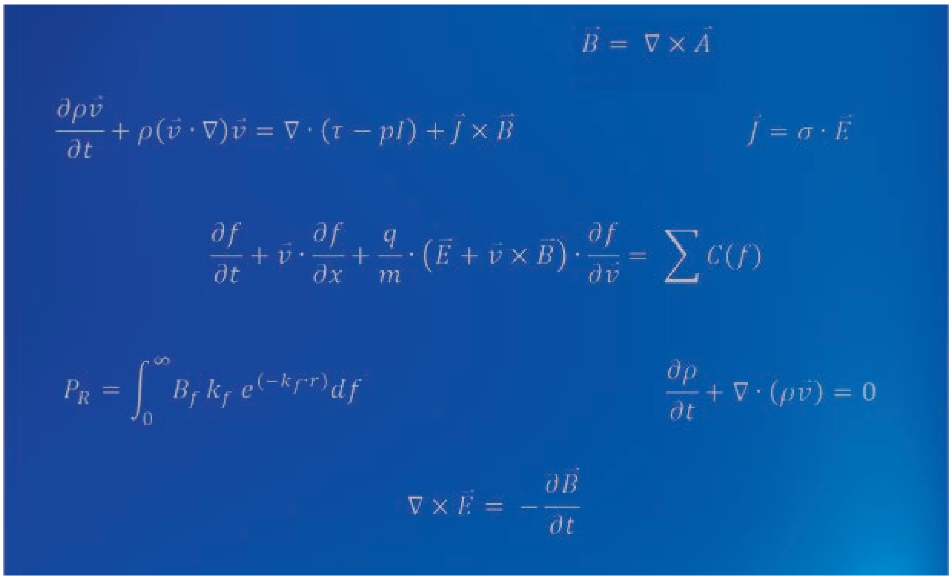

Photo: Max Fuhrmann/TU Braunschweig, Graphic: Muhamet Alija/TU Braunschweig

Experimental and Theoretical Research of Arc Plasmas in Air

Part 1: Investigation of the behavior of spark gaps after surge current tests

Introduction

At the elenia, the plasma technology team is researching ways to further develop lightning protection devices (class 1). For this purpose we use a model of a surge arrester based on a spark gap. Besides the practical work in the lightning protection laboratory, the theoretical investigations are a very important part. For this purpose, we are also engaged in the development of extensive computer models and plasma simulations in order to gain an even deeper understanding of the processes. the focus is on calculations of thermodynamic properties, transport properties and radiation processes for higher pressures of up to 500 bar and a wide temperature range of up to 150000 K.

Classification of research

Lightning protection devices are so-called class 1 arresters and ensure that transient results such as lightning strikes are handled safely and without interference in distribution networks. The resulting high energies can be dissipated through the connection created by the spark gap to the protective earth conductor without damaging devices.

Test setup for investigating the recovery voltage

A surge current generator is available in the lightning protection laboratory for investigating the effects of lightning pulses in the model arrester. The surge current form (8/20 µs) for the tests is standardized according to international standards. The aim of the investigation is to study the plasma generated between the contacts of the spark gap. In previous work, the high current phase, the period during which the surge current flows, was investigated. Further, the region after the zero-crossing of the surge current is in focus. Since the investigations with a low-voltage transformer are very complex due to the high parameter diversity, a special circuit was developed. By replacing the transformer, the line-following current behavior can be investigated using a constant DC source. The test setup is shown in figure 1.

Furthermore, this method can be motivated by the fact that during the transient period of a lightning pulse, the sinusoidal line voltage can be considered constant. The left mesh of the test setup in figure 1 is the surge circuit via which a surge pulse is applied to the model spark gap.

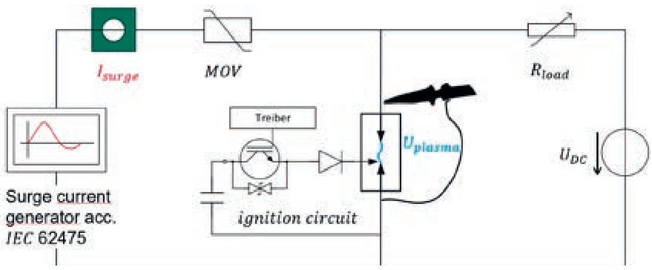

Figure 1: Test circuit for the investi-gation of the deionisation behavior of spark gaps

This is triggered in time by an ignition device developed at the laboratory, so that the surge current can flow. Due to the resistance R_{load} in the right mesh, the high current phase is not affected. After the energy of the surge generator has discharged, the spark gap is

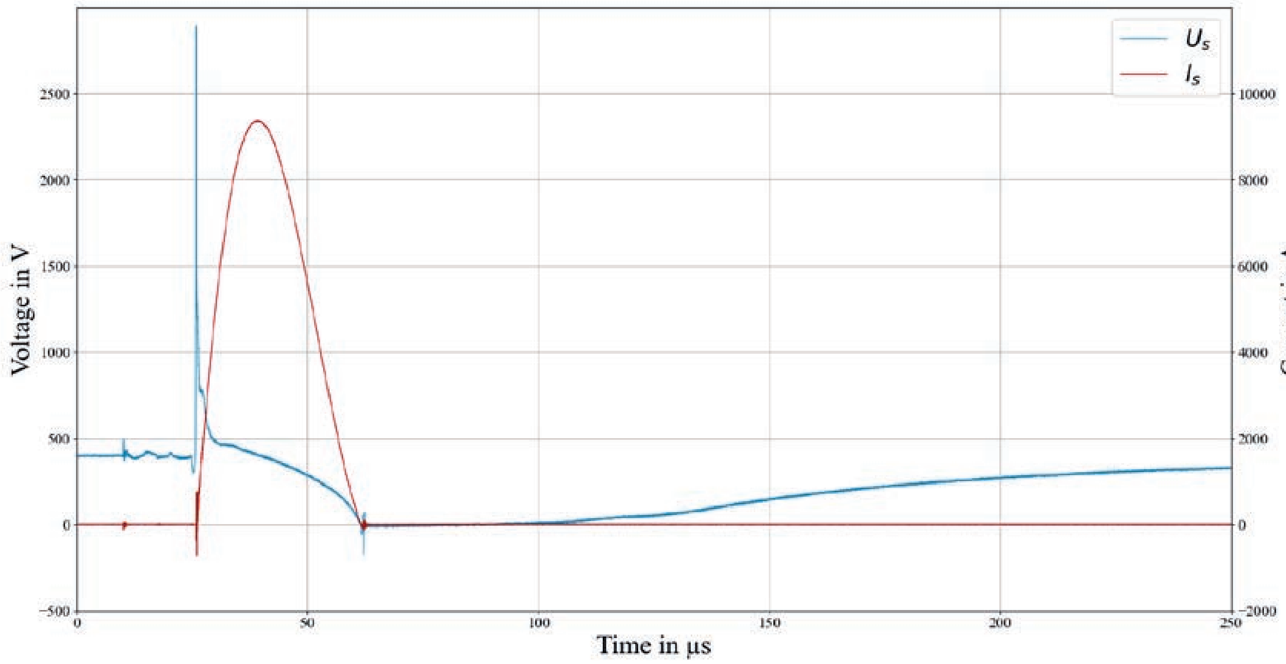

Figure 2: Measurement of the recovery voltage of the model FS with test circuit

Graphics: Enno Peters/TU Braunschweig

loaded with a voltage U_{DC}. The clamp quantities current and voltage as well as internal quantities like the plasma properties plasma pressure are measured.

In addition, a high-speed camera will be used to scan the high-current phase with visual data.

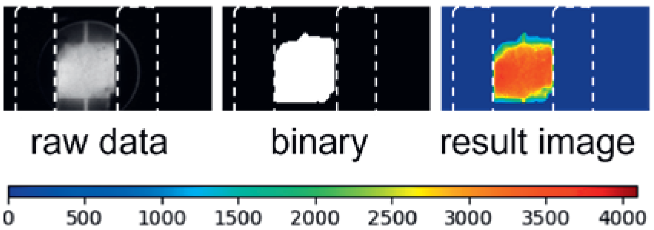

Figure 3: Image processing at the time of the current maximum of a 10 kA pulse

The propagation of the plasma can be evaluated using an image analysis tool.Furthermore, work is being done to obtain a local description from the images in the form of current densities, which provide information about hotspots and thus increased material erosion. These hotspots can influence the temporal behavior after the surge current zero crossing and are therefore the subject of current research.

Evaluation

In principle, the circuit is investigated with regard to conductance behavior under various conditions, such as different voltage loads. The aim is therefore to use the new ignition circuit, which has the following advantage for research purposes. It is time-controllable and works independently of the surge circuit. Thus, a constant and reproducible energy input is generated during ignition, which increases the comparability of the investigations. Furthermore, there is no parallel element next to the spark gap that could influence the de-ionization process under grid load, which allows a focused investigation.

Figure 2 shows the first results with the test circuit for investigating the deionization behavior. It can be seen that the surge current starts to discharge immediately after ignition (voltage peak). After the surge current has decayed, the voltage at the switching path has also returned to zero. The number of charge carriers then decreases, so that the voltage across the gap starts to rise again. During this period, the right-hand mesh in Figure 1 is active.

Outlook

For future studies, it is planned to estimate the interactions of the components in the time domain from the high-current phase beyond zero crossing. This will allow an evaluation of the selected test parameters, such as different surge current amplitudes and geometric changes of the model spark gap.

PROJECT NAME

Arc technology

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Part 2: Computational models for thermal plasmas

Introduction

With a successful research stay at the Laplace Research Laboratory at the University Toulouse III – Paul Sabatier in France, a cooperation in the research field of plasmas is established. During the research stay the theoretical models for the plasma properties are studied and the calculation framework for plasma properties has been developed for different gas mixtures. The plasma properties are calculated for different pressures and for higher temperatures. The plasma properties are one dataset to develop the computational model for a thermal plasma. In figure 1 the plasma laboratory at the Laplace Research lab is shown.

The starting point for the computational model is a general physical description of the plasma. This model type is suitable for a spatial and time-resolved analysis of the plasma behavior. From single particle description the basic modelling equations are developed to a description of the plasma as a liquid. The plasma is considered as a single liquid, where all species in the plasma have the same temperature.

The plasma properties are the input dataset for the basic modelling equations of the plasma. In order to study the physical processes in the plasma, further physical domains are added and coupled in the computational model.

Computational model

Starting with the Lagrangian and Hamiltonian mechanics and using the Liouville theorem, the distribution of the species in a plasma can be derived. The distribution is given by the generalized Boltzmann equation. This is single-particle description with a dependency on seven variables.

From the Boltzmann equation, the magnetohydrodynamics (MHD) equations are derived. A set of equations for the description of the electric and magnetic fields and the description of the plasma as a fluid is used. The set of equations is solved together.

The MHD equations for the plasma are built by the set of conservation equations for the mass, the momentum and the energy. The influences of the electric and magnetic fields are formulated by Maxwell's equations. The set of equation can be coupled. A weak coupling is formulated by the joule heating and the Lorentz force.

The plasma properties, as one input data for the MHD equations, are explained in more detail in the next subsection. The plasma properties can be divided into the thermophysical and the radiative properties

Thermophysical properties

The thermophysical properties of a plasma covers the thermodynamic properties and the transport properties. The properties represent the physical behaviour of the gas forming plasma. Furthermore, the properties are the link from the microscopic to the macroscopic quantities.

The plasma properties are temperature and pressure dependent values in the equations of the computational model. The basis for the calculation is the gas mixture with the composition and the partition functions. The equilibrium composition is calculated by the Mass action law and the chemical base technique.

Both are the dataset for the calculation of the thermophysical properties.

With the concepts of the statistical thermodynamics the thermodynamic properties are calculated by different functions. These functions are the mass density, enthalpy and the specific heat capacity.

The transport properties are calculated by applying the Chapman-Enskog theory. It gives the relevant collision integrals to calculate the binary diffusion, the viscosity, the thermal conductivity and the electrical conductivity of the plasma.

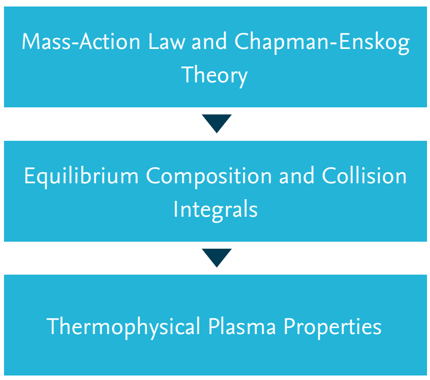

Figure 2: Calculation thermophysical plasma properties

In Figure 2 the steps for the calculation of the thermophysical plasma properties are shown.

The properties are calculated in a wide pressure range (1 bar – 500 bar) and temperature range (300 K – 150.000 K). Figure 3 shows an example of the calculated elec-

Figure 1: In the plasma laboratory of the Laplace Research Laboratory Graphics: Muhamet Alija/TU BS

trical conductivity over temperature and for four different pressures.

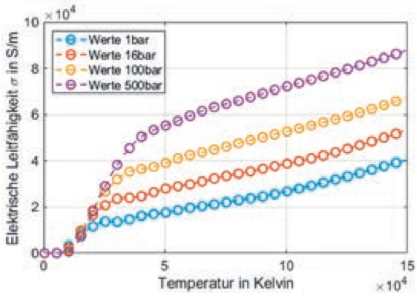

Figure 3: Calculated electrical conductivity [1]

Radiative transport

The calculation of the radiative properties completes the calculation of the plasma properties. A precise calculation of the radiative mechanisms in the plasma is performed. This covers the spectral lines and the continuum of the atoms and molecules, as well as the band systems of the molecules in the gas mixture. With the radiative mechanisms the emission and absorption coefficients can be calculated. The coefficients are the data set for the radiative transport. The coefficients are included in the radiative transfer equation.

The radiative transport is an important part for the energy transfer in the plasma. For a suitable numerical solution of the radiative transfer equation different radiation models are used. This is the net emission coefficient or the PN approximation. Figure 4 shows the net emission coefficient for an air plasma for a different pressure in a wide temperature range is shown.

Additional equations for the radiation are implemented in the computational model and solved together with the MHD equations.

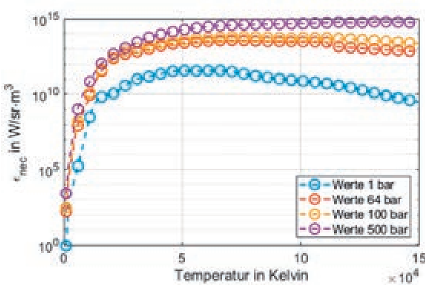

Figure 4: Calculated net emission coefficient [1]

Plasma-electrode interaction

An additional part in the computational model is the plasma electrode interaction. This is formulated by equations for the current and heat transfer. In the electrodes the current and heat conduction processes are considered. For this the properties of the electrodes are needed. The temperature dependent properties of the electrodes include the heat capacity, the electrical conductivity, the thermal conductivity and the radiative properties.

Solution computational model

The theoretical model is developed by the basic equations and properties for the plasma and the electrodes. Considering appropriate simplifications and assumptions, a mathematical model is obtained. The mathematical model is a set of coupled differential equations that is solved for the computational domain. The solution of the equations is carried out by appropriate numerical methods. The steps outlining the development of the computational model are shown in figure 5.

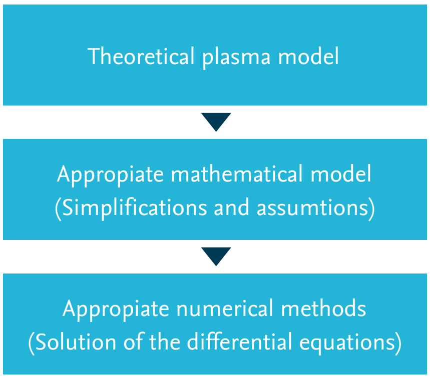

Figure 5: Steps of the development of the computational model

Appropriate numerical methods for the discretization of the differential equations are the finite element method or the finite volume method. With the boundary conditions, a linear system of equations is obtained from the set of differential equations. Further iterative approaches are applied to solve the linear system of equations.

Outlook

The simulation of the processes and interactions in the plasma are the subject of further investigations.

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[1] M. Alija, Y. Cressault, P. Teulet, M. Kurrat, Thermophysical and radiative properties of an air arc plasma for high pressure and temperature, CAE conference Rouen, France, 28.06 – 29.06.2021

Research field plasmas

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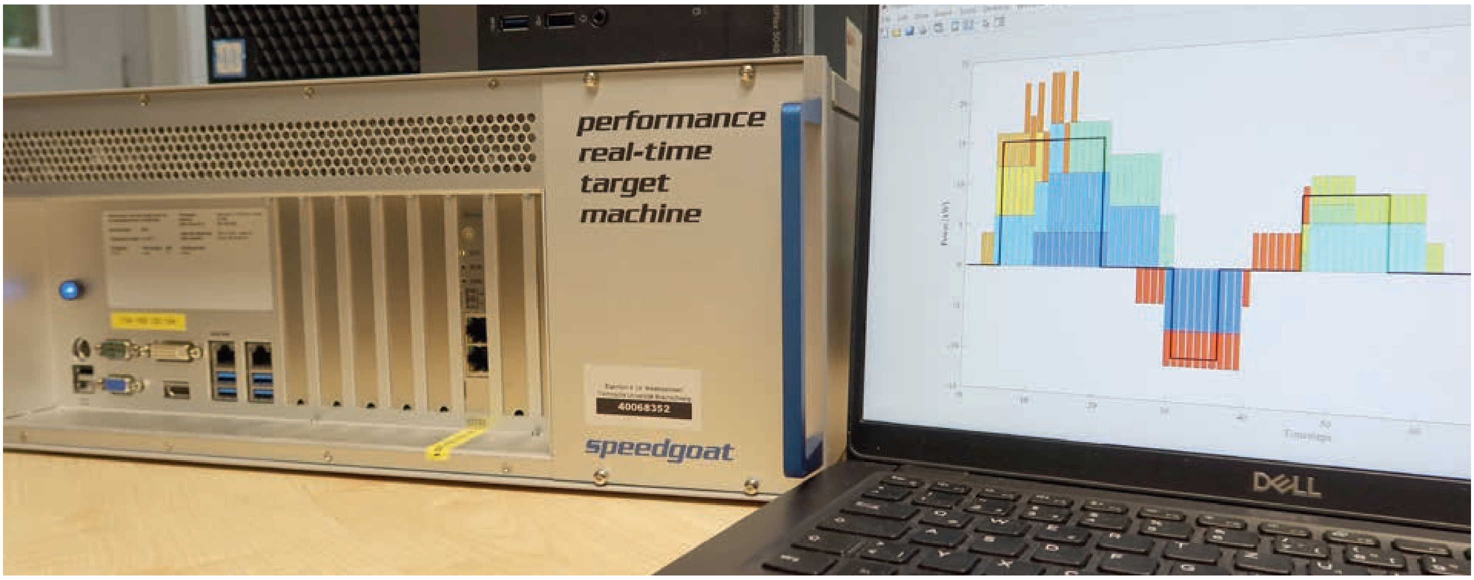


flexess

Development of strategies and solutions to leverage future flexibility potentials

The energy transition and the associated integration of renewable energies into the electricity system entail a significant change in all areas of the energy sector. A crucial factor for the successful transformation of the electricity, heat and mobility systems is the targeted use of flexibility, i.e. the change of input or output in response to an external electricity grid or price signal, at all levels of the energy system.

Flexibility provision across sectors

For the provision of flexibility, the four case studies of full electric residentials, commerce, trade and services, industrial processes and electric mobility are considered, considering regulatory framework conditions and economic incentives. The four subsystems are bundled centrally into an overall system via the components grid operators, aggregators/electricity market participants and electricity markets.

The case study "residentials" include the investigation of flexibility potentials in existing single-family and multi-family houses as well as in new buildings. Thereby, the use of photovoltaic systems, battery storage, electric vehicles and heat pumps in connection with local energy management is conceivable as flexibilities.

In the sector of trade, commerce and services, the flexibility potential of existing climate control systems of supermarkets or other stores is to be investigated in particular.

Due to high energy demands and extensive control options for processes and machines, the industrial sector offers high flexibility potentials. Revenues from self-generation and storage capacity can form additional economic incentives to use flexibility potentials.

The electromobility case study focuses on the potential of flexibility in the context of possible applications for vehicle fleets, e.g. use as flexible energy storage.

Flexibility use as a grid service and market-oriented

In addition to potential providers of flexibility, flexess also looks at potential users of flexibility. In contrast to most related research projects, both the grid-serving use and the sale of flexibilities on the relevant energy markets are investigated.

The use of flexibility as a grid service focuses on the cost-efficient elimination of grid congestion at the distribution grid level. For the sale of flexibility on the energy markets, the potential for aggregate procurement optimisation through flexible modes of operation is identified.

Scope of work

The primary aim of the research project is to develop strategies and solutions for leveraging future flexibility potentials in the introduced case studies.

Therefore, methods, technologies and solutions to leveraging flexibility will be developed for the case studies. This content will be tested at model and laboratory level, as well as in field tests. As part of the field test, the extent to which existing infrastructures (e.g. smart metering systems/smart meter gateways or monitoring portals) can be used to implement a cost-effective system connection must be investigated.

Based on the results, the methods, technologies and solutions developed are evaluated and recommendations for energy policy and the energy industry are derived.

Modelling and simulation

For the simulation, the flexibility providers considered in the different case studies are modelled by the responsible project partners and coupled via the co-simulation platform TISC. The elenia is responsible for the modelling of flexible controllable residential buildings and electric mobility fleets in the simulation environment eSE (elenia Simulation Environment).

Available flexibilities are transmitted by each provider to the central flexibility manager flex-control in form of varying schedules and prices. This manager, modelled in eSE, consists of the following actors: flexibility platform, grid operator, aggregator and energy market. The flexibility manager is designed to be used in all simulation studies, laboratory and field tests.

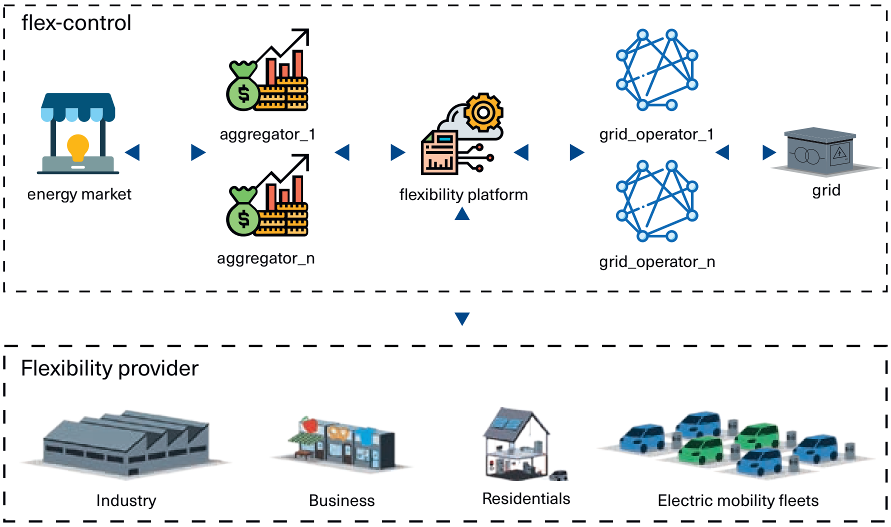
After a defined time sequence, offered flexibilities are provided to a grid operator model, which calculates the use of flexibilities for the elimination of grid congestions in a cost-optimised way. Flexibilities that were not used as a grid service are forwarded to an aggregator via the platform. The aggregator pools the transmitted schedules, for optimal marketing of the flexibility on the electricity markets, considering the applicable market restrictions. Sold flexibilities or flexibilities used for grid congestion management are reported to the providers. These are responsible for the realisation of the schedules with their facilities. The delivery verification and settlement as well as the balancing calculation for the flexibility provision are performed by the platform at the end of the simulation. Finally, a system for investigating flexibility management in energy supply is created.

Flexibility use in laboratory and field tests

In addition to the development and simulative investigation of the flexibility strategies, these contents are tested for the case study “residentials” in the energy management laboratory (EML) of the elenia-energy-lab laboratory association.

The central component for the laboratory tests is the real-time simulation system that was acquired as part of the project. The MATLAB Simulink Real-Time (Simulink RT) development environment is used to implement a modular laboratory control system based on the hardware-in-the-loop (HiL) principle.

The HiL-principle enables the analysis and validation of the developed flexibility strategies by mapping a model residentials using hardware devices (PV system, battery storage system, wallbox, heat pump). Therefore, a multi-layer block diagram is created on the graphical programming level of Simulink RT, which handles the coordinated (bidirectional) communication with the system components.



Model structure of the flexibility manager flex-control

The real-time capable system makes it possible to monitor the performance values and other dynamic system parameters every second. Based on forecasts for load and generation capacity as well as presence and utilisation profiles, the time series are used to create schedules for the provision of flexibility from the devices. After transmitting the alternative schedules to the flexibility platform flex-control, the schedule selected by the flexibility users is returned to the energy management system. The real-time laboratory control system converts the chosen schedule into active power requirements for the devices. Real-time operation in a closed loop makes it possible to investigate and optimise the effects of real device behaviour on the provision and retrieval of flexibility.

In addition to the laboratory experiments in the EML, the developed methods are used in another laboratory experiment in the learning factory of the IWF. There, industrial plants are emulated, flexibilised and linked to the flexibility manager. An identical procedure is used in the field tests with REWE and the Berliner Verkehrsbetriebe.

PROJECT NAME

flexess

PROJECT RUNTIME

December 2019 – December 2022

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IWF, SMA, Carano, BVG, TLK, BS|NETZ, BS|ENERGY, REWE, GEWI, TransnetBW

WEBSITE

www.tu-braunschweig.de/elenia/forschung/flexess

SUPPORTED BY

Bundesministerium für Wirtschaft und Energie
aufgrund eines Beschlusses des Deutschen Bundestages

Innovative Prosumer Households

Development and implementation of operating strategies for prosumers in the application field of stationary 2nd-life storage

In an energy system with intermittent 100 % energy feed-in from renewable energies, generation systems installed at household level, supported by storage concepts such as (2nd-life) battery storage, play a decisive role from a grid perspective. The technical components (see Figure 1) can be used, for example, to limit the exchange power at the grid connection point even with high connected loads of electromobility (20 kW and more), thus avoiding or delaying grid expansion. On the other hand, prosumers can support the grid by providing grid ancillary services. The prerequisite is the coordination of power flows both in-house (between generation plants and connected loads) and in the direction of the grid by means of intelligent and networked control and energy management systems (EMS).

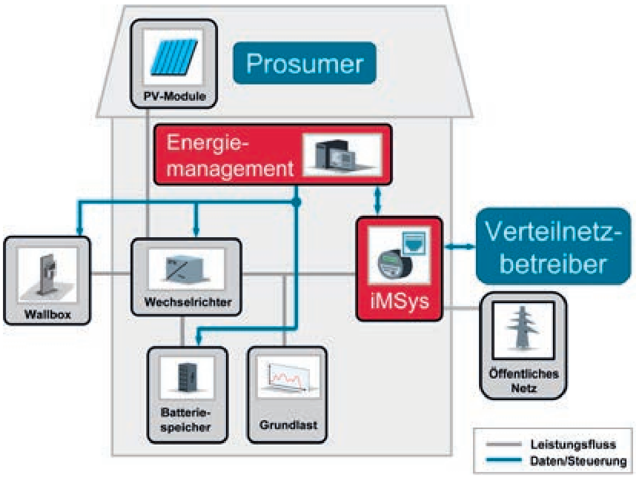

Figure 1: Components of the considered NetProsum2030 prosumer household

Operating strategy to take dynamic electricity rates into account

At the beginning of the project, annual simulations based on data analyses and user profiles were used to determine the most economical dimensioning for the PV system and the battery storage system from the prosumer's point of view based on the net present value calculation. Taking into account the assumed user profile of the electric car, the size of the PV generator was 9.9 kWp and the capacity of the battery storage was 12.5 kWh. The determined capac-

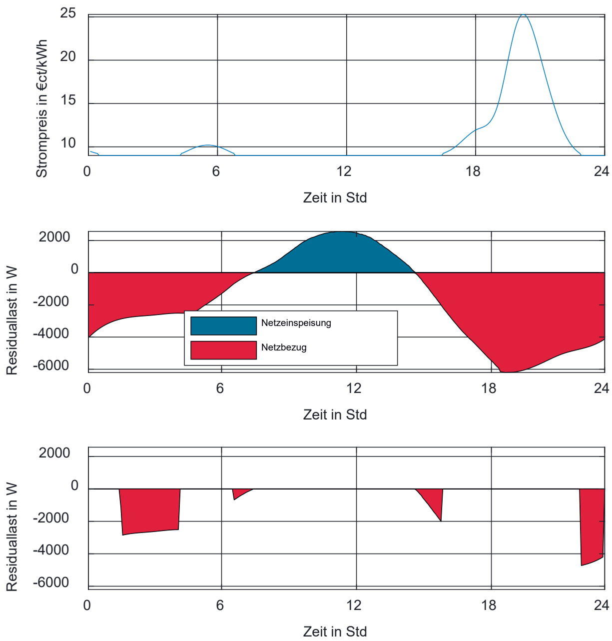

Figure 2: Residual load optimized by the EMS taking into account dynamic electricity prices

ity as well as an active power of 20 kW to be used bidirectionally was taken into account as a lower limit for the implementation of the 2nd-life storage system.

Based on this, operating strategies for the EMS were designed and implemented. An advanced variant for the consideration of time-variable electricity prices is shown on figure 2. The upper diagram shows the (dynamic) electricity price varying throughout the day. The energy management system solves an optimization problem based on a generation and load forecast to determine the cost-optimal operation mode for the battery storage. The result is the avoidance of grid consumption in times of high electricity prices (cf. middle and bottom plot). The prosumer can thus contribute to a grid-supporting mode of operation.

Stationary 2nd-life storage

The energy storage system consists of 23 automotive battery modules, each with a nominal capacity of 111 Ah and a nominal energy capacity of 1.6 kWh. The cells in the modules are connected in a 4s3p circuit, resulting in a rated voltage of 14.8 V. Due to the serial connection, the system voltage of the storage unit is 340 V and the nominal energy capacity is 36.8 kWh.

Through further use, the economic value of the batteries can be increased compared to direct recycling. In order to use batteries of the same age as far as possible, the battery modules must be characterized before use. For this purpose, a battery condition evaluation method was developed, which includes the current interrupt (CI) method, electrochemical impedance spectroscopy (EIS) and capacity analysis. Sensitivity analysis has shown that heavily aged modules are reliably detected by all methods. Finer differences can be detected by EIS, but this analysis method requires cost-intensive measurement equipment and a precise measurement setup. For this reason, the CI method was integrated into the developed central battery management system (BMS). The CI method characterizes the battery modules on the basis of the voltage change caused by current pulses. The determined internal resistance (Fig. 3) is dependent on aging. Using relays, the modules can be connected in parallel to a resistor so that a discharge current pulse can be used for characterization.

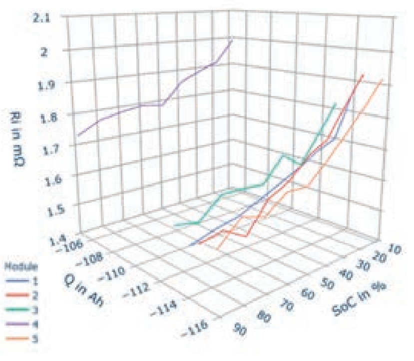

Figure 3: Internal resistances after 500 ms (CI-Method)

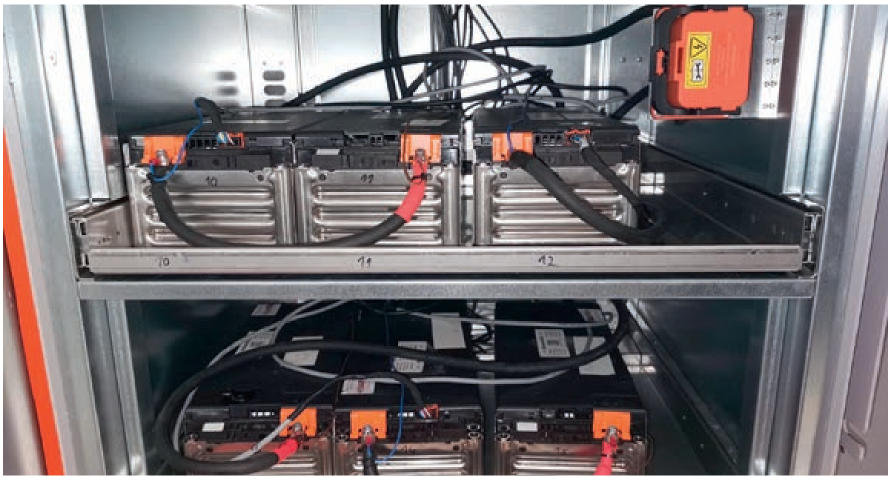

Figure 4: Placement of the battery modules in the safety cabinets

Alternatively, the entire system can be stressed with a current pulse. In this case, all serially connected modules are stressed with the same current.

The BMS is based on a PXI system from National Instruments, which monitors the module voltages, module temperatures and currents.

The Manual Service Disconnect (MSD) connector (Figure 4, top right) is used to safely disconnect the battery system so that modification work can be performed. An insulation monitoring device monitors the insulation from the housing so that in the event of a fault the BMS can switch off the battery storage system.

By using battery modules of the same age, the service life and safety of the 2nd-life storage system can be increased. In further operation, aging data can be obtained through the characterization function, so that in the future a forecast of the aging process of the battery type will be possible in a data-controlled manner. In the BMS, other cell chemistries and open-circuit voltage curves can be stored for further investigations (other battery types), so that an aging forecast can be made for specific usage profiles.

PROJECT NAME

NetProsum2030

PROJECT RUNTIME

September 2017 – August 2021

PROJECT LOGO

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Bundesministerium für Wirtschaft und Energie

aufgrund eines Beschlusses des Deutschen Bundestages

Community Helleheide on the former airbase in Oldenburg, Source: GSG Oldenburg, City of Oldenburg

Digitalized Energy Systems

Understanding interaction dynamics in energy communities and developing a collaborative R&D platform

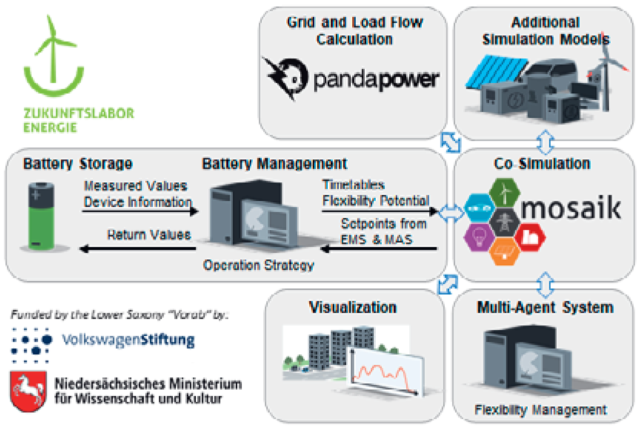
Digitalization is a global megatrend that enables new functions and processes across industries and networks. Digitized energy systems offer the opportunity to make an important contribution to the successful design of the energy transition by making operation more efficient and sustainable. In the safety-critical energy system digitization is simultaneously creating new interactions and sensitive dependencies. For the systemic investigation of the functionally coupled and networked domains and technologies in the digitalized energy systems with regard to their interactions, it must also be possible to network energy system research more efficiently, to better integrate the necessary specialist disciplines and to transfer research results more easily into practice. Based on these problems, the *Zukunftsabor Energie* (ZLE) formulates two central research goals: the research and development of digitalized energy systems and the digitalization of energy system research and development. The ZLE is supported by the *Zentrum für Digitale Innovationen Niedersachsen (ZDIN).*

Research and development of digitalized energy system

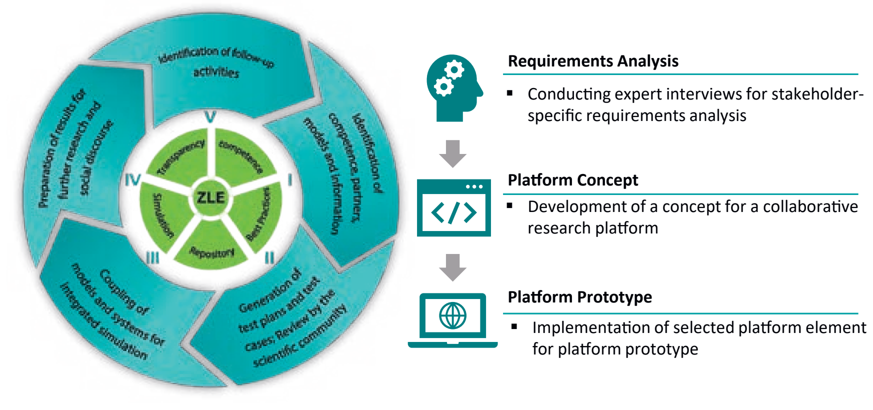
The central research question of the first project pillar of the ZLE is the identification and modeling of digitalized energy systems for energy communities with a focus on possible interactions between the energy and information systems. The technical challenges associated with the interactions and the implications for stability remain largely unexplored on a systemic and large scale. Three communities were selected as exemplary study areas and as basic for modeling the communities' energy system (CES): "Ölper" Berge in Braunschweig, "Rüsdorfer Kamp" in Heide, part of the Quarree100 research project and the "Energetische Nachbarschaftsquartier – ENaQ" on the site of the former air base in Oldenburg. Multiple energy supply scenarios were developed for the energy communities, based on the current design of the CES and necessary future adjustments in terms of meeting the set greenhouse gas emissions targets.

Modeling of the communities' energy system

Based on the identified scenarios for the local energy communities' energy systems, requirements specifications for CES modeling were developed. In a CES, a large number of different components must be modeled and linked together for simulation. In future CES in the sense of smart microgrids even require a target-oriented coordination and control of the individual plants, which again increases the modeling effort. Due to the large number of models required and the interdisciplinary way of working in ZLE with seven different research partners, a co-simulation approach based on the mosaik framework was chosen (see figure). Co-simulations enable complex,



ZLE's approach of the co-simulation-based modeling of communities' energy systems in ZLE



Platform elements and approach for the development of a collaborative research platform in ZLE

interdisciplinary simulations by coupling of different simulation tools and models. The co-simulation framework supports most common programming languages. Another advantage of the co-simulation approach is the possibility to reuse existing, heterogeneous models and create a simulation scenario out of them. Therefore, ZLE e.g. decided to use pandapower for the load flow calculation of the electric power system.

Digitalization of energy system research and energy system development

In order to realize the second project objective – the digitalization of energy system research and development and thus to strengthen digital energy research in Lower Saxony – a research and development platform (R&D platform) is to be conceptualized and implemented in a basic version at ZLE. The aim of the platform is to support cooperative joint projects in the application field of digitized energy systems on the basis of modern information technology methods and technologies, in order to make a significant contribution to the sustainable safeguarding of results, transfer, connectivity of the future laboratory and transparency for a dialog with society.

The R&D platform which to be developed will integrate at least the following five platform elements: Competence, Best Practices, Repository, Simulation and Transparency (see figure). Within the ZLE competence element, an R&D competence network with, e.g. specific technical competences and test laboratories will be presented. The ZLE repository will provide harmonized data, simulation models and scenarios in compliance with Deutsche Forschungsgemeinschaft (DFG) requirements. ZLE best practices will include providing standards for cooperative experimental designs and scenario techniques. In perspective, the ZLE simulation is to represent an online-capable co-simulation platform. As part of ZLE transparency, an area will be created on the R&D platform for publishing, processing and presenting R&D results. For the start of the development of the R&D platform, a user-specific requirements analysis of various stakeholders is carried out on the basis of expert interviews. Stakeholder groups interviewed include energy researchers, ICT companies, grid operators, research networks and electricians. Valuable insights and desired characteristics can be generated for the R&D platform, by analyzing the interview transcripts. These are the basis for the platform concept to be developed, from which an online accessible prototype of the collaborative R&D platform of the ZLE will emerge in the further course of the project.

Open Science Declaration of the Zukunftslabors Energie

The ZLE has developed an Open Science Declaration and will sign it together with all research partners in the near future.

Thus, the ZLE is committed to transparent science and accordingly aligns its scientific activities with Open Science Standards. The knowledge gained from energy research during the course of the project is to be made freely accessible to everyone. At the same time, this creates opportunities for collaboration and networking between science, business and society and enhances the quality of research.

In this sense, all program code developed within the scope of the first project objective of the ZLE, as well as all data collected and simulation models set up, are freely accessible and can be retrieved via the R&D platform element ZLE repository.

PROJECT NAME

Zukunftslabor Energie

PROJECT RUNTIME

October 2019 – September 2024

PROJECT LOGO

ZDIN Zentrum für digitale Innovationen Niedersachsen ZUKUNFTSLABOR ENERGIE

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Grid-Serving Prosumer

Ancillary services provided by components of modern households in the low voltage grid

The elimination of large generation units such as nuclear or coal-fired power plants has a significant impact on the provision of grid-serving functions. While the large generators of these power plants were responsible for the provision of ancillary services (AS) in the last decades, this task will in the future be assigned to the increasing number of inverter-based components in the distribution grid, such as photovoltaic systems. The research project *SiNED – Ancillary Services for Reliable Power Grids in Times of Progressive German Energiewende and Digital Transformation* is focusing on the further development of existing ancillary services in future power grids. In particular, the opportunities based on the advancing energy transition and increasing digitalization and the resulting changes in requirements are being taken into account.

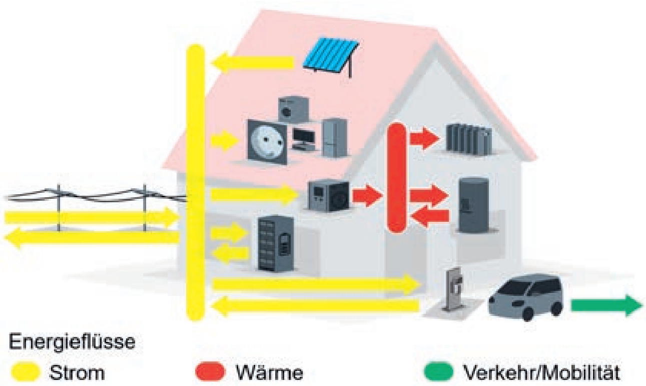
Transformation of households in low-voltage grids

For decades, low-voltage grids were characterized by rigid consumption of households that could not be influenced. Since the beginning of the millennium, however, this has changed – initially slowly and increasingly in recent years. PV systems enable households to reduce their consumption from the grid and, in rising numbers, produce enough power to feed into the low-voltage grid. Other modern household components include battery storage systems (BSS), heat pumps (HP), and electric vehicles (EV) because they provide significant flexibility to the energy system. EVs, for example, are parked on private property in the evening and should be fully recharged the next morning after about ten to twelve hours of parking. However, it does not matter whether they are charged immediately after parking or just before starting the next trip.

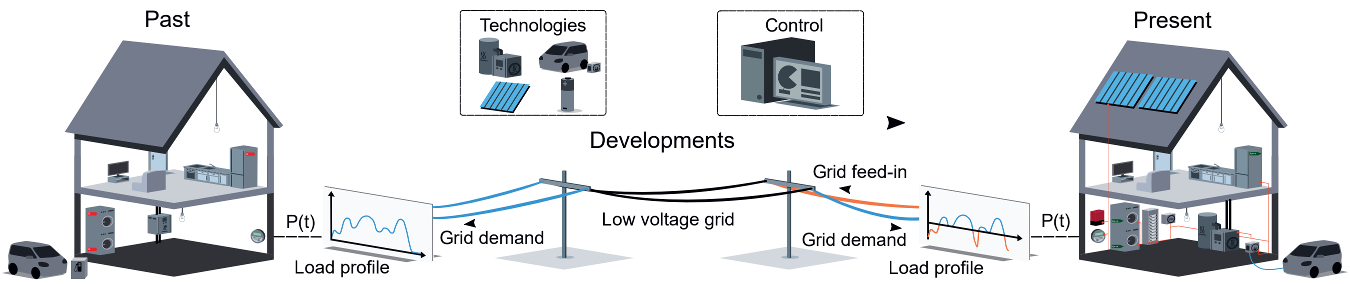
The modern prosumer components mentioned are capable of performing a grid-serving function in addition to providing their primary task, which in the case of domestic BSSs is, for example, the intermediate storage of PV energy in order to maximize self-consumption. Identified ancillary services that could potentially be provided are voltage control, local congestion management, frequency control and momentary reserve. Thus, voltage control via reactive power supply in the converters of the modern components could be more advantageous than conventional grid expansion or the equipment of local substations with controllable transformers. In the case of thermal overload of network resources, the control of flexible loads such as HP or EV is suitable, since a high simultaneity of these is often responsible for the grid congestions. For frequency control, inverter-controlled components are suitable, as they can be controlled more precisely and are significantly faster than conventional large-scale power plants.

Challenges of ancillary service provision by prosumers

Despite the great potential offered by modern household compo-nents at the low-voltage level, there are some regulatory issues



Power flows of various energy sectors in modern prosumer households



Transformation of households at the low-voltage level from consumers with rigid load profiles (on the left hand-side) to modern prosumers with efficient and flexible components (on the right hand-side). Graphic: Christian Reinhold/TU Braunschweig

to be addressed and technical hurdles to be overcome initially. First, domestic BSSs are intended for temporary storage of PV power generated on-site; multi-use risks loss of EEG subsidy and further apportionment difficulties. Furthermore, the use of the converters in the modern components, e.g. for voltage control, could lead to additional losses by providing reactive power. This could jeopardize the economic viability of the plants. Another problem is the lack of information and communication infrastructure in German low-voltage grids, which means that equipment can neither be observed nor controlled. Furthermore, minimum power requirements for products such as control power make it necessary to combine several plants into virtual power plants.

Goals oft he project
Within the project, the potentials for the provision of AS by prosumer components are analyzed first. Furthermore, the contribution of the trade, commerce and services (T&C) sector is discussed. This is followed by an estimation of the penetration of prosumer components for the years 2020 and 2030. Subsequently, it is analyzed to what extent the mentioned components can contribute to local (voltage control, congestion management) and global AS (frequency control, momentary reserve). One focus is the comparison of voltage control by prosumer components via reactive power supply with alternative voltage control concepts. Finally, the influence of AS provision by prosumers on low-voltage grids and the integration potential of modern components will be investigated.

Modeling the provision of ancillary service by prosumers and its components
A concept that is to be developed for the provision of AS by modern prosumer components will be successively integrated into the existing simulation environment eSE – elenia Simulation Environment. eSE was already developed in the predecessor project *NEDS – Sustainable Energy Supply Lower Saxony* and will be extended by a model for the coordinated control of the provision of AS. As part of this, various voltage control concepts as well as components such as controllable local network transformers, string controllers and shunting vehicles to represent the GHD sector will be added.

PROJECT NAME

SiNED

PROJECT RUNTIME

November 2019 – October 2022

PROJECT LOGO

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Electric Field Cultivation

Overall concept and modelling of agricultural systems with regenerative energy supply

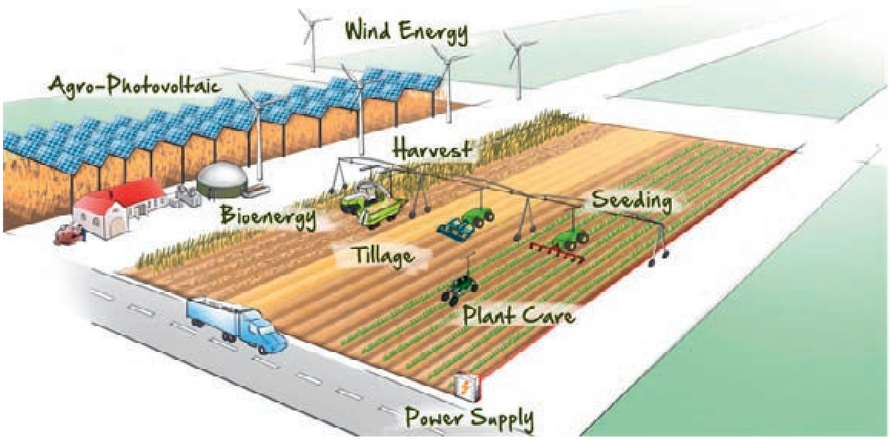
Both energy generation and the supply of energy to customers are facing major challenges as a result of the implementation of climate policy goals. Power fluctuations during generation, e.g. from weather-dependent wind or solar energy, as well as in energy demand (electromobility in individual and freight transport) require new holistic concepts for their calculation. In this context, the use of so-called "smart grids" is being promoted as the basis for efficient and reliable system operation. Due to a future changeover to an electrical supply for the energy-intensive field cultivation, agriculture is a significant factor influencing this system. A conversion of agriculture to electrical energy will have far-reaching consequences for the design of technology and processes as well as for people and the environment. Infrastructure, jobs in agriculture as well as the structure of agricultural land will have to be rethought. At the same time, this change opens up completely new opportunities for sustainable and environmentally friendly agriculture. In the process, individual and equally social aspects in the energy, agricultural and ecological sectors must be considered.

The research project Energy-4-Agri
The research project Energy-4-Agri deals with the investigation and modelling of overall concepts for agricultural systems with regenerative energy supply in the framework of the energy transition in Germany. Together with the Institute of Mobile Machines and Commercial Vehicles (IMN), Institute of Geoecology (IGÖ), the division of Industrial/Organizational and Social Psychology (AOS) at the Institute of Psychology of the Technische Universität Braunschweig and the Institute of Design Research (IDF) of the Hochschule für Bildende Künste Braunschweig, a holistic conception and multi-criteria evaluation of the energy supply for sustainable agricultural systems as a contribution to the decarbonization of agricultural production is carried out.

Based on a detailed analysis of the energy demand in field cultivation and animal husbandry in the context of field measurement campaigns on reference farms in Lower Saxony, the prerequisites for the electrification of the corresponding agricultural production systems are investigated. Future scenarios describe the expected developments of the next decades. Alternative structural and technological concepts as well as their effects are considered in a merged modelling approach. The extensive changes in the energy sector in agriculture, caused by the new energy supply concepts, are evaluated with regard to the technical-economic feasibility and especially with regard to the social acceptance and ecological impact.

First results
As part of a preliminary investigation by the elenia Institute, two concepts of all-electric agricultural machines were modelled and simulated in an exemplary process chain in field cultivation.

Based on today's large-scale technology, a fully electric agricultural machine can already be built by replacing the combustion engine and tanks with an electric motor and battery system. The battery-powered agricultural machine draws its energy from a battery system that is integrated into the agricultural machine or can be replaced as a counterweight (front or rear). The batteries are recharged at a charging station. The advantage of the battery-powered agricultural machine lies in its unrestricted mobility and the possibility of bidirectional charging of the battery storage. Furthermore, the battery integration in the exchangeable counterweight can help to separate the possible operating times of the agricultural machine from the charging times.



Conceptual image of electric field management with regenerative energy supply
Illustration: Johanna Frerichs/TU Braunschweig

The second machine concept considered was the cable-connected agricultural machine, which is permanently supplied with energy via a cable and does not have its own energy storage. The advantages of this concept are higher theoretical engine power than battery-powered agricultural machines, but mobility is limited due to the cable, which is why cable-connected agricultural machines are not suitable for all processes in agricultural operations.

For an exemplary process chain, consisting of soil cultivation and harvesting, carried out by cable-connected agricultural machinery, as well as the processes of sowing, fertilisation, application of crop protection and harvest transport, carried out by battery-powered agricultural machinery, initial simulations were carried out and the impact of different charging strategies and compositions of renewable energies on the distribution grid was investigated.

The simulations have shown that the integration of all-electric agricultural machinery into the grid leads to voltage band violations and overloads in low-voltage grids. Grid optimisation or reinforcement is required for the times when cable-connected agricultural machinery is in use or battery-powered agricultural machinery is recharged after the sowing and harvest transport processes. However, these times of use are limited to a few weeks a year in the context of the investigated process chain, which is why a grid expansion or reinforcement must be critically questioned, especially from an economic point of view.

In contrast, grid integration in the distribution grid under consideration was unproblematic at the medium-voltage level. Farms with a medium-voltage connection therefore have an advantage, as the grid integration of fully electric agricultural machinery in the context of the investigated process chain does not require any grid-side measures. In the event of full electrification of the machinery, a grid connection at the medium-voltage level could also become necessary for farms with a previous low-voltage connection. The higher reference and feed-in power at medium-voltage level can also promote the expansion of renewable energies on farms.

PROJECT NAME

Energy-4-Agri

PROJECT RUNTIME

December 2019 – December 2022

PROJECT LOGO

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Landwirtschaftskammer Niedersachsen

Landwirtschaftsbetriebe in Niedersachsen

WEBSITE

www.tu-braunschweig.de/energy-4-agri

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aufgrund eines Beschlusses des Deutschen Bundestages

Photo: Marcel Lüdecke/TU Braunschweig

Green Power for Tenants

Integration of storage systems in apartment buildings to provide access to green, locally generated electricity

With the increasing penetration of the energy system by fluctuating renewable energies and electromobility, storage systems for grid stabilisation and local grid relief are becoming increasingly important. The current increase in the number of PV storage systems installed in single-family homes owned by the owners is an important first step in the development of stationary storage systems. According to the Federal Statistical Office, however, more than half of all German households are in multi-family houses, almost three quarters of them renting. However, tenants and flat owners, hereinafter referred to as flat users, have so far lacked a sensible option for installing and using storage systems. The installation and operation of individual micro-storage units per residential unit in the flats or in the basement is ruled out for cost reasons and usually due to technical and spatial restrictions. In contrast, the joint use of a larger storage systems for several flat users would be considerably simpler and more cost-effective. At the same time, storage capacities could be utilised much more efficiently: Balancing effects in the consumption profiles of several users reduce the simultaneity of load peaks and troughs.

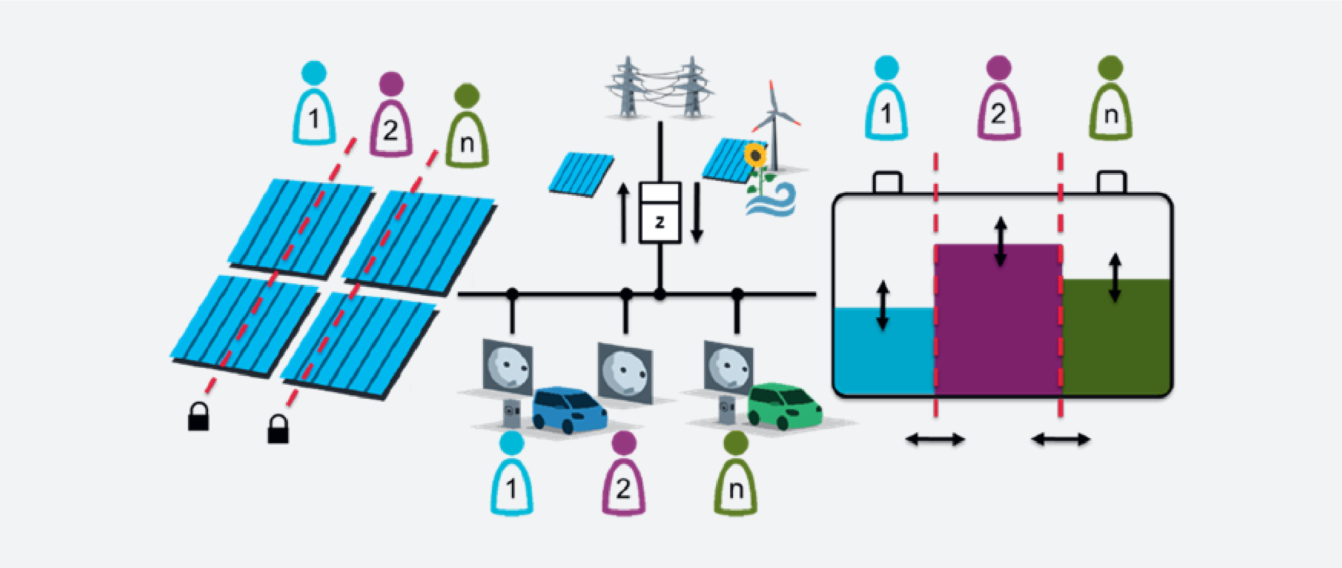
Obstacles to multiple use within a building

However, a virtual division of storage facilities into "storage slices" and thus a multiple use of storage facilities by several residential users and market partners is ruled out today for regulatory and calibration law reasons. The billing of delivered and intermediately stored electricity quantities requires measurement technology and process chains that are approved under calibration law. Today, these only exist for the billing of such electricity quantities on the basis of separate physical measurement, e.g. for each residential unit. If a storage facility is to be used several times and there is also only one physical measurement, the measured values must be broken down into several billing values for different electricity qualities, converted and made available to the relevant market partners. These include the local electricity grid operator, the electricity supplier who provides the locally generated electricity, the stored electricity as well as residual electricity quantities from the public grid for the residential parties – and possibly also other electricity suppliers, after all, the residential parties must still be able to choose their energy supplier freely.

Key elements of the project

The main technical innovations in the project are the development and validation of metering and billing solutions as well as associated energy management functions, ICT solutions and data services in multi-family houses. The experience gained from the previous project PV Storage Meter, in which measurement technology and billing concepts for multiple simultaneously used PV storage systems were developed and tested, will be combined with existing tenant electricity models. The main task of elenia is the development of a data and control platform which, in addition to the networking of all components, is used to offer users the possibility of interaction. To this end, the flat users are made aware of their consumption behaviour through visualisation. In addition, the management of their virtual system shares is made possible, which can provide incentives for a change in consumption behaviour.

From an economic point of view, intelligent processes and operating methods make a positive contribution to the energy, mobility and heating transition, especially in the residential sector. The use of new types of energy management solutions in combination with modern storage technologies creates a high potential for increasing the absorption capacity of the distribution networks in urban areas with regard to additional generation and consumer power. This can



Virtual allocation of the facilities to the tenants

potentially reduce the grid expansion costs of the distribution grids. In addition, the use of a regulation-compliant concept for the multiple use of PV storage systems also provides benefits for building owners and flat users. The building owners benefit from the potential of reducing the maximum power demand from the upstream grid in regular operation, the increase in value of the property portfolio and the apartment users can reduce their costs and make an active contribution to the energy transition by directly influencing the use of the different power qualities (PV, storage, upstream grid) and thus reducing the CO_2 emissions of their user unit.

Current work

A battery storage system consisting of a Tesvolt HV 70 battery storage unit and an STPS60 battery inverter from SMA is currently being measured in the energy management laboratory at elenia. Static and dynamic control deviations as well as losses of the system are recorded. A fair distribution of losses to the different users is later possible via modelling, without having to use non-transparent distribution keys.

Furthermore, in cooperation with the PTB, a measurement procedure and the corresponding calculation rules are being developed that will allow the necessary billing values to be collected as cost-effectively as possible.

From prototype to mass product

The aim of this project is to open up multi-storey residential buildings for storage use in combination with renewable energy generation and new consumers from the mobility and heat sector coupling and thus to provide a large part of the population with economically attractive access to locally generated, innovatively managed and affordable PV and CHP electricity and to electric mobility. For this reason, in addition to simulations to test the developed operating algorithms and laboratory tests on the demonstrator setup, field tests are planned for validation. After successful validation of the economic viability of the MELANI operating mode, a rollout to as many apartment buildings as possible is planned in order to tap into untapped potential with regard to energy management, the expansion of renewable energies and the associated CO_2 savings.

PROJECT NAME

MELANI

PROJECT RUNTIME

November 2020 – October 2023

PROJECT LOGO

melani

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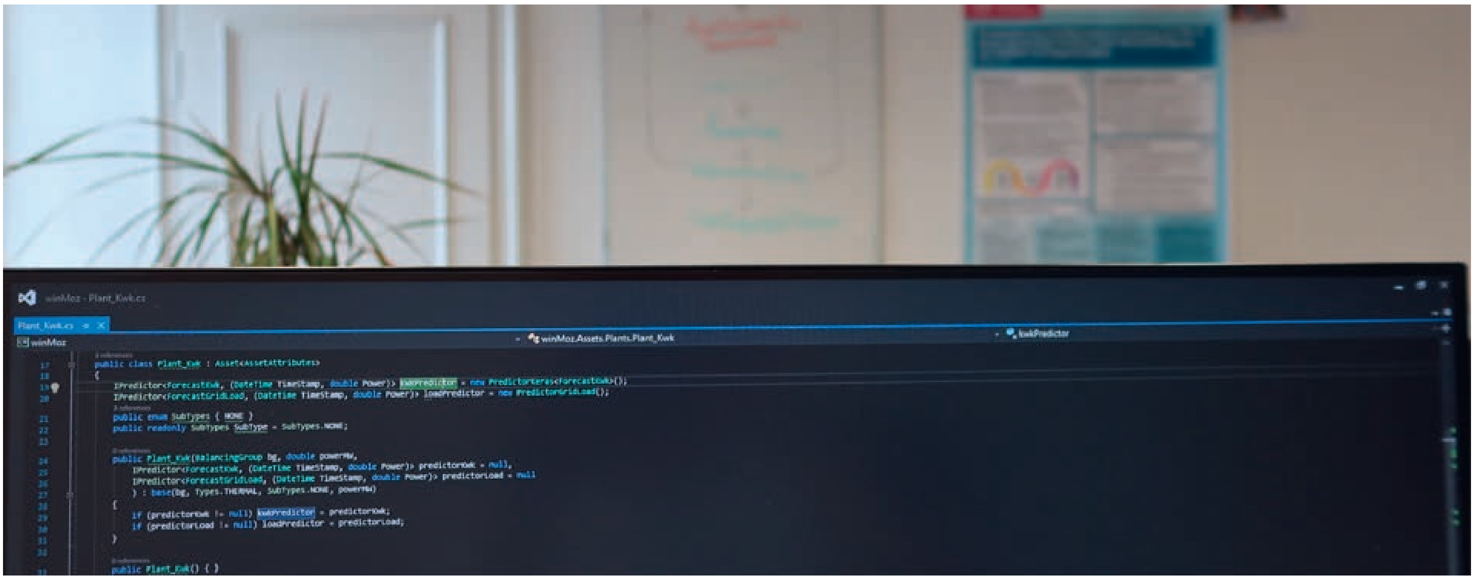


Photo: Mattias Hadlak/TU Braunschweig

MozuBi

Agent-based modelling of future balancing group management using artificial intelligence

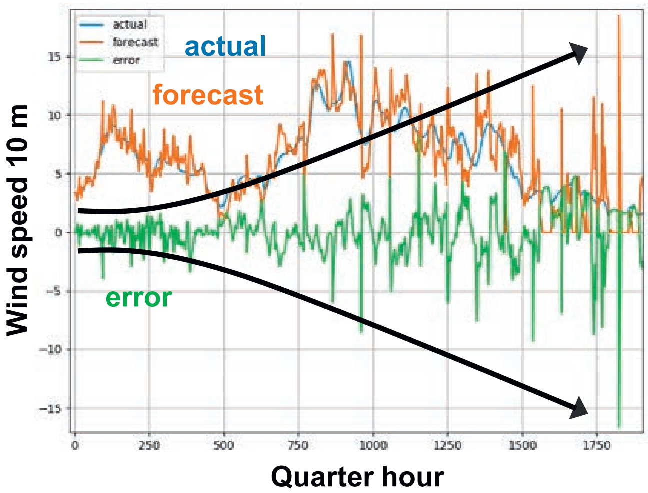
A balancing group forms the link between the physical world of energy flow in the electricity grids and the virtual world of energy trading. In this context, balancing group management is a key instrument for minimising deviations between generation and consumption. Thus, balanced balancing groups form the basis for a stable electricity grid.

The steadily increasing complexity due to the growing penetration of supply-dependent energy producers and the integration of flexibly controllable loads presents new challenges for balancing group management. The Institute for High Voltage Technology and Electrical Power Systems (elenia) and the Institute for Future Energy and Material Flow Systems (IZES gGmbH) are therefore working on a joint research project "MozuBi – "Modellierung der zukünftigen Bilanzkreisbewirtschaftung (Modelling Future Balancing Group Management)". The aim of the research project is to comprehensively model changes in balancing group system regarding different incentive structures for an accurate balancing group management. Then, the modelling results are evaluated and repercussions on the energy (sub)markets are analysed.

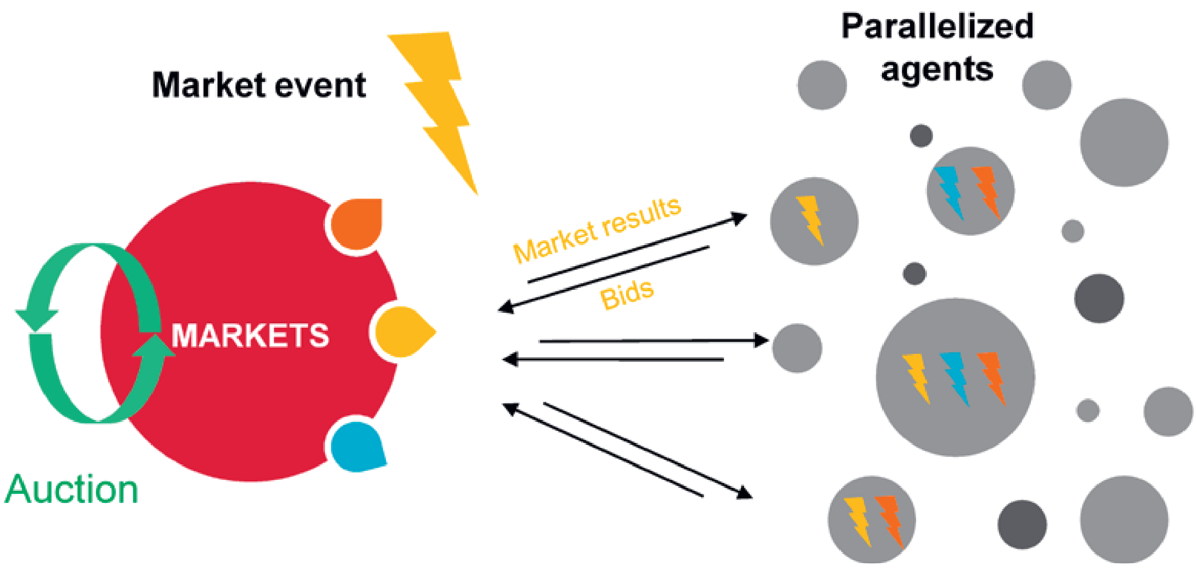
So far, the fundamental barriers, interdependencies and conflicts of interest in balancing group management have mostly been dealt with in isolated issues. In this project we pursue an overall systemic perspective in order to develop holistic approaches for optimising the system transformation. Therefore, the process chains of the individual actors (power plant operators, direct marketers, etc.) are first simulated in an agent-based approach in order to comprehensively analyse the interrelationships and feedbacks in the balancing group system as well as the system boundaries, considering various development scenarios. The focus is on the identification of parameters and starting points in today's balancing group management with the intention of stimulating a more precise management by the players.

Agent-based modelling of the energy system

The model is developed in C# with the aim of producing an open source code. For this purpose, only freely accessible libraries from the .NET environment are used. In addition, an object-oriented approach has been chosen to ensure the maintainability and traceability of the code. A rough distinction is made between markets and agents (balancing groups, producers, consumers and grid operators). Different types of generation, such as thermal power plants, wind power plants, photovoltaic plants or storage facilities can be created in the model. Plants with low outputs are aggregated into larger total plants depending on geographical areas. Each plant



Simulated wind forecast



Schematic flow of a market sequence within the simulation Graphic: Henrik Herr/TU Braunschweig

and each consumer are then assigned to a balancing group, which is allocated to the transmission or distribution grid operators.

The agents interact with the markets by placing bids to buy or sell electricity on the respective market. The whole process is controlled by a central simulator that counts step by step every 15 minutes and triggers the market auctions (market event) at given times. Once an auction event is triggered, all agents calculate their schedules in parallel and submit bids for the corresponding markets. The markets calculate the prices based on the offered bids and report to the agents which bids have been contracted, which leads to another schedule adjustment. Each agent can be assigned different trading strategies depending on the assets being marketed.

Forecasting
An essential aspect of schedule creation are forecasts for the respective agents. These forecasts concern various time series such as load, generation or expected market prices. They are generated using statistical and machine-learning approaches, which is also an essential aspect of the project.

The input data for each simulation can be stored in the simulation databases. Similarly, simulation results, such as balancing group deviations or market results, can be stored temporarily for further use in various analyses.

Publication of project results
Within this year, we will discuss our main model approaches with our strategic partners from the fields of TSOs, DSOs, utilities, EEX and the BNetzA and publish them at various conferences.

Once the model development is complete, we will calculate various energy industry scenarios. The influence of previously identified system parameters and framework conditions on balancing will be analysed in order to derive recommendations for action to increase the accuracy of balancing group management, if necessary.

Due to the modular open-source approach, the model can be used and modularly extended by any user after completion and publication. Thus, even after completion of the research project, it can contribute to answering many individual questions of different users in the field of balancing group management.

PROJECT NAME

MozuBi

PROJECT RUNTIME

January 2018 – December 2021

PROJECT LOGO

mozubi

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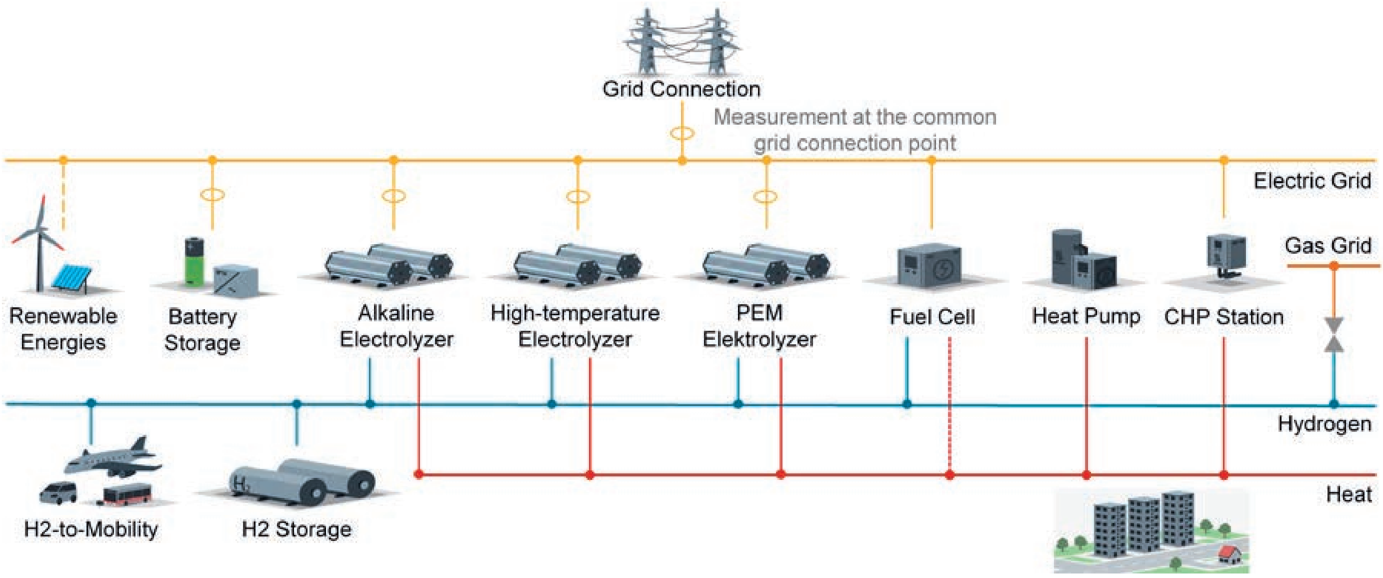

Graphic: Henrik Wagner/TU Braunschweig

Hydrogen Competence Center

Establishing a hydrogen competence center on the campus of Technische Universität Braunschweig

The greatest challenge of the German energy turnaround remains the transport and storage of renewable energies. One solution is emerging in connection with hydrogen technology. Surplus regenerative energy can be converted into hydrogen by power to gas technologies and thus made storable. This energy can be made available again using fuel cells. The joint project H2_Campus_TUBS, led by the Steinbeis-Innovationszentrum energie+, aims to establish a hydrogen competence center (HCC) at the TU Braunschweig campus.

The elenia coordinates the sub-project of holistic modeling, simulation and experimental analysis of along the hydrogen conversion chain in the HCC. The aim is to bundle the expertise available in the various faculties and institutes of the TU Braunschweig in the field of hydrogen production and utilization.

elenia's research objectives in H2_Campus_TUBS

elenia is responsible for the work package grid and system integration of the energy-intensive plants within the H2_Campus_TUBS project. The focus of the study is the battery storage (>600 kWh) to be installed in the HCC and the development of its possible operation modes. When using an electrolyzer for hydrogen production, it is advisable to use a battery storage system to ensure constant operation and to compensate for the fluctuating generation of the required electrical energy. Renewable energies form the basis for the production of so-called green hydrogen. The battery storage system used in the HCC thus acts primarily to shift energy to times of low feed-in from renewable energies. At the same time, there is the possibility of using it to provide system services, e.g. as a grid booster to maintain grid stability.

Integration of the Hydrogen Competence Center in teaching activities at the TU Braunschweig

Another goal is the integration of research activities into lectures and student laboratories for the continuous development of subject-relevant majors as well as into the graduate academy GradTUBS. In this context, elenia acts as the interface to the master's degree program in electromobility, which is jointly supported by the electrical engineering and mechanical engineering departments. The knowledge gained in the project in the future technology of hydrogen and the associated possibilities of sector coupling are directly incorporated as empirical values for the evaluation of future hydrogen-based mobility concepts.

PROJECT NAME

H2_Campus_TUBS

PROJECT RUNTIME

June 2021 – May 2025

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Photo: Gian-Luca Di Modica/TU Braunschweig

Research Project LISA4CL

Charging – inductive, fast, autonomous for city logistics

A new research project started in May 2020. The project *LISA4CL Laden – induktiv, schnell, autonom für City Logistik* is concerned with the development of a standard-compatible, high power, inductive charging system and its intelligent power grid integration. Especially for frequently used vehicles or even fleets, short charging times and the associated shortest possible idle times are necessary. For several years now, inductive charging systems have been developed, promising a massive increase in customer acceptance of electric and hybrid vehicles. The first standards and specifications have emerged that form the basis for today's systems with charging capacities around three kilowatts (kW). However, charging times with these charging powers are very high, as this power class was primarily developed for home use with regard to overnight charging. High power systems are needed specifically for public sector and fleet operations (in the non-public sector). Accordingly, the further development of standards and specifications for high power inductive charging has begun.

In addition, intelligent grid integration of charging systems is important because the penetration of electric vehicles and consequently also the grid load is increasing. The focus is on ensuring safe grid operation. Grid-oriented charging approaches play an important role with regard to grid stress reduction and minimization of grid expansion. In addition, from an economic and environmental point of view, generation-oriented charging approaches are of particular importance for increasing the share of renewable energy used.

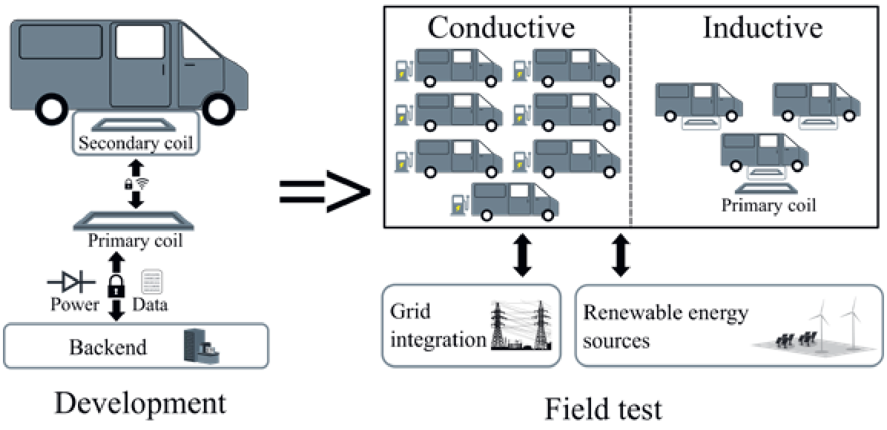
Project consortium

The project consortium consists of two research institutes and one industrial partner. The participating research institutes are the elenia Institute for High Voltage Technology and Power Systems and the IMAB Institute for Electrical Machines, Traction and Drives at the Technische Universität Braunschweig. The industrial partner is INTIS – Integrated Infrastructure Solutions GmbH, which is developing and implementing the inductive charging system together with IMAB. As consortium leader, elenia organized the digital kick-off meeting. The meeting was a successful start for the project and the upcoming collaboration.

Project content

The Figure Overview of the *LISA4CL project* schematically shows the contents of the LISA4CL project. The project is divided into three parts. In the first part, a standard-compliant, high power, inductive charging system for use in light commercial vehicles will be developed and built, which will provide higher power of up to 22 kW compared to current standards. The charging system consists of the fixed charging station (primary unit) and the secondary unit,

Inductive charging system of the InduktivLaden project Photo: IMAB/TU BS



Overview of the LISA4CL project

which will be integrated in test vehicles. The development is based on the results of the previous project InduktivLaden, in which an inductive charging system for an e-Golf was implemented (see Figure *Inductive charging system of the InduktivLaden project*). The second part of the project comprises the grid and system integration of the charging infrastructure. Here, grid-oriented and generation-oriented concepts for charging are developed, which are tested with simulations and in the laboratory. In the last part, the inductive charging system and the charging concepts for grid and system integration are used in field tests at a city logistics company in real operation. This part is divided into a field test with conductive charging infrastructure and a field test with the inductive charging system in order to compare the charging technologies with regard to demand-oriented charging infrastructure.

Due to the cooperation of the project partners in various standardization committees, the project results will be directly incorporated into future standards and guidelines. The involvement of the industry partner INTIS ensures a high level of practical relevance. The inductive charging system is being developed as a market-ready product. In addition, on the scientific side, the research results will flow into doctoral projects at the institutes. Furthermore, they will find their way into corresponding courses, such as lectures, laboratory practicals and student theses, and will be presented and discussed at national and international conferences and meetings. The project and its methodology have already been presented at the *NEIS 2021 – Conference on Sustainable Energy Supply and Energy Storage Systems*.

Project objectives of the elenia

Within the project, the elenia is responsible for project coordination and content-related aspects such as the communication interfaces of the inductive charging system. The focus of elenia is on the following work packages:

1.) Development of various communication interfaces of the inductive charging system, such as the interface to the vehicle and to the backend.
2.) Development, testing and validation of grid-oriented and generation-oriented charging algorithms.
3.) Conducting field tests with conductive charging infrastructure and the inductive charging system as well as the developed charging concepts at a logistics company.

PROJECT NAME

LISA4CL

PROJECT RUNTIME

May 2020 – April 2023

PROJECT LOGO

LISA4CL

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elenia (TU BS), IMAB (TU BS), INTIS

WEBSITE

www.tu-braunschweig.de/elenia/forschung/forschungsprojekte/lisa4cl

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Photo: Cornelius Biedermann/elenia

How to Improve Power Quality?

Effects of future low-voltage grid use cases and their mode of operation on voltage quality

The U-Quality project is dealing with the voltage quality in the low-voltage grid with the increasing number of electric vehicles, photovoltaic systems, battery storage systems and power-to-heat systems.

The voltage quality in the distribution grid depends on the generators and consumers connected in the grid. The current changes in these so-called load use cases in the context of the energy, mobility and heat transition therefore have a major influence on the voltage quality. Maintaining this quality is one of the central and current tasks for distribution grid operators. The project partners will conduct research in the area of voltage quality during the project period until mid-2022 and develop solutions to enable more electric cars to be charged in the electricity grids, among other things. In particular, solutions will be developed to improve the voltage quality.

Research in 2020 and 2021

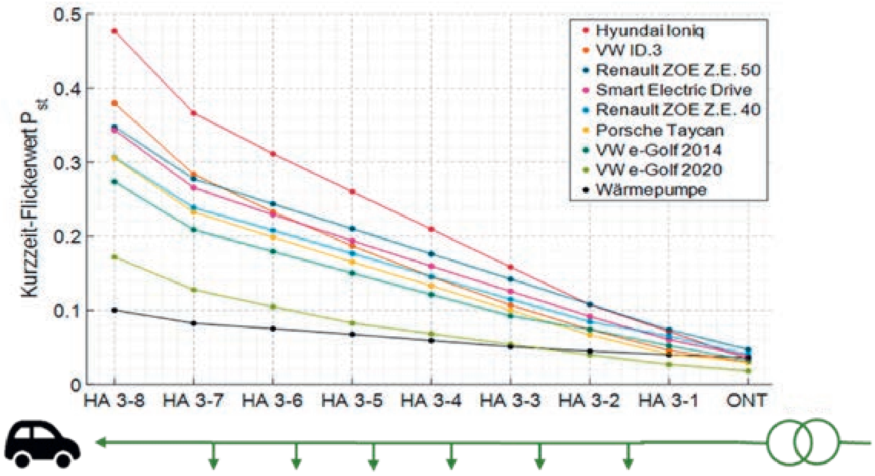
In the years 2020 and 2021, various research work was completed in the project, dealing with different sub-disciplines of voltage quality. One core aspect was the recording of voltage quality in the low-voltage grid. For this purpose, field measurements were carried out in a suburban low-voltage grid in Braunschweig, which has a high penetration of PV systems and heat pumps. In the field test network, power measurement devices were integrated at various points in the network, e.g. at the local grid station, for a fortnight each in winter 2019/2020 and late summer 2020, in order to record the voltage quality. Various PV inverters, battery inverters and a heat pump were measured in the laboratory environment, as well as a large number of electric vehicles at the institute's own charging stations. The figure U-Quality measurement of various BEVs and PHEVs shows the charging stations and some of the measured vehicles.

Another research focus was on the development of a controller that maintains or improves the power quality in the low-voltage grid. For this purpose, a controller concept was developed in cooperation with Ruhstrat Power Technology, which provides a Unified Power Quality Conditioner (UPQC) for the controller. The controller and its controls were modelled using MATLAB/Simulink and initial simulations were then carried out using this model. In the next step, partial aspects of the controller concept were tested in the laboratory environment on the basis of the simulations. Furthermore, laboratory tests and simulations were carried out to investigate a possible influence of the Q(U) control on flicker values during rapid voltage changes.

Results of the field measurement

The results of the field measurements show, among other things, that rapid voltage changes (RVC) cause flicker. In the field measurement campaign, rapid voltage changes with maximum voltage changes of up to 7.3 % were measured. These rapid voltage chang-

U-Quality Vermessung verschiedener BEV and PHEV. Photo: Di Modica/elenia



Short-term flicker values in grid simulations with time series of real measured switching edges of BEV and WP. Graphic: Till Garn/elenia

es also resulted in the maximum measured flicker values, which, however, did not violate the limit values. Furthermore, the unbalance was reduced at night, which is why EVs with single-phase charging and low penetrations do not pose any problems for the unbalance.

Results of the measurement of individual components

The effects of the EVs on the voltage quality vary significantly between the different vehicle types. For harmonics from the 50th to the 200th order, the Renault Zoe 2020 has the highest RMS values of all EVs measured. The maximum values of the Renault Zoe 2020 occur in this range for odd orders around the 200th harmonic. In addition, the load profiles and the switching edges of the vehicles were recorded. These could be used in simulations (cf. figure: *Short-term flicker values in grid simulations with time series of real measured switching edges of the BEV and WP*).

Further measurements showed that the start-up of a non-modulating heat pump generates rapid voltage changes and increased flicker values, which, however, like the measured PV inverters, did not violate the limits of the standards DIN EN 50160, IEC 61000-3.

Results Investigation Influence of Q(U) control

The influence of the Q(U) control on flicker values during rapid voltage changes was determined in the simulations and laboratory tests. This can lead to an increase, but also to a reduction of the flicker values. However, even in grids with a high PV penetration, this influence is very small and negligible compared to the benefit of Q(U) control. Furthermore, flicker will be considered in the future with regard to heat pumps, electric vehicles and PV systems. For this purpose, simulations will be carried out with grid use case scenarios that were developed for the project.

The results were published at national and international conferences and meetings, where they were presented and discussed. The project was presented at the 16th Symposium on Energy Innovation EnInnov2020 in Graz. The results of the field and laboratory measurements were published at the conference Zukünftige Stromnetze 2021, the ETG Congress 2021 and CIRED 2021.

Further work objectives in the project

As you read these lines, the project consortium will be in the final stages of investigating the voltage quality controller described above and preparing for a demonstrator field trial with the distribution grid operators. We are very much looking forward to the implementation and are looking forward to exciting results.

The latest information on the project is also available on our project website “u-quality.de”. If you are interested in the research project, please do not hesitate to contact me!

PROJECT NAME

U-Quality

PROJECT RUNTIME

September 2019 – August 2022

PROJECT LOGO

U-QUALITY

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Bayernwerk, Netze BW, Regionetz, Stromnetz Hamburg, Avacon, BS Netz, Maschinenfabrik Reinhausen, Phoenix Contact, SMA und Ruhstrat Power Technology

WEBSITE

www.u-quality.de

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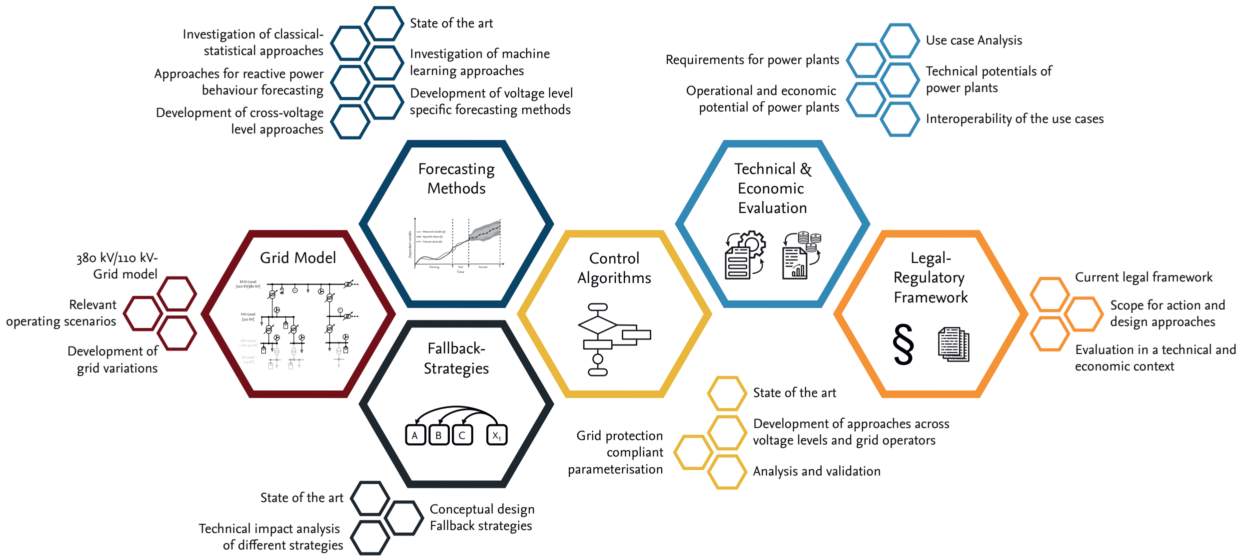


Reactive Power Management

with dynamic reactive power sources at the interface of distribution and transmission grid

With the energy transition, the electrical power system in Germany is undergoing a fundamental transformation process that has a major impact on existing concepts for maintaining grid and system security. This also applies to conventional methods for voltage control and the closely related reactive power management (RPM) in transmission (TG) and distribution grids (DG).

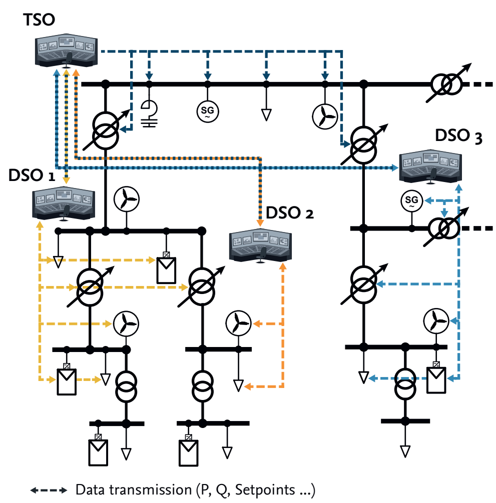
The increase in the installed capacity of renewable energy sources (RES) in DG and the simultaneous shutdown of synchronous generators in TG lead to a theoretical reactive power potential in the DG being created by the converter-coupled RES and a large part of the reactive power potential in the TG being successively reduced. However, the expansion of RES also results to an increasing load on the grids, an increasing reactive power demand and thus a higher demand for transmission capacities. At the same time, the increasing demand for reactive power is becoming more and more fluctuating.

These circumstances lead to substantial changes for the RPM with regard to operational and planning aspects. In the future, the residual reactive power demand of the TG must be covered. An option are reliable, distributed and dynamic reactive power sources from the DG.

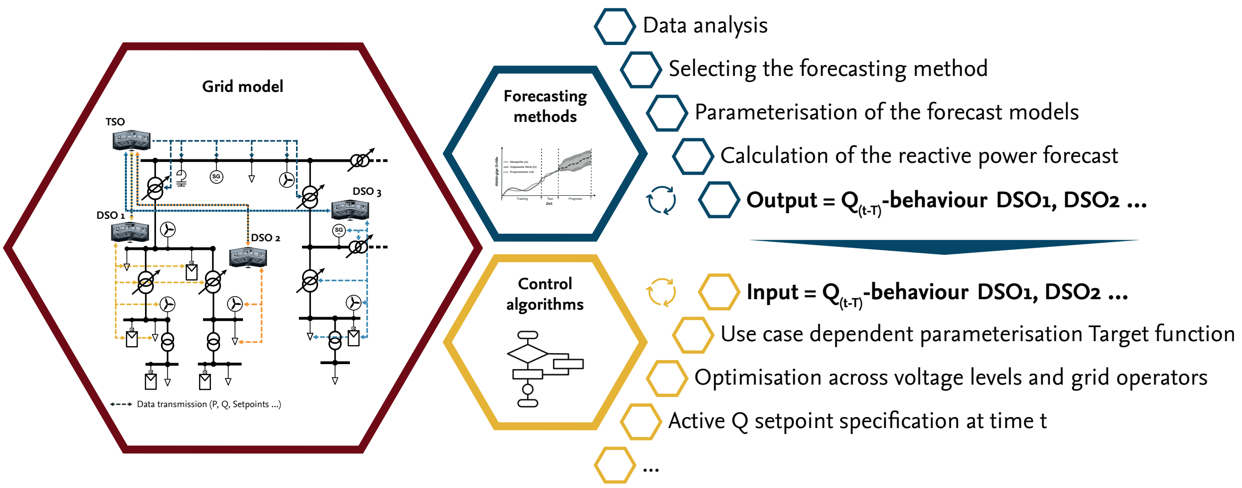
Research questions derived from this are continuously being addressed in various research projects. In the PV-Wind-Symbiosis project some research questions have been already answered, see the final report on the joint project 2019. Focus of PV-Wind- Symbiosis were the efficiency of the reactive power supply from PV and wind energy plants, the technical effects of the feed-in on a grid section of a real high-voltage grid (HV grid) and the economic consideration of the integration of individual RES as reactive power sources in an RPM.

In the follow-up project Q-Integral, the focus of the investigations is the interface between the DG and the TG. In cooperation with the transmission system operator *50Hertz* and the downstream distribution system operators *E.DIS*, *TEN* and *WEMAG*, different approaches for a system operator and voltage level spanning RPM are being developed with the real grid models of these partners. A schematic representation of the concept of the RPM can be found in the following figure.

The object-oriented simulation environment currently comprises the modules *Grid Model*, *Forecasting Methods* and *Control Algorithms*. The modules Forecasting Methods and *Control Algorithms* use the Python interface of *DIgSILENT PowerFactory* as a central module to access the functional scope of the grid calculation software and the physical grid model.



Concept of the Reactive Power Management



Interaction of the modules Forecasting Methods and Control Algorithms in Q-Integral

Within the module *Forecasting Methods*, various methods are investigated for forecasting the reactive power behaviour of the grids. The prediction at time *t-T* is intended to enable optimisation of the reactive power behaviour of the grids across voltage levels and grid operators at time *t* in the *Control Algorithms* module. For this purpose, the interrelationships between generators, loads, operating resources and different grid variables are quantified by means of a comprehensive data analysis. The results are used to select the appropriate forecasting method. Depending on the given observability of individual grids, the forecast models are trained and subsequently validated on the basis of existing data sets. Depending on the quality of the data, the data-driven approach enables a calculation of the forecast of the reactive power behaviour of individual substations within the distribution grids. In order to obtain a statement about the predicted reactive power behaviour at the grid interconnection points and to consider the reactive power behaviour of the grid resources, additional power flow calculations are currently being carried out in the grid model with the forecast results. The long-term goal is a purely data-driven forecast. The existing development approach for reactive power forecasting can be read in full in M. Schuster et al. 2021.

The module *Control Algorithms* comprises the RPM of the individual grid regions, which have to cooperate more efficiently due to the geographical and electrical proximity. In the implemented RPM, the respective reactive power sources such as RES, synchronous generators and transformer tap changer are used to meet the respective requirements of the grid region at a given time. First, the current state of the grid is analysed and assigned to an application case. Subsequently, the objectives associated with the use case are pursued by controlling the reactive power sources intelligently and automatically.

Studies are also currently underway on the other work packages (see cover image). These include the development of fallback strategies of integrated RES in case of communication failure as well as the investigation and evaluation of the legal-regulatory scope of action of a RPM in the technical/operational context.

PROJECT NAME

Q-Integral – Aktives BM mit dynamischen Blindleistungsquellen an der Schnittstelle VN u. ÜN

PROJECT RUNTIME

April 2019 – March 2022

PROJECT LOGO

Q-INTEGRAL

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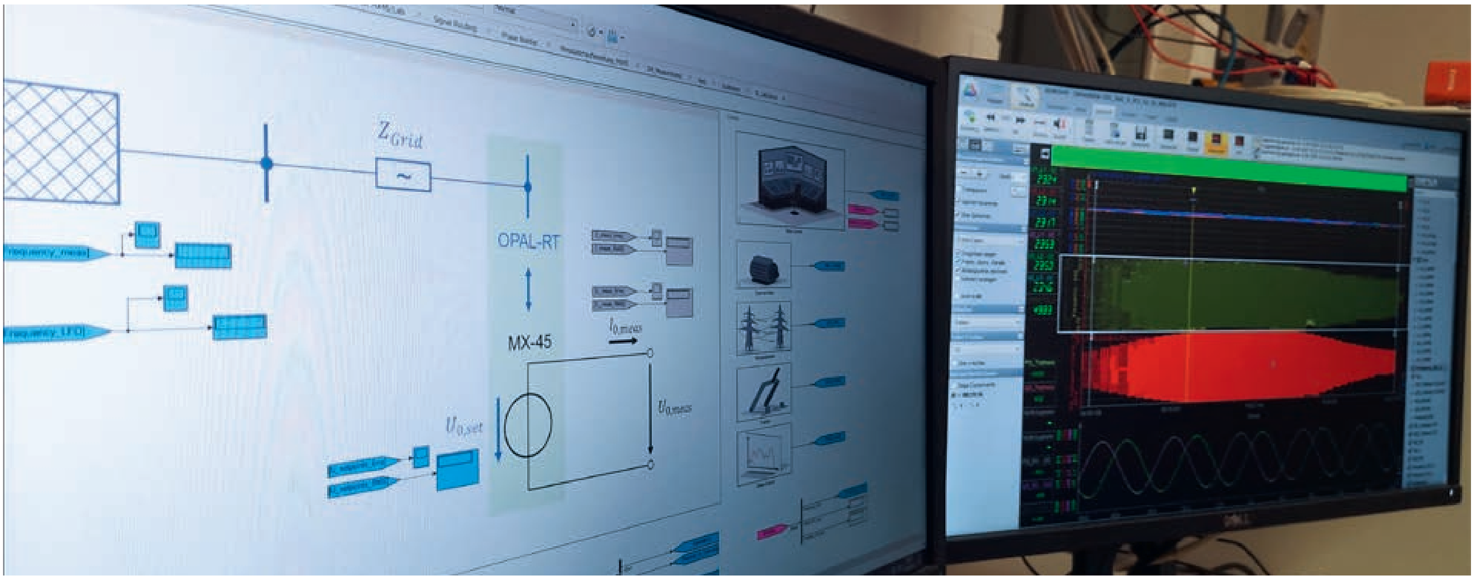

Grid Control 2.0

Stable grid operation with 100 % renewable energies

Motivation & Objectives

The electrical power supply and in particular the control of the electrical net-work in Germany are undergoing a transformation process. While grid control today is essentially based on the characteristics of large power plants with synchronous generators, converter-based generation plants are increasingly being used for generating electricity. Feed-in situations in which more than 90% of the load is covered by renewable energies are already occurring in Germany today. However, in order to ensure system stability, conventional power plants, so-called “must-run units”, must remain connected to the grid at these times.

These and other changes in the supply system as well as in grid operation will entail a far-reaching transformation. This is where the Grid Control 2.0 project comes in. In particular, new states that were not present in a power grid based on synchronous generators will be addressed within this project. Examples are the reduction of rotating mass-es or the dominance of converter-based generation in grid sections. Fault scenarios and system services, accompanied by a safe and stable operation of the grids, are the focus of this research project.

The overall objective of the research project Grid Control 2.0 is to demon-strate that the electrical interconnected system in Germany can be operated safely and stably with a very high pro-portion of power converters. For this purpose, concrete control procedures are developed and tested and validated both in the laboratory and in the field.

Today’s integrated electrical system has grown historically and is therefore geared to the characteristics of synchro-nous generators. Power converters, on the other hand, have other characteristics that are equally suitable for ensuring system stability. In this respect, requirements must be identified and de-scribed independently of the respective technologies. Subsequently, control procedures can be developed for power converters that meet these requirements. It is checked which technologies have to fulfil which requirements in order to function in the overall system at any time.

In the research project Grid Control 2.0 not only medium- and long-term scenarios with a high converter-based power generation are considered. In addition, transition paths from the cur-rent system, which is often still conven-tional, to a system almost exclusively supplied by converters are investigated.

Research aspects at elenia

As part of the joint project, elenia is working on the integration of voltage-influencing power converters into the distribution grid. In this context, the focus is on the provision of instantaneous reserves and their

PROJECT NAME

Netzregelung 2.0

PROJECT RUNTIME

December 2016 – August 2022

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PROJECT PARTNER

Research Institutes: Fraunhofer IEE, Uni Kassel
Manufacturer: Siemens, SMA Solar Technology AG
Grid Operator: 50Hertz, Amprion, TenneT, Transnet BW, EWE Netz, Mitnetz, Westnetz
Associations and networks: VDE | FNN, DERlab, dena

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effect on the superimposed grid levels. The aim of the investigations is to investigate the contribution of these converter systems to the stabilization of the grid in the event of rapid load changes in networks with a reduced proportion of feed-in from large power plants. A further focus is placed on the influences of voltage-influencing converter technology on the distribution networks, in particular on local voltage quality and network protection measures.

Advanced development of the control approaches of grid-forming inverters

Grid-forming inverters are considered promising solutions to the problems of the future power grid. Therefore, various control approaches with their respective properties are now being discussed in the research landscape. Most of the control approaches have in common that the essential equations are based on the equation of motion of the synchronous machine, the swing equation. The advantage here is that essential elements from the field of network dynamics are simulated as in the synchronous machine and thus the dynamic behavior in interconnected operation is largely the same. A particular challenge here, however, is the handling of short-circuit situations. While a synchronous machine has very large short-circuit currents, inverters are usually limited to their simple rated current. Here it is necessary to find a compromise between the provision of the short-circuit current for e.g. protective devices and the operating limits of the inverter.

At elenia, various procedures could be developed and verified in the laboratory within the framework of the research project in order to present a solution for this conflict of objectives. Figures 1 and 2 show the experimental setup and the effective current limitation in order not to exceed 1 p.u. and thus the rated current. Of particular interest here is both the fault occurrence and the fault explanation. Here, the control must intervene very dynamically and at the same time not lead the system into an unstable operating point due to the rapid intervention. The developed procedures were then tested for functionality in the laboratory using a rapid prototyping inverter for agile development. The requirements were thus fulfilled and the functionality was also proven in the laboratory.

Challenges in integration into the distribution grid

Another particular challenge in the area-wide integration of grid-forming inverters is that their low power class is used in the distribution grid. This results in new requirements that the original dynamic behavior of the synchronous machine must be balanced together with concepts in the distribution grid, e.g. in the area of grid protection.

A special topic in the context of grid protection is the avoidance of unwanted island grids as a result of grid disconnection, caused for example during maintenance work or by a grid fault. In these situations, normal inverters must recognize that they are no longer being operated on the interconnected grid and then switch off specifically. The grid-forming inverter, on the other hand, tries to maintain a stable grid at all times if possible, which is why it is used in the first place. Thus, there is also a conflict of objectives here, in that on the one hand, such unwanted island grids must be switched off safely and on the other hand, the grid-stabilizing property of the grid-forming inverter should not be impaired

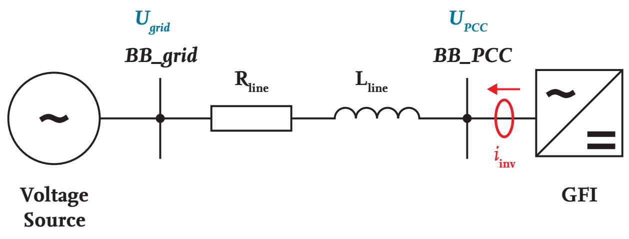


Figure 1: Laboratory set-up for grid fault testing

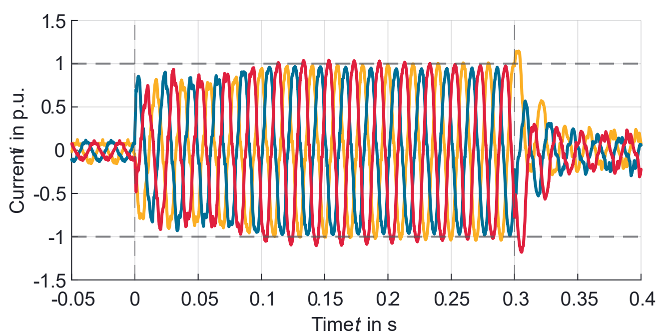


Figure 2: Verification of the mode of operation of the current limiter on the basis of measured currents

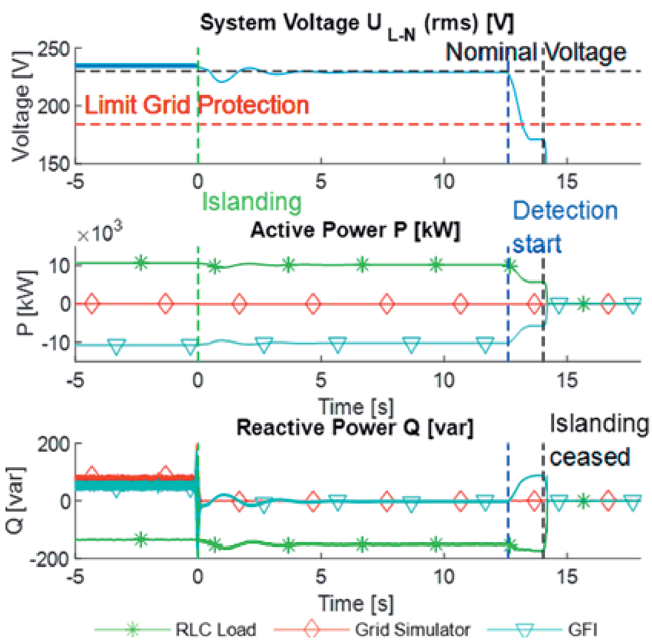
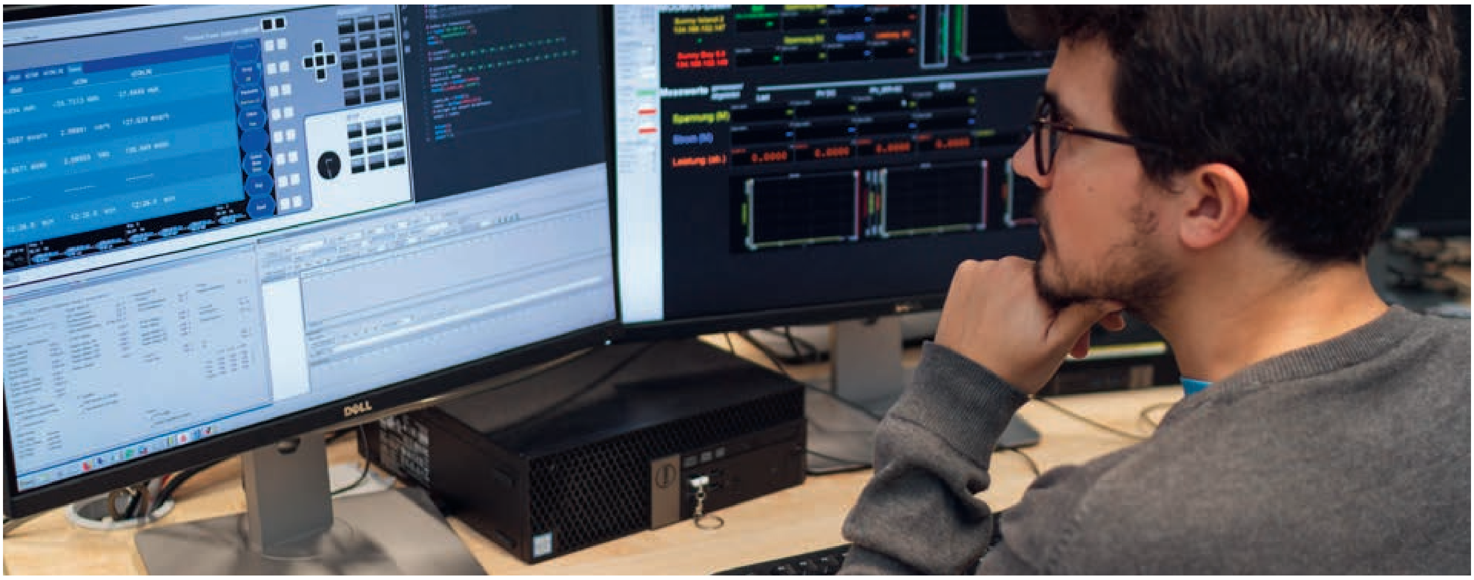


Figure 3: Illustration of islanding and disconnection of a grid-forming inverter



Robust Grid Operation

Highly available distribution grid operation in the event of a disruption of the ICT infrastructure in the smart grid

The power distribution grids of the future are characterised by a high number of renewable energy plants and decentralised grid participants such as electric vehicles, storage units and controllable loads. A large number of new players, such as operators of virtual power plants or smart meter gateway administrators form diverse interfaces to this finely granular system structure. This is accompanied by increasing networking by means of information and communication technology (ICT). This is necessary in the sense of the envisaged future overall construct of the smart grid and for the coordination of heterogeneous technologies, with mostly volatile behavior, as well as a multitude of new market actors and market processes. The behaviour of weather-dependent systems can still be predicted reasonably well. In complex market processes with a heterogeneous variety of actors, however, it is all the more important to be able to fall back on networked sensors and actuators in view of the fundamental functional principles of the current energy supply system. In addition to the traditional goal of security of supply, the aspect of IT security is therefore becoming increasingly important.

The IKTfree project and its contribution to the energy transition

The project IKTfree, funded by the German Federal Ministry of Economics and Energy (BMWi), deals with the contribution of distributed resources in the electrical distribution grid in order to provide measures that enable stable operation over as long a period as possible in the event of a failure of the communication infrastructure. In view of the increasing number of decentralised generation plants and network participants in the distribution network and the ever greater dependence of the information and communication infrastructure due to the implementation of smart grids, this topic is playing an increasingly important role at the energy policy level. For this reason, the Institut für Vernetzte Energiesysteme des DLR, together with the elenia Institute for High Voltage Technology and Power Systems as a project partner, is investigating the behaviour of various operating components in the event of disrupted ICT connections, and is drawing up recommendations for action to ensure stable grid operation. In addition, the IT risk in the distribution grid is being analysed.

Up to now, security of supply and ICT security in the smart grid have been dealt with in the research landscape mostly for critical infrastructure and components with robust ICT. IKTfree is intended to carry out an analysis of the components of the last mile of the distribution grid in order to develop an emergency operation in the event of a failure of the ICT and thus contribute to an optimisation of the distribution grid operation.

Research in 2020 and 2021

After the relevant scenarios, components and parameters were identified in the previous work packages, the various reactions of the components to a failure of the communication infrastructure were determined. The resulting effects on an electricity distribution network were then evaluated. For this purpose, four benchmark low-voltage networks were used, representing rural and urban networks, connected to a medium-voltage network, thus simulating a distribution network.

In order to test the structures and determine the negative local effects, a structured selection of load flow calculations was carried out at different component expansion levels and operating points. The penetration of PV systems, battery storage and electric cars was varied by means of sensitivity analyses. The results showed that, with regard to the scenarios considered, negative ef-

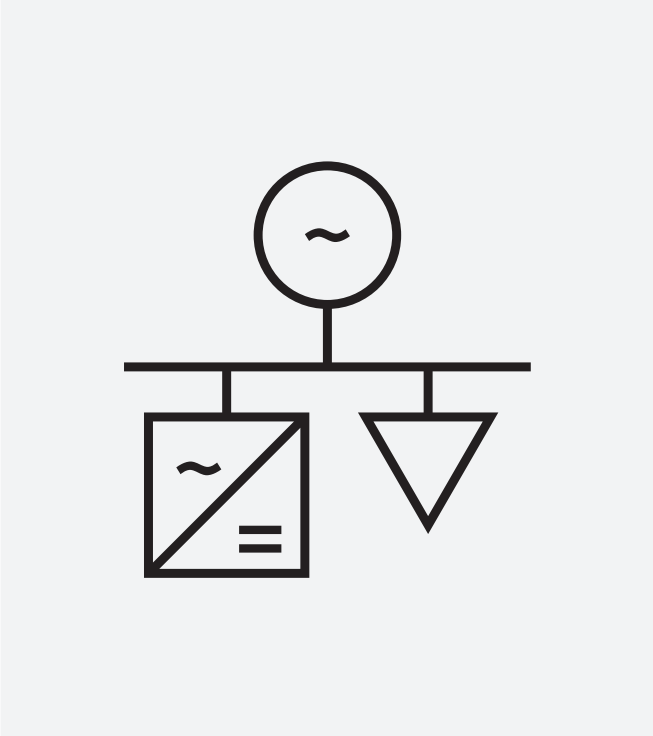


Figure 1: Aggregated model for global impact studies

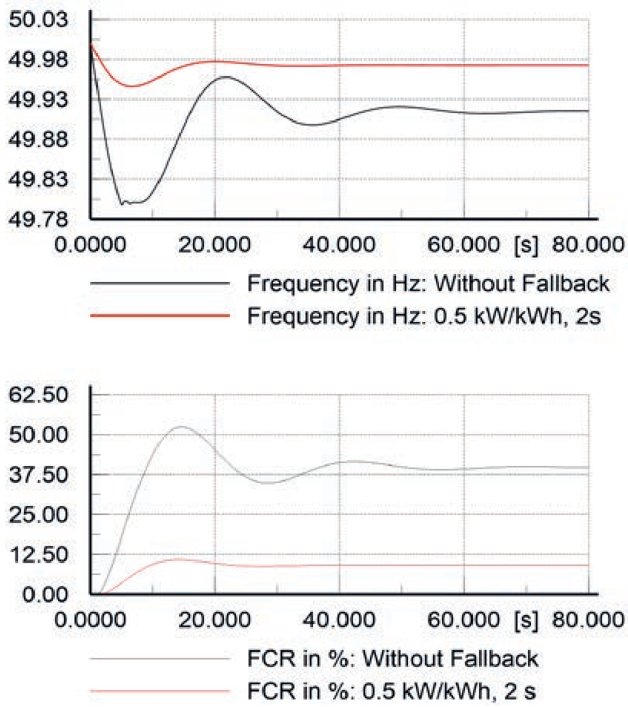


Figure 2: Frequency response without and with fallback

fects mainly occurred in the meshed grid and related to line overloads. It was found that a management system is required to balance generation and consumption locally and thus avoid overloads at high load or at high feed-in.

In addition, investigations were carried out into the overall stability of the system. For this purpose, a balance model was used that simulates the frequency of the European power grid in the event of a sudden power shift and the activation of the Frequency Containment Reserves (FCR). The impact of an area-wide communication infrastructure failure on the frequency and activation of FCR when public charging stations for electric cars change their operating point as a result of the ICT failure was investigated. The results have shown that the future high number of charging stations and charging powers can lead to frequency fluctuations and large activations of FCR in case of a negative reaction to a communication failure. This could jeopardise system operation, as these reserves may not be sufficient to maintain operation in the event of further failures in the system. As a countermeasure, an additional P-f characteristic was tested in the home storage systems, which leads to a relief of the FCR activation.

A demonstrator is currently being set up in the laboratory to test the fallback algorithms to be developed for the various components. For this purpose, a communication link is being set up between the components and the demonstrator in order to send the setpoints and measure the current parameters.

What lies ahead of us?

The project team is eagerly looking forward to the year 2022. The plan for the next few months is to concretise the measures for avoiding and correcting errors in order to avoid or reduce the effect of errors. With the derivation of these measures into a control system and their implementation in the simulation environment, it will be possible to evaluate the effectiveness of the measures. Subsequently, the results will be validated by laboratory tests. Finally, the results obtained will be disseminated and the corresponding measures presented to the various professional associations and committees.

PROJECT NAME

IKTfree

PROJECT RUNTIME

October 2018 – June 2022

PROJECT LOGO

IKTfree

CONTACT

Edwin Rebak
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+49 531 391-7759

PROJECT PARTNER

Deutsches Zentrum für Luft- und Raumfahrt (DLR) – Institut für Vernetzte Energiesysteme e.V., EWE Netz GmbH, VDE Verband der Elektrotechnik Elektronik Informationstechnologie e.V. Forum Netztechnik/Netzbetrieb (FNN)

SUPPORTED BY

Bundesministerium für Wirtschaft und Energie

aufgrund eines Beschlusses des Deutschen Bundestages

ALPHEUS

Augmenting grid stability through low head pumped hydro energy utilization and storage

The energy consumption of industry and private households often does not coincide with the generation of energy by wind, sun or water. In countries with large topographic differences in altitude, technically established pumped storage power plants help to temporarily store part of the energy as needed. The ALPHEUS project, in which the Technische Universität Braunschweig is also involved with elenia Institute for High Voltage Technology and Power Systems and Leichtweiß-Institute for Hydraulic Engineering and Water, Department of Hydromechanics, Coastal and Ocean Engineering, is now working on solutions so that areas in the lowlands can also benefit from this technically well-known technology.

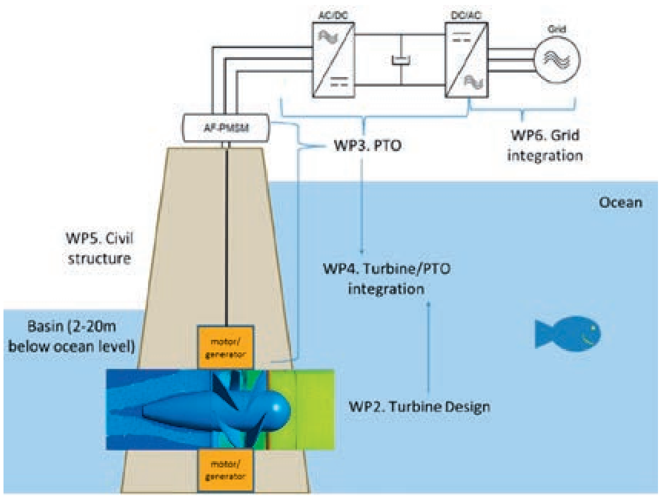
Due to the slow expansion of the grid, current power grids are not yet able to absorb the fluctuations of renewable energy sources such as wind energy without resorting to fossil-fuel power plants that emit climate-damaging CO_2 or temporarily throttling their feed-in again and again. In mountainous regions such as the German low mountain ranges and the Alps, Pumped Hydro Storage (PHS) power plants relieve the strain on the grids. When there is excess power generation, water is pumped into storage reservoirs at higher topographical levels. When electricity consumption rises, the water flows back down to the valley through turbines. This process is currently the most mature and cost-effective way of storing energy.

But what do countries like the Netherlands and Belgium do? They do not have the natural topography required for PHS, with large differences in altitude across the landscape. As a result, energy backup consists almost entirely of fossil fuels and thermal power plants. Despite major advances in battery research in terms of efficiency and initial cost, lithium ion batteries are not considered an economical storage alternative. Their lifetime compared to the energy required for their production is significantly worse than that of PHS.

As part of the ALPHEUS project, conceptual designs are being developed for new and retrofitted low head PHS basins. A comprehensive assessment of the mechanical, electrical, and structural components will allow the costs of these systems to be determined and the risks to be evaluated. Information and decision support tools are being developed to disseminate knowledge to the community.

In addition to developing the appropriate turbine technology that can operate efficiently in both pumping and turbine mode at low heads and exploring the siting potential for new and retrofit pumping systems and basins, elenia is primarily investigating the impact on power system stability.

Researchers from elenia at the TU Braunschweig are modeling special converter units for feeding the generated power into the in-



Project concept of ALPHEUS

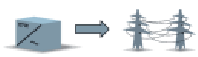
The German Bight offshore wind farm – ALPHEUS power plant shall make the concept of "Energy Islands" possible

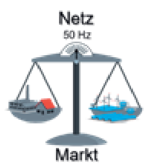
terconnected grid. They then measure their impact on the grid and evaluate the extent to which such power converters can contribute to stabilizing the interconnected grid in a variety of ways in addition to simply feeding power into the grid. This will allow an evaluation of how larger power grids respond to distributed energy storage.

elenia is working on work package 6 "Grid integration"

Work package 6 consists of 3 tasks:

1.) Controller design for a grid-connected inverter (Compliant with the EU grid codes, e.g. requirements for grid connection of generators: Commission Regulation (EU) 2016/631) and develop a simulation model which can be used for further grid studies





2.) Estimate the contribution of pumped storage flexibility to grid stability

3.) Economic evaluation of flexibility and regulatory constraints according to Directive (EU) 2019/944 on common rules for the internal market for electricity

PROJECT NAME

ALPHEUS

PROJECT RUNTIME

April 2020 – March 2024

PROJECT LOGO

CONTACT

Mohammed Qudaih, M.Sc.
m.qudaih@tu-braunschweig.de
+49 531 391-7787

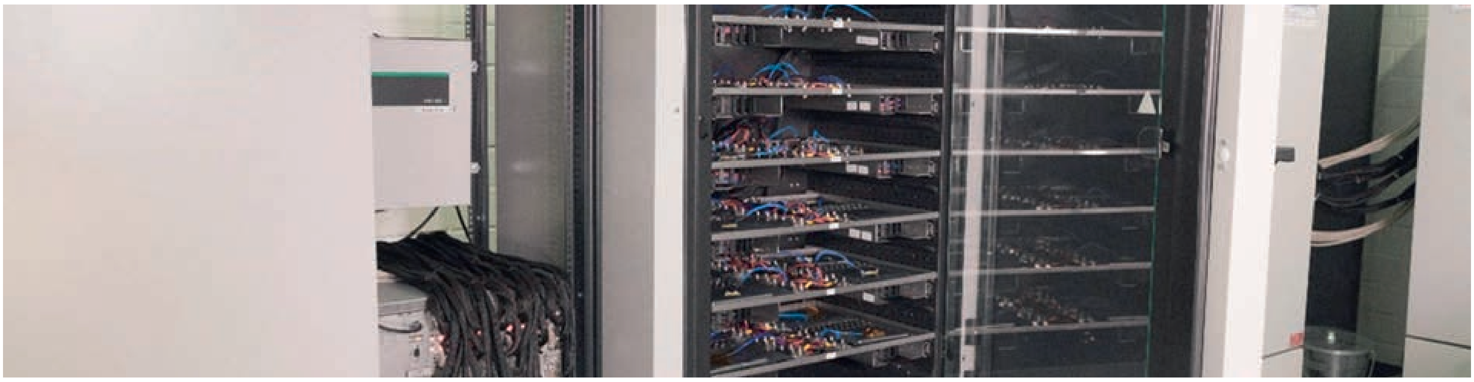
PROJECT PARTNER

Advanced Design Technology, Ltd., Technische Universität Braunschweig, Chalmers University of Technology, Delft University of Technology, IHE Delft Institute for Water Education, Ghent University, Norwegian University of Science and Technology, University of Pau and Pays de l'Adour, The University of Stuttgart, Tuscia University, Uppsala University

SUPPORTED BY

Photo: Stephan Passon/PTB

Doctoral Theses



Battery Technology

Kerstin Ryll

Key figure based analysis of the properties of lithium-ion battery cells along the life cycle

The increasing use of lithium-ion batteries in various applications of electromobility and energy storage of renewable energies places a wide range of demands on the energy and performance data of the batteries. In order to determine whether the batteries are able to meet these requirements, comprehensive knowledge of the cell properties is necessary. Characterization methods are used to derive parameters from the measured data. By means of these parameters information is gained, which allows conclusions about the cell properties.

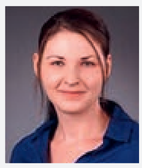
The present paper, entitled "Key figure based analysis of the properties of lithium-ion battery cells along the life cycle", deals with two issues in this topic. In the first step, parameters are derived from the available measurement data that can be obtained along the life cycle. Systematic data analysis is used to identify those parameters with particularly high significance from the large number of possible parameters. As an interpretation aid for the characteristics, the state of knowledge about the interrelationships of the identified characteristics with the cell properties is summarized in an explanatory model.

In the second step, these so-called indicators are validated using test cases. The test cases are cell batches that were manufactured with the same and varying production parameters. The batches are analyzed with the aim of determining whether and which specific constellations result in the characteristics of the indicators, in order to provide interpretation aids for the analysis of cell properties.

As result of the analysis, two sets of indicators are defined, which refer to the two cell properties cell voltage and cell capacity. Each set contains specific indicators for the beginning of the life cycle as well as indicators for the state of health determination. For the indicators related to cell capacity, a reliable description of the cell property can be derived for the batches and a differentiation between the batches can be made. The indicators assigned to the area of cell voltage provide less detailed and reliable information because the batches have a high variance in the available parameters.

The analysis of this work is based on the measurement data from cell conditioning and cyclic aging as well as regular electrical characterization units of 137 lithium ion cells, which were manufactured in the Battery LabFactory Braunschweig within the project "DaLion – Data Mining in the Production of Lithium Ion Battery Cells".

Kerstin Ryll



TIME AT ELENIA

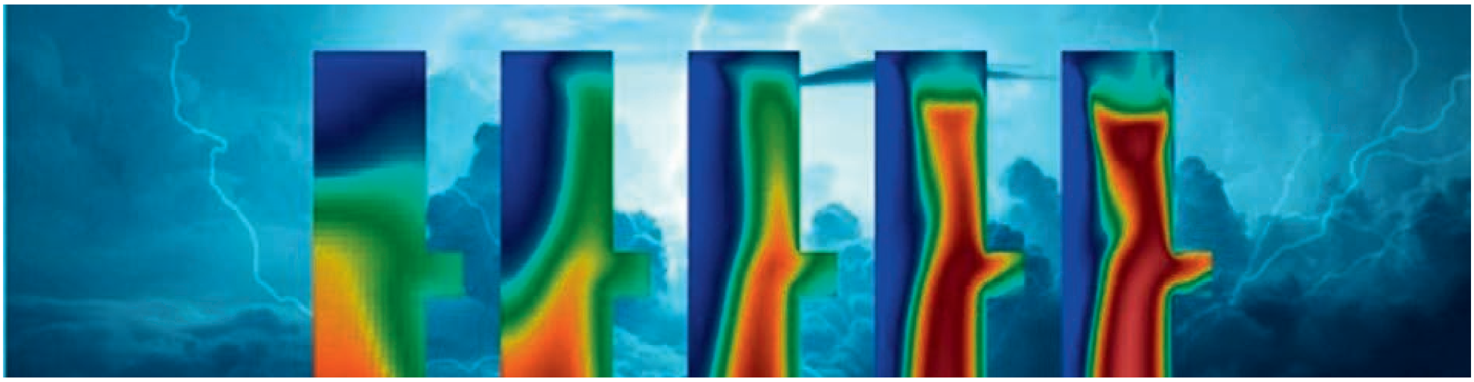
07/2014 – 10/2020

ACTIVITIES AT ELENIA

- Collaboration in the research area electromobility and in the battery technology team
- Work on the research projects Teach4U, Mobile4e, DaLion and BaSS
- Formation and characterization of cells along the life cycle in the Battery LabFactory Braunschweig (BLB)

NOW ACTIVE AT

- Volkswagen AG in cell development as an engineer



High Voltage-, Plasma- and Vacuumtechnology

Christian Sander

Development of a simulation model for switching arcs in surge arresters

Surge protective devices are used to protect electric circuits from surge voltages and impulses. Overvoltage is created by lightning and load switching. Spark gaps are used to handle high energetic surge impulses. When an overvoltage occurs an arc plasma ignites between the electrodes of the spark gap that carries the current and protects the circuit. The high temperatures and pressures make high demands on the mechanical and thermal stability of the device. An experimental approach is difficult because of the high energy density, the short time scales and the compact construction of encapsulated spark gaps so an empirical approach is often used. The development of simulation models thus gives the opportunity to gain detailed insights and a better knowledge of arc plasma behavior in spark gaps. This work focusses on the development of such a simulation model. A special emphasis is placed on the differences resulting from higher energy densities compared to other switching arcs. Under these conditions the elementary approximations used in the modelling of thermal plasmas are only valid to a limited extent. Because the simulation program is newly developed for these conditions the model's convergence behavior makes up a large part of the thesis. The employed approximative methods for the calculation of the magnetic field and of radiation transport are investigated and evaluated. The interaction with the enclosing walls is investigated in further detail. Finally the simulation is compared with experimental results to test the accuracy of the model. It turns out that the model is suitable for the qualitative description of the system, but it overpredicts the pressure in the arrester.

Christian Sander

ACTIVITIES AT ELENIA

- external PhD student 2013 – 2020

NOW ACTIVE AT

Since 2012 Mitarbeiter bei Phoenix Contact in Blomberg

- Technology development for overvoltage protection devices
- Plasma simulation
- Electronics
- Measurement methods
- Embedded firmware development

Photo: Henrik Herr/TU Braunschweig

Grid Operation and Grid Planning

Jonas Wussow

Technical approaches to increasing the capacity of low-voltage grids for electric vehicles

Electric mobility represents an important approach to reducing CO2-emissions in the transport sector. The increasing number of battery electric vehicles will pose a particular challenge to existing suburban low voltage grids.

The present work focuses on the impact of charging processes on grid operation and possible approaches for increasing the capacity of suburban grids. The investigations are carried out on the basis of three representative, suburban low-voltage grids and a realistic model for the charging processes. The investigated scenarios are based on existing statistics regarding charging behaviour and energy demand. In addition, an extreme day is defined, which, for example, represents a Sunday with many excursions in good weather.

The investigations show that only a few electric vehicles can be integrated into the existing grids, especially on the defined extreme day, due to the high energy requirements. These days pose challenges for the low-voltage grid with regard to voltage stability and utilization of the equipment. With conventional charging, on the other hand, higher penetration rates tend to be possible.

Three possible solutions with a total of 17 different measures are presented and investigated, in order to integrate additional electric vehicles while continuing to operate safely on the grid. Grid-oriented charging can be achieved by providing reactive power during the charging process and a voltage-dependent charging power reduction. For households with a PV storage system, its functions will be extended. These include the provision of reactive power at any time and additionally the charging of the storage from the grid on days without PV generation. In addition, grid-side measures such as the controllable local power transformer, conventional grid expansion and storages in the low-voltage grid will be investigated.

With the support of the developed approaches, the capacity of existing suburban low-voltage grids for electric vehicles can be increased. The effectiveness of the individual measures depends on the respective grid topology. A good technical effectiveness is shown by the reduction of charging power, PV storage systems charged from the grid and, in the case of voltage problems, string storage systems.

In a cost-effectiveness analysis, extended provision of reactive power of the PV storage systems and parallel line are the best alternatives for voltage problems. For grids with load problems, the voltage-dependent charge power reduction depending on the selected characteristic curve and the replacement of the local power transformer have the lowest cost-effectiveness ratios.

Jonas Wussow

TIME AT ELENIA

Since 10/2013

ACTIVITIES AT ELENIA

Reasearch projects
- InduktivLaden (2013 – 2016)
- NetProsum (2017 – 2020)
- LISA4CL (since 2020)
- Service projects

Focus: Grid integration of electric mobility
- Project coordinator of EFZN project SiNED (since 2020)
- Head of research focus group “Electromobility” (01/2019 – 12/2019)
- Working group leader “Energy Systems” (since 03/2021), team leader Grid Operation and Grid Planning” (since 07/2020)

Grid Dynamics and System Stability

Julia Seidel

Technical-economical evaluation of frequency maintenance with photovoltaic systems

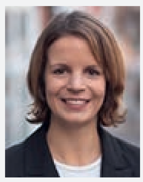
The energy transition in Germany is not only leading to an extension of renewable, in particular fluctuating generation technologies, but also to a changing power system. System stability must be guaranteed even with a future increase in power electronics and fewer synchronous generators. As a measure of frequency control, the control reserve plays an important role in this context. If photovoltaic systems are included in the provision of control reserve power, the latter can be provided from the power plants feeding into the grid, thereby reducing conventional must-run units.

This thesis shows the contribution of photovoltaic systems to frequency control. The provision of negative manual Frequency Restoration Reserve is evaluated by means of different verification methods. The focus lies on the use of a reference subsystem. With two photovoltaic systems, the operational test as well as statistical analyses of the accuracy of the procedure are conducted. The requirements of the prequalification for the control reserve market are fulfilled.

However, with their highly dynamic characteristics, photovoltaic inverters can also provide faster control reserve products. The provision of Frequency Containment Reserve is proven in the laboratory with a photovoltaic inverter. It is also shown that activation times of less than one second can be achieved for the provision of control reserve. With this technical feature, the frequency is to be stabilized in a future inverter-dominated grid with less rotating mass. A parameter analysis is applied to define a new control reserve product with an activation time of one second, the fast Frequency Containment Reserve. This replaces a part of the existing primary control and is hence used in combination with the Frequency Containment Reserve. The combined application of both products leads to a stable frequency response even with a lower accelerating time constant of the grid and a lower self-regulating effect of the load. Without countermeasures, frequency stability could not be ensured in the scenarios under consideration.

The implementation of the fast Frequency Containment Reserve requires hourly time slices and an asymmetric tendering process to leverage the potential of photovoltaic systems. The economic analysis by means of opportunity cost analysis shows that the provision of negative control reserve is profitable for suppliers with photovoltaic systems. If negative prices are increasing on the spot market or in case of a curtailment due to overcapacities of fluctuating generation, the provision of positive control reserve can also be economically profitable

Julia Seidel



TIME AT ELENIA

04/2014 – 03/2020

ACTIVITIES AT ELENIA

Technical focus: Frequency control

- Work on the research projects PV-Regel and NEDS
- Working group leader Energy systems

NOW ACTIVE AT

- Nordex Energy SE & Co. KG

Energy Economics and Energy Management

Frank Soyck

Measurement methods and determination of measurement uncertainty of Photovoltaic storage systems with simultaneous multiple use

The conversion of the energy system towards renewable energy sources creates a lot of new challenges. Battery storage systems are one option to cover the increasing need for flexibility. However, PV storage systems, when used purely for optimized self-consumption, are only temporarily and partially used. These unused shares of the battery storage systems offer great potential for further applications. To leverage this potential, a suitable measurement and billing method for the multiple use of battery storage systems is necessary.

The central challenge in measurement and billing of battery storage systems with simultaneous multiple use is that the individual amounts of energy cannot be measured directly. This dissertation answers the question how the various energy flows, which occur during simultaneous multiple use of PV storage systems, can be measured and billed individually and which measurement uncertaintiy exists.

The measurement method developed for simultaneous multiple use is shown in detail. The method includes the definition of the measured variables, the general description of the logical procedure of the measurement method, and the presentation of the components of the measuring system used.

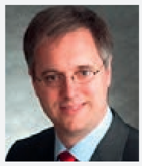
Comprehensive laboratory measurements are carried out using synthetic and real test profiles in order to determine the reference values for the calculation of the measurement uncertainty as well as to determine the estimated values and distribution functions of the model parameters for the measurement function.

The measurement uncertainty is determined by evaluating the measurement function for variations of the parameters in order to calculate the deviations from the reference values. These deviations are compared with the uncertainty of the reference values as well as with the measurement uncertainty of a measurement

method without modelling.

As a result of the measurement method presented in this dissertation the measurement uncertainty can be reduced by more than half compared to the previously known measurement methods without modelling due to the combination of model building and power measurement together with an appropriate allocation of the deviations.

Frank Soyck



TIME AT ELENIA

Since 01/2012

ACTIVITIES AT ELENIA

Reasearch projects

- emil (2012–2016)
- PV-Speicherzähler (2014–2018)
- elenia-energy-labs (2015–2018) and MELANI (Since 2020)
- Service projects

Focus: Energy Management

- Laboratory manager elenia-energy-labs
- Research line coordinator of the EFZN Line of Research Integrated Energy Systems / Sector Interlinking (since 12/2017)
- Working group leader “Energy Systems” (since 2020)

Grid Dynamics and System Stability

Björn Osterkamp

Frequency maintenance with photovoltaic systems as part of a critical infrastructure

The energy transition in the electricity sector, which is intended to address global warming, is leading to a transformation from fossil-based electricity generation towards renewable generation. At present, a significant amount of electricity is already generated by wind and solar power plants.

The times in which conventional power plants only remain on the grid for system stability are increasing. In order to reduce these must-run units, the participation of photovoltaic systems on control reserve is essential. Photovoltaic systems in particular play a major role due to their high installed capacity.

This thesis shows that photovoltaic systems can provide negative manual Frequency Restoration Reserve in a safe and reliable way. Key elements are the verification of the provided control reserve with accuracy, the possibilities for a safe and cost-effective power plant communication and the evaluation of the economic potential of pools for participating in the control reserve market.

The statistical analysis of laboratory and field tests shows that the accuracy, required by transmission system operators, can be achieved with various verification methods. Additionally it is shown by using laboratory testing and synthetic feed-in profiles that inverters can be evaluated with regard to their accuracy in the provision of control reserve. This represents a first step towards laboratory prequalification.

A cost-effective and reliable power plant communication plays a major role in participation in the control reserve system. In the future, existing communication facilities, such as the smart meter gateway, could be used for the necessary communication to provide control reserve. The systems must be matched to the requirements of the transmission system operators at an early stage, particularly with regard to security, latency and functionality.

The addition revenues for the participation of photovoltaic systems in the control reserve market depends strongly on the current market design, the availability of cost-effective communication technologies and the prices in the control reserve market. In the future, the provision of control reserve with a large pool of photovoltaic systems is economically profitable. This leads to additional revenues of up to 19% on average.

Björn Osterkamp

TIME AT ELENIA

11/2013 – 08/2019

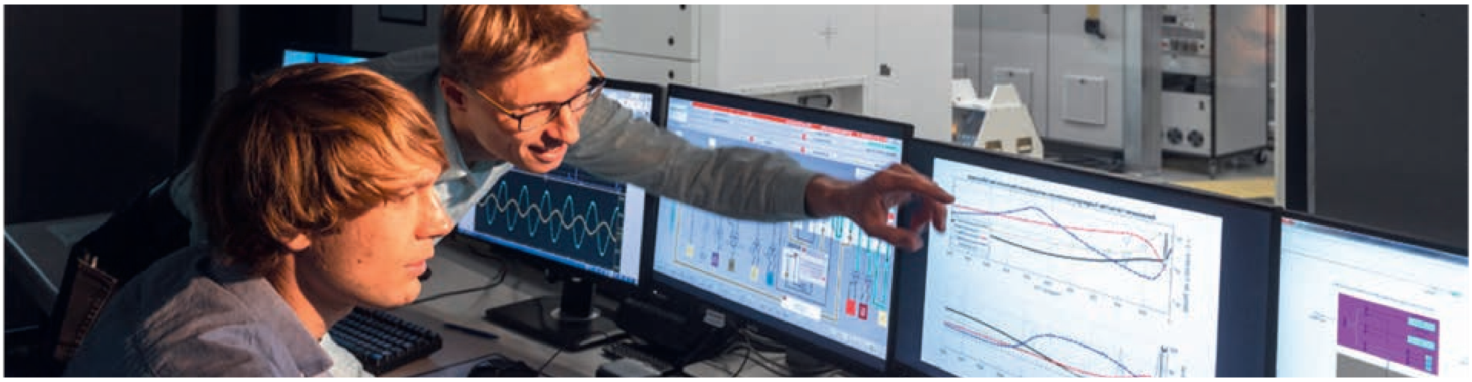
ACTIVITIES AT ELENIA

Technical focus: Frequency control

- Work on the research project PV-Regel and several service projects
- Working group leader Energy systems

NOW ACTIVE AT

- Stromnetz Hamburg GmbH



Grid Dynamics and System Stability

Sönke Rogalla

Analysis of frequency-dependent grid interactions of self-commutated inverters by means of differential impedance spectroscopy and harmonic source observation

In the present work a new method for the improved harmonic characterization of grid-tie inverters is introduced. Contrary to the established methods, which assume that an inverter behaves for harmonics like an ideal current source, the approach presented here interprets the inverter as frequency-dependent voltage source in series connection with an impedance (Thévenin equivalent). This allows not only to identify the actual harmonic emissions of an inverter, but also to analyse interactions between inverters and the upstream grid, such as resonant oscillations.

The characteristic Thévenin equivalents are determined by means of the so-called differential impedance spectroscopy, which is described in detail in this thesis. Differential impedance spectroscopy allows the determination of the effective output impedance as well as the determination of internal harmonic sources of an inverter. Thus, a characterization method is available with which it is possible to distinguish between harmonics emitted by the inverter and harmonics that occur as a reaction to existing grid voltage distortions. Furthermore, the inverter impedance can be used to describe resonance effects – e.g. by applying the so-called impedance-based stability criterion – and to investigate measures to avoid resonances.

In order to demonstrate the method, a test bench for impedance spectroscopy measurements of inverters up to a power of one megawatt was set up and exemplary investigations were carried out on various devices under test. By means of systematic test series and accompanying simulations, essential harmonic-relevant effects of an inverter, such as non-linearities of the filter components or the blanking-time effect of the inverter bridge, were investigated. Their effects on the results of the Thévenin model determination were analysed. This leads to a better understanding of the physical principles that are responsible for the emergence of the measurable harmonics. In addition, the influence of control parameters on the shape of the output impedance of an inverter was investigated by analysing an exemplary inverter. This allows deriving the effectiveness of software changes as corrective action in case of occurring resonances.

Sönke Rogalla

NOW ACTIVE AT

- Fraunhofer – Institut für Solare Energiesysteme ISE

High Voltage-, Plasma- and Vacuumtechnology

Carola Schierding

Suitability of field mills as traceable measuring equipment in the electrostatic field

The present work is focused on the determination of the suitability of electric field meters as a traceable measuring device in an electrostatic field. Present manufacturers' specifications on the measurement uncertainty of electric field meters are based on an idealized test configuration, constant measuring distance and homogeneous field distribution, which does not represent the practical application of electric field meters.

The paper begins with an overview of the measuring method and the characteristics of different types of electric field meters. Considering the work of other authors and literature, the state of knowledge regarding the detection range of electric field meters, the measurement of inhomogeneous fields and calibration is presented.

Based on the obtained knowledge a modular measurement setup is developed. This allows to consider the potential influencing factors of environmental conditions, distance dependency and measuring object size as well as measuring object geometries on the measuring method of electric field meters.

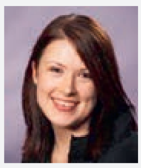
Then, the mode of operation of electric field meters in electrostatic fields is discussed by simulative considerations. Based on these findings, the detection range of the electric field meter can be determined by means of a measuring cone truncated in dependence of the characterizing measuring angle. For the metrological determination of the measuring angle, a method is developed and the measurement setup is modified.

Additionally, conditions for optimal application range and limits of the measurement of the electric field meter can be derived from this. These conditions consist of the optimal measuring distance range and the tilting of the electric field meter to the measuring object and are investigated and determined by adjustments of the measuring setup. The correction of inhomogeneous electrostatic fields is considered to take into account the indirect influence of the electric field meter and the measured objects. For this purpose, methods for the determination of correction factors of inhomogenities caused by the electric field meter and the measuring objects are described and used.

Due to the results, a measurement uncertainty consideration is performed using a consistent method for evaluation and declaration of the measurement uncertainty according to GUM. The results of the measurement uncertainty evaluation for ideal and real applications are presented, thus allowing the electric field meter to be used as a traceable measuring device.

Due to the results, a measurement uncertainty considera-tion is performed using a consistent method for evaluation and declaration of the measurement uncertainty according to GUM. The results of the measurement uncertainty evalua-tion for ideal and real applications are presented, thus allow-ing the electric field meter to be used as a traceable measuring device.

Carola Schierding



TIME AT ELENIA

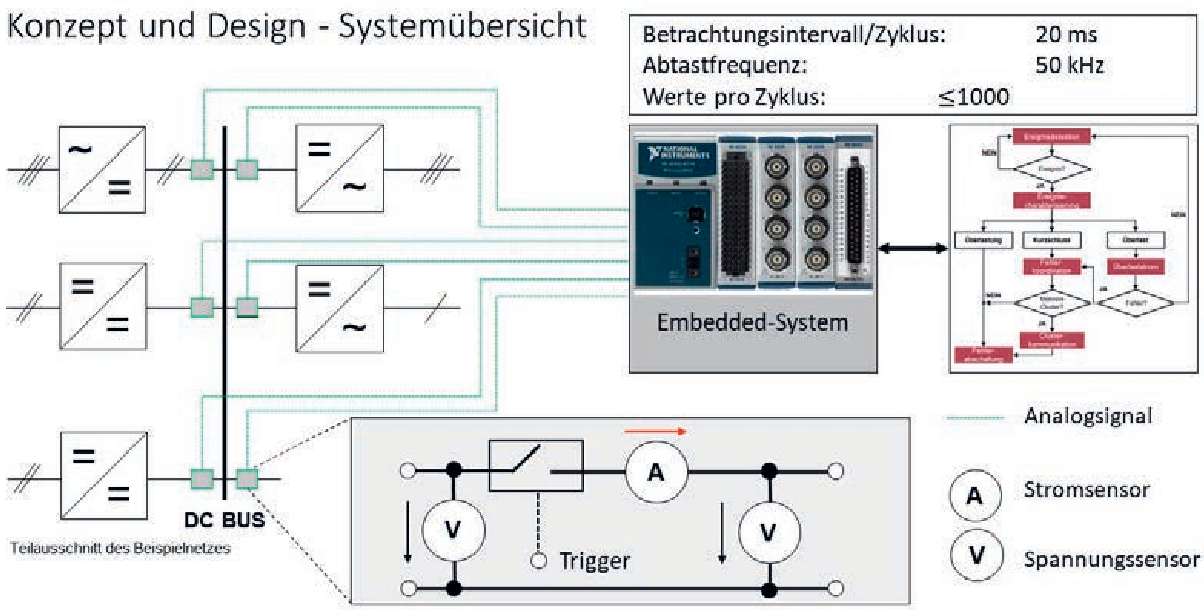
02/2015 – 01/2017
01/2017 – 01/2021
(extern)

ACTIVITIES AT ELENIA

- Mitarbeit im Schwerpunkt Komponenten der Energieversorgung
- Forschungs- und Projektarbeit im Bereich Hochspannungsmesstechnik, Dielektrische Materialprüfungen, Grenzflächenuntersuchungen, Messungen von Teilentladungen
- Mitglied im PMO

NOW ACTIVE AT

- Physikalisch-Technische Bundesanstalt (Braunschweig)



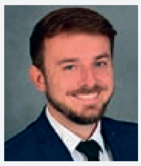
DC Systems and Switching Technologies

Christoph Klosinski

Protection system design for low voltage direct current networks

Direct current networks will be an important backbone of future energy supply and distribution. High-voltage direct current transmission already plays an important role, as energy can be transmitted more effectively over longer distances. In the low-voltage range (up to 1.5 kV DC) the focus is not in energy transmission, but rather in distribution of energy. Therefore, factors such as the increasing number of DC consumers, producers and the more dynamic grid control play a key role. If more and more technically sophisticated DC components are available on the market, a widespread use of low-voltage DC networks could be achieved. Many challenges still need to be overcome, especially in the field of DC protection. Well-developed DC protection systems that provide effective and selective protection for such networks are required. At the same time, the digitalisation of the industrial sector (Industry 4.0) and the interconnection of physical and virtual objects (Internet-of-Things) represent a great potential for the establishment of novel protection technologies. Especially for multiple feed-in, meshed networks, volatile consumption and generation. This results in increased protection requirements for fast, reliable and selective fault clearing. In this work, a unit- and algorithm-based protection system is developed to fulfill these requirements. For the determination of useful DC protection criteria, tests are performed using various load changes within a 1 kV DC model network. The found criteria will be used for the development of a novel protection concept using event detection, characterisation, localisation and selective switch off algorithms. For these algorithms, the transient phenomena within the DC network at load change will be analysed by sampling and processing of current- and voltage signals from sensor-equipped switching units distributed at specific locations within the DC network. Furthermore, it consists of an embedded-system-based protection unit to evaluate the network status in real time and executes the right decision based on the processed data in the event of a transient phenomenon to ensure reliability of supply. The reliability, speed and selectivity of the protection system have been validated in different network topologies. In all cases, the tested overload and short circuit cases have been reliably detected and – only if necessary – switched off successfully. Furthermore, transient overload cases did not lead to any shutdown by the protection system. The proposed protection system thus represents a flexible, expandable and effective way of protecting DC networks. With this developed approach, only a simplified analysis of the network conditions and components is required to ensure an effective protection.

Christoph Klosinski



TIME AT ELENIA

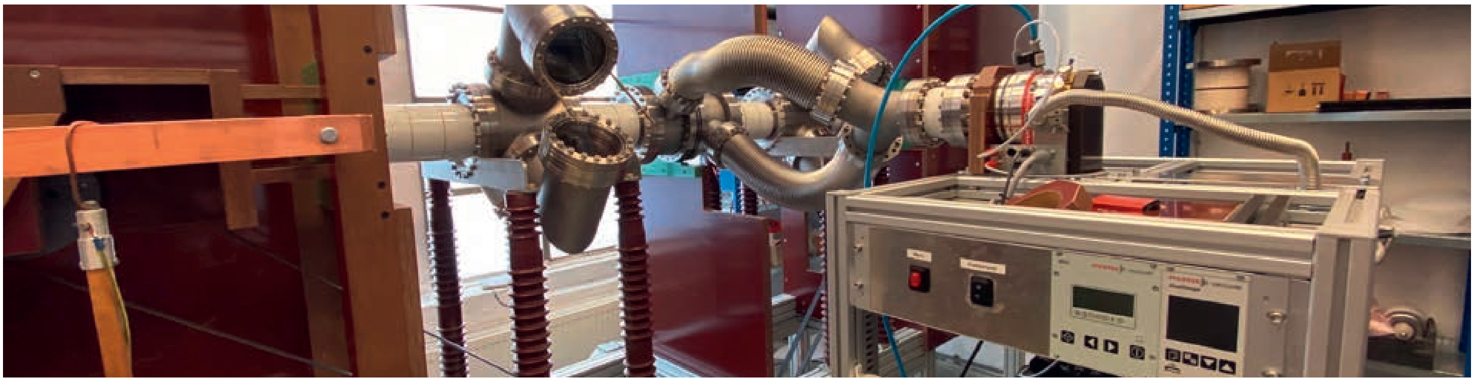
01/2014 – 12/2019

ACTIVITIES AT ELENIA

- Research Group Leader DC Systems
- Investigation and development of DC protection systems within the scope of SMS-I & II
- Investigation of Switching Chamber Materials

NOW ACTIVE AT

- Phoenix Contact GmbH & Co. KG



High Voltage-, Plasma- and Vacuumtechnology

Benjamin Kühn

Vacuum Breaker — Design of a vacuum interrupter test system and investigation of long gap arcs

In this work, a higher level of abstraction, based on the requirements engineering has been chosen to approximate the requirements for empirical test set-ups. For this purpose, a functional description, on the example of a test set-up for the investigation of plasmas under vacuum atmosphere, for high-voltage applications is performed. In the context of a functional to physical conversion, based on expert interviews and yearlong experiences with test set-ups, a new test set-up is designed, simulated and stepwise commissioned. One highlight of the test set-up is a completely redesigned operation mechanism, based on a servo motor in combination with a belt transmission. During commissioning and during the orienting investigations, the potential of the new operation mechanism becomes apparent.

The results of the 15 mm investigations are compared to other researchers and the 30 mm represent a parameter variation, which previously has not been examined with TMF electrodes. Additionally, the AC voltage polarity of the moving electrode is changed throughout the process of investigation. The basic pin electrode shows for 15 mm gaps a continuous constricted plasma column for short circuit currents with a peak of 7 kA. An increasing gap to 30 mm results in an optical divided plasma column. This behavior is also detectable for TMF electrodes with a slightly higher peak current of 12 kA and the same final gap. Furthermore, an influence of the polarity of the moving electrode and the anode activity is observed for pin electrodes. As far as the moving anode is concerned, an anode activity is only detectable at higher short circuit currents compared to the moving cathode.

In summary, this work presents a guideline for the design of empirical test set-ups. It is shown, that well-structured design approaches increase the final output and quality of scientific data. The orienting investigations provide descriptions of constricted vacuum plasma columns at selected final gaps of 15 mm and 30 mm and the discovered interaction between moving electrode and anode activity for pin and TMF electrodes. Furthermore, a comparison between the plasma behaviors of both contact systems is discovered. Using pin electrodes, the plasma shows an optical disconnection for gaps above 17 mm. This behavior is also detectable under the use of TMF electrodes with comparable conditions. The only difference is, that this behavior is here superimposed by the additional magnetic field influence of the contact system. The approach of a servo drive mechanism in combination with a belt transmission shows a general suitability for interruption applications for single and double break applications, which in itself represents added value for industry and science. The option to perform variable opening trajectories, supplies a great advantage for the scientific community, by enabling the possible parameter variations.

Benjamin Kühn

TIME AT ELENIA

2014 – 2020

ACTIVITIES AT ELENIA

- Working in the group components for power supply
- Switch-off investigations of double interruptions in vacuum with additional potential control in cooperation with ABB
- Member of the PMO

NOW ACTIVE AT

- Avacon Netz GmbH

Olga Pronobis

Charging management concepts with integrated requirements management for unpredictable behavior of electric vehicle fleets

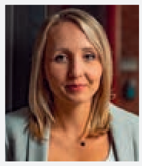
To limit the effects of climate change, CO_2 emissions must be reduced. The Bundes-tag sets the target of limiting emissions in Germany to 45 % by 2030 (compared with 1990). To achieve this goal, primary emitters, the transport and energy sectors, must reduce their emissions. Such a reduction can only be achieved if the two sectors complement each other. It is important that the use of fossil fuels to power vehicles is reduced as far as possible. Electric vehicles with energy from renewable energy plants offer a substitute.

In the present thesis charging management concepts are defined. The degree of complexity of these concepts allows their implementation in any electric vehicle fleet scenario. Depending on the concept, costs and CO_2 emissions can be saved by the implementation with the setting of the charge management requirement. In order to analyse the charge management concepts, a charge management model will be created which will allow a simulation of these concepts. The simulation scenarios are created using a fleet of electric vehicles, whose driving and standing times are very variable and therefore cannot be planned. In addition, the fleet must have a high availability. The simulation results are used to derive an evaluation matrix of the charge management concepts as well as recommendations for action for imple-mentation.

As a result, the scenarios examined show that even with the implementation of a static charge management system (charge management concept 1) the necessary grid connection capacity can be reduced by 54.42 %. Within the following charge management concepts, the reduction increases to up to 77.48 %. This reduction of the grid connection capacity lowers the costs for the grid expansion as well as the service price. Within charge management concept 2, approximately 10 % of CO_2 emissions can be avoided. In the charge management concepts 3 and 4 a reduction of 7 % is achieved. A high availability of the fleet vehicles and thus a high level of safety is given in all charge management concepts.

An essential finding is that from an ecological and economic point of view the use of a charge management system makes sense in every fleet scenario. Based on the recommendations for action, a suitable charge management concept can be derived for each application. For implementation, the fleet operators are free to use the charge management model and the charge management concepts.

Olga Pronobis



TIME AT ELENIA

04/2017 – 03/2021

ACTIVITIES AT ELENIA

- Technical focus: Charging infra-structure/Charging management
- Processing of the research project silent & ready
- Working group leader Energy Technologies
- Research-supervisor Electromobility

NOW ACTIVE AT

- Intelligent Energy System Services GmbH

Photo: Stephan Passon / PTB

High Voltage-, Plasma- and Vacuumtechnology

Stephan Passon

Metrological infrastructure for the measurement of superimposed impulse voltages in HVDC systems

Since the dramatical incidents of Fukushima with the following nuclear disaster the German government has invested in renewable energy production and the planned shut-down of all nuclear power plants. This shutdown needs to be compensated by the European electrical grid as well as all renewable energy production facilities. Only High Voltage Direct Current (HVDC) is capable to deliver the transportation over wide distances of electrical power with reduced losses. By using HVDC technology all crucial aspects on the security of energy supplies have to be well known and taken into account.

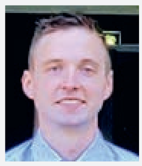
The work of this PhD thesis will focus on this field of HVDC energy transportation.

In order to establish a superimposed measurement capability at the PTB, first the pure impulse side of the generation circuit will be evaluated. This is done at low voltages, beginning with corresponding calibrators and attenuators. Afterwards, with this equipment, the high voltage measurements validate these low voltage results.

At second, the HVDC voltage measurement capability is optimized, also beginning with low voltages at the 10 V level. With these results, all scale factors are extrapolated by linearity measurements to high voltages up to 1000 kV.

In the end the superimposed voltages are produced and measured by combining the impulse and HVDC insights. The superimposed divider including the coupling elements is researched by different measurement procedures. As a result, the high voltage measurement equipment is evaluated by the uncertainty estimation of the entire system.

Stephan Passon



TIME AT ELENIA

2015 – 07/2021

ACTIVITIES AT ELENIA

- Technical focus: High-voltage metrology
- Working in the research projects UPS, SMS2, AutoHybridS, FASS

NOW ACTIVE AT

- PTB

Labs and Workshops

Battery Test Laboratories

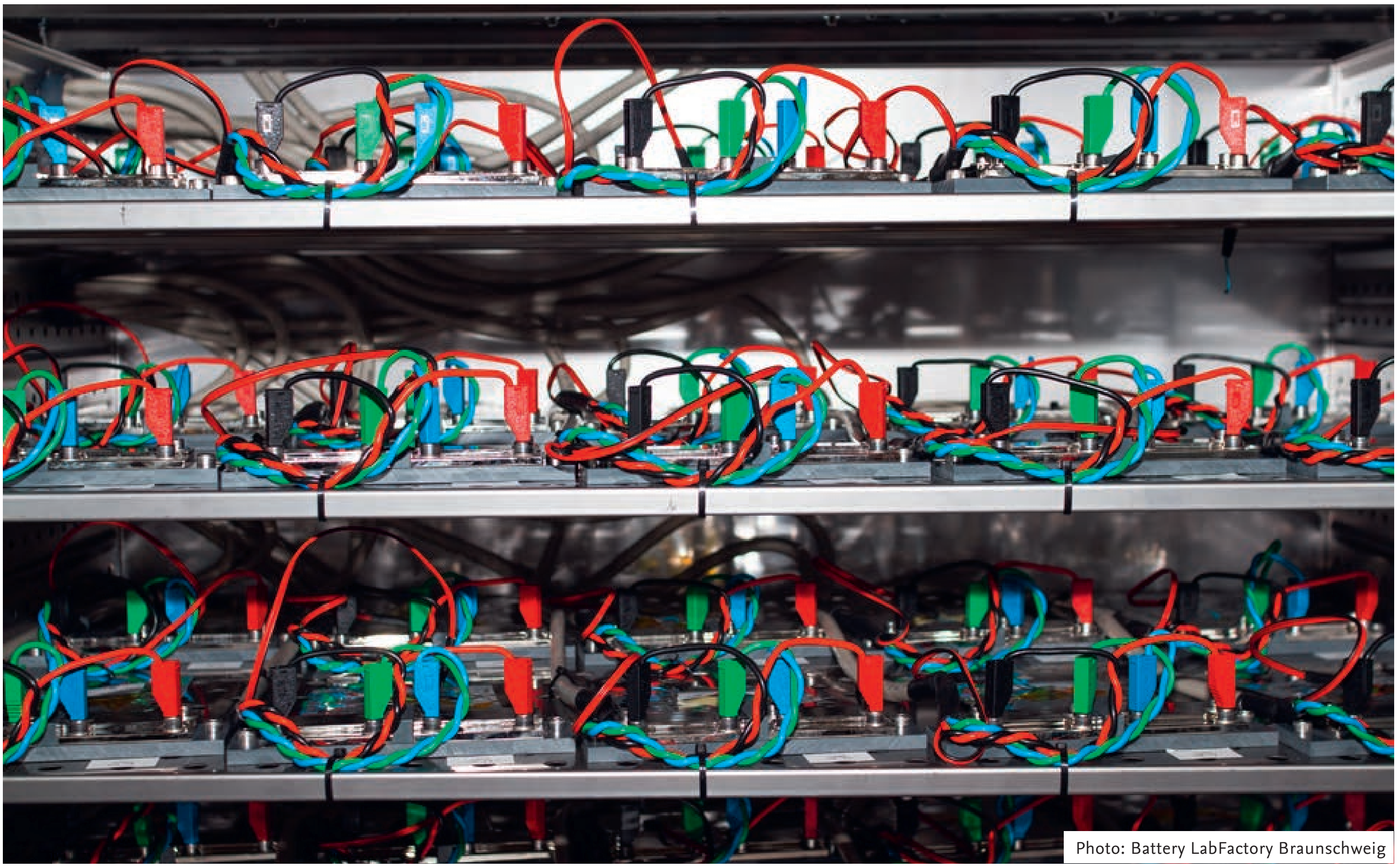


Photo: Battery LabFactory Braunschweig

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TASKS AND SERVICES

- 3-Electrode Cell Manufacturing
- Formation of Battery Cells
- Electrical Characterization
- Aging Studies
- Modeling and Simulation
- Post-Mortem Analyses by Digital Microscopy

Battery Test Laboratories at elenia

Testing and inspection possibilities at cell, module and system level

Battery technology continues to advance due to the increasing demand for electrical energy storage in mobile and stationary applications. As a result, this topic is increasingly becoming the focus of current research projects. Here, lithium-ion batteries have an important role, as they can provide comparatively high energy and power densities as electrical energy storage devices. Their high efficiency and long-term stability also contribute to their leading position. Nevertheless, there is still great potential for research in the field of battery technology in order to meet the demanding requirements placed on these energy storage devices.

The elenia Institute for High Voltage Technology and Power Systems has a number of battery test facilities at various locations. Thematically, these can be distinguished as follows with regard to the research focus:

The battery test laboratory (BatLab) in the basement of elenia contains test systems for special three-electrode measuring cells, which have a lithium reference electrode in addition to the positive and negative poles. This makes it possible to charge the electrodes separately. Since the beginning of 2020, these cells can be produced in a glovebox under argon atmosphere. Current research work is concerned, among other things, with the model-based design of fast-charging strategies for different cell material systems.

At the Battery LabFactory Braunschweig (BLB) and the associated hall (formerly the Institute for Energy and Systems Process Engineering, InES), the focus is on tests with large-format cells without a reference electrode. Cells produced in the pilot line are tested, but also commercial cells or cells provided by project partners. Current research activities include the influence of formation on cell performance, electrical and electrochemical characterization for quality assessment and long-term cycling to identify aging mechanisms.

In our laboratories at the Physikalische Bundesanstalt Braunschweig (PTB), the focus is on the module and system level. The investigations mainly concentrate on battery module and system diagnostics. Current projects include the characterization of battery modules to identify their suitability for second-life applications. Furthermore, electrical and thermal safety tests are performed on cell and module level.

A wide range of equipment for testing batteries is available at the four locations for the various tests. The portfolio includes equipment from Ametek, BaSyTeC, Digatron, EL-Cell GmbH, Gamry Instruments and Greenlight. To guarantee constant environmental conditions during the tests, temperature test chambers with a wide temperature range are available. To ensure a safe test environment, all test stands are equipped with an F90 temperature cabinet and the battery testers, as well as comprehensive safety equipment that takes effect in the event of an accident, i.e. the thermal runaway of a battery. This consists of a cabinet extinguishing system from Wagner as well as an exhaust air system and a multi-stage emergency filter from Stöbich technology. According to the hazard classification for battery faults according to EUCAR, it can be tested up to Hazard Level (HZ) 5.

The battery test systems can be used to charge and discharge lithium-ion batteries of various formats with current and voltage profiles in order to characterize their electrical properties. So-called capacity tests are performed at constant current load to determine the energetic properties. Current ratio, internal resistance and impedance measurements enable the electrical performance to be assessed. Periodic charge, discharge and storage cycles are used to record the decreasing available capacity and the increase in internal resistance. This allows the cyclic aging characteristics of different materials or loading procedures to be derived. In addition, the results of these aging studies have been supported by post-mortem analyses since 2021. In this process, the cells are opened and microscoped in an inert gas atmosphere. Special methods such as differential stress analysis and electrochemical impedance spectroscopy can be used to determine various causes of battery aging. Furthermore, the calendar aging in safety chambers is a subject of investigation, e.g. to determine the self-discharge over a certain period of time or to quantify the calendar aging influence by different electrical characterization tests.

Apart from the classical test procedures for determining the electrical properties of battery cells, special pulse methods are also used to parameterize battery models with the aid of battery test systems. The focus is on electrical equivalent circuit models, which allow the electrical behavior of the battery to be simulated. As with the other battery test methods, care must always be taken to ensure that the batteries are tested under constant and identical environmental conditions. Several temperature chambers with a wide temperature range are available for this purpose. These also allow the battery models to be parameterized as a function of the permissible operating temperature. With the aid of electrothermally parameterized battery models, the use of the tested battery cells can be checked for various areas of use and applications.

Photo: Kerstin Ryll/TU Braunschweig

Cell Tester of Fa. BaSyTeC

- 48 channels ± 50 A, 0–6 V, parallel connectable
- 48 channels ± 25 A, 0–6 V, parallel connectable
- 52 channels ± 20 A, 0–6 V, parallel connectable
- 90 channels ± 5 A, 0–6 V, parallel connectable
- 3 channels ± 30 A, 0–150 V, parallel connectable

Cell and Module Tester of Fa. Digatron

- 6 channels ± 100 A, 0–6 V

System Tester of Fa. Greenlight

- 1 channel ± 600 A, 5–200 V

Impedance Spectroscopy of Fa. Ametek and of Fa. Gamry Instruments

- 2 channels ± 20 A, 0–10 V, 10 μHz–1 MHz
- 24-fach Multiplexer ± 3 A, 0–32 V, 10 μHz–1 MHz

3-Electrode Cell Tester of Fa. EL-Cell
Test system for three-electrode measuring cells

- 32 channels ± 0,1 A, 0–6 V, EIS
- 8 docking stations for other cell testers
- -40 °C to 180 °C and -20 °C to 80 °C
- S* docking stations for other cell testers

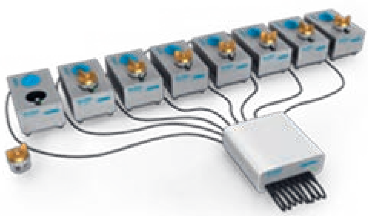


Photo: EL-Cell GmbH

Temperature Test Chamber of Fa. Binder

- 6 x KB 420/S*, KB 700/S*
  - Test volume 6 x 420 l and 2 x 700 l
  - -5 °C to 100 °C
- MK 240/S*
  - Test volume 240 l
  - -40 °C to 180 °C
- 2 x BF 115
  - Test volume 112 l
  - 30 °C–100 °C

Temperature Test Chamber of Fa. Weiss and Vötsch

- Test volume 600 l and 34 l
- -40 °C to 180 °C and -20 °C to 80 °C
- S* incl. cabinet extinguishing, exhaust air and emergency filter

Photo: Battery LabFactory Braunschweig

Photo: M.Braun GmbH

Glovebox of M. Braun

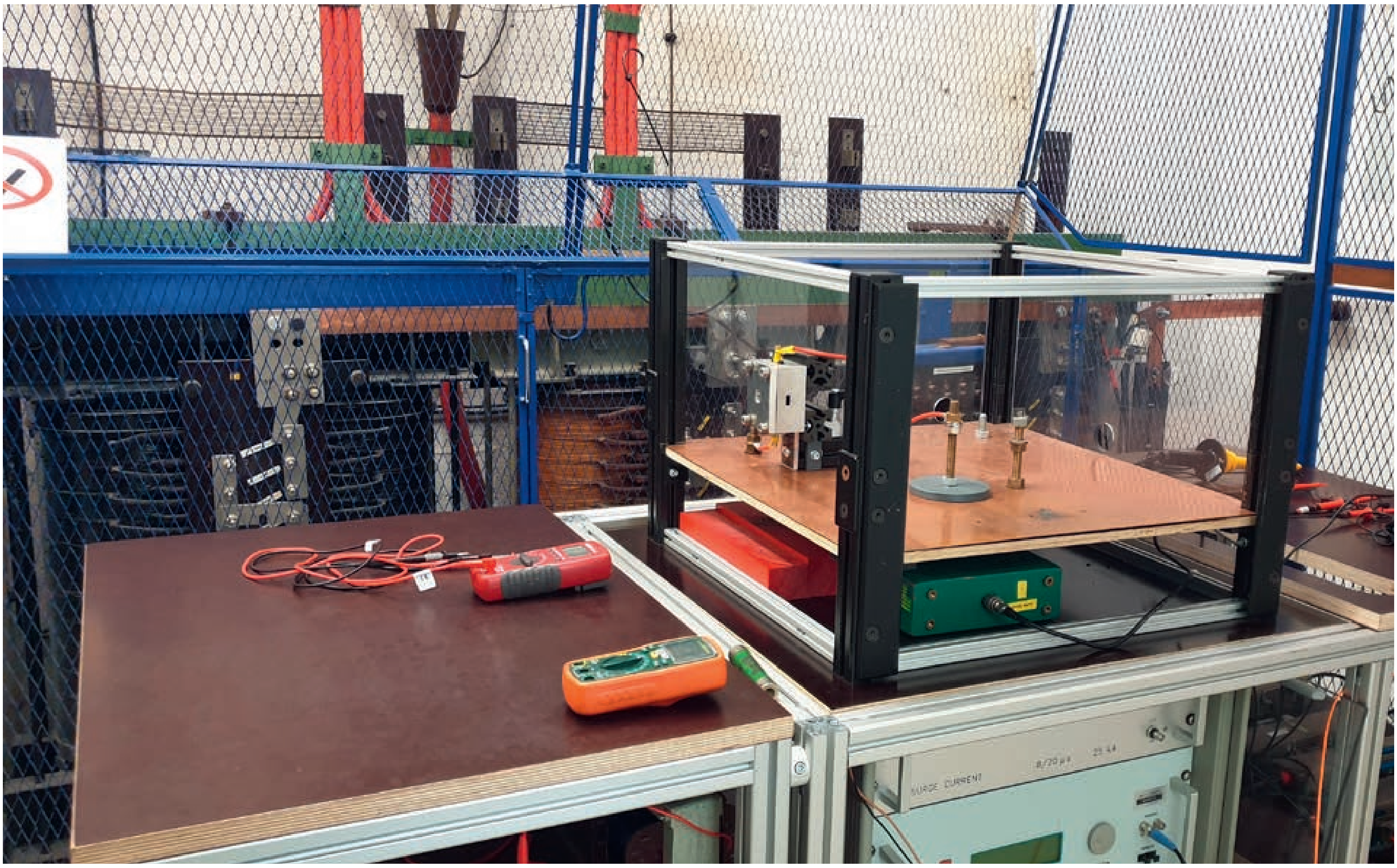
- 0,8 m³ Box volume
- Sluice furnace to 120 °C

Keyence Digital-microskope VHX7000

- 20×–2500× Magnification 3D measurement software

Photo: M.Braun GmbH

Lightning Protection Laboratory



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TASKS AND SERVICES

- Measurements with the low voltage grid with voltages between 50 V to 750 V
- Prospective short circuit currents up to 15 kA at 250 V
- Research on spark gaps with surge currents up to 25 kA (8/20 μs) or 600 A (10/350 μs)
- grid impedance adjustable
- different grid synchronisation angles
- Diagnostic of high dynamic plasma parameters (pressure, temperature and conductivity)

Lightning Protection Laboratory

AC power test field with high rated short-circuit power and surge currents of up to 25 kA

Surge arresters (SPD's class 1) are categorized as primary protection and ensure the safe operation of electrical and electronic equipment. They limit overvoltages that occur as a result of a lightning strike or switching operations in the grid. In surge arresters based on the spark gap technology, a plasma is ignited between two electrodes in the event of an overvoltage. This creates a short-circuit to the grounding system, whereby high energies can be diverted. The requirements for modern surge arresters increased, there is for example a higher demand regarding the energy absorption capacity. Due to the short-circuit to the grounding system, interactions with the connected grid occur, as a result a grid-driven short-circuit current occurs in the plasma. This follow current should be extinguished as quickly as possible after the successful discharge process which is a further requirement.

Various surge voltage and surge current generators are available at the elenia for the research on questions conserning surge arresters. Especially notable is the "lightning protection laboratory". In addition to a surge current, a low-voltage transformer is also connected to the device under test. This low-voltage grid emulation is fed by the medium-voltage grid at the 6 kV level. This allows to observe the interaction of the surge current and the follow current. Figure 1 shows the simplified schematic diagram of the laboratory.

The surge current is generated by a surge current generator (1). Here 8/20 µs pulses with up to 25 kA or 10/350 µs pulses up to 600 A can be generated. The low voltage grid emulation is realized by three parallel connected 130 kVA transformers resulting in a testable current of 15 kA (2). Resistance and inductance banks are available for setting the ohmic-inductive ratio for different test setups (2). For the analysis of very fast plasma processes within µs scale, a stable and time-discrete measurement technique is necessary. At the elenia five EMC shielded measuring probes with an amplitude resolution of 14-bits at a sampling rate of 100 MS/s are available for this purpose. The measuring probes are connected to the measuring system via fiber optic cables (3). Additional measuring equipment is also available, such as Pearson and high-voltage probes (4), potential probes (5), pressure sensors (6), spectrometers (7) and a high-speed camera (8).

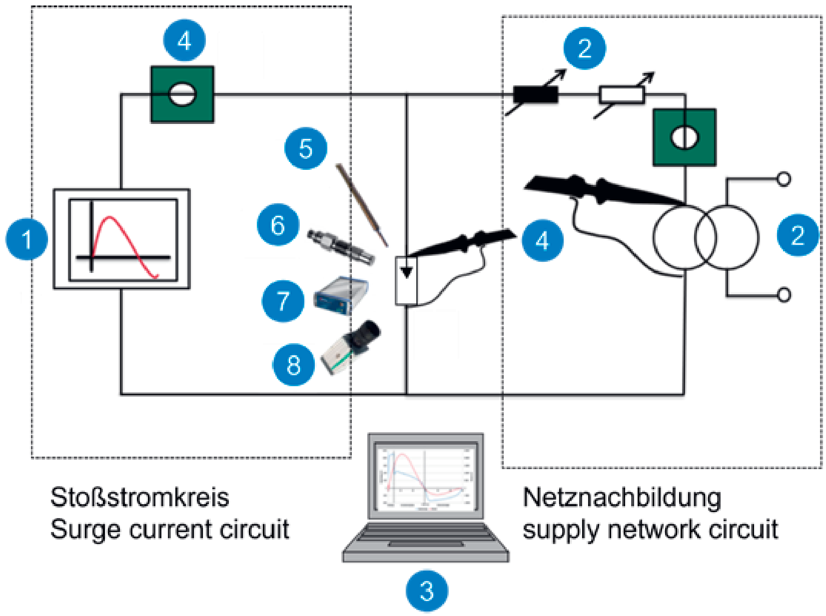
The current goal of the research is to describe the transition from the highly conductive plasma to the insulating state after surge current. With the help of the measurement technique described in Figure 1, experiments take place in this plasma phase. Recently, the laboratory has been completely renovated with regard to a better cable routing. In particular, very high surge currents cause EMC interference with the device under test or the measurement equipment. Thus, the coupling paths have been minimized as good as possible. The test setups are now also modularly expandable, so that the test arrangement can be changed at any time. Optical examinations are carried out in parallel with electrical measurements currently. For these investigations, new precision mounts have been installed in the lab, which allow an optimized optical alignment of the measurement equipment to the plasma chamber. The research makes it possible to model the spark gap arresters and thus to ensure a targeted development of the surge protection. Additionally, the laboratory can be used for grid frequent (50 Hz) short circuit current test, for example for low voltage switchgear.

Photos: Tobias Kopp/TU Braunschweig

→

Overview of the "lightning protection laboratory" for research of transient plasma behaviour

- 1: Surge current generator EMC 2004
- 2: Low voltage grid up tp 750 V with adjustable grid impedance
- 3: Transientrecorder: BitGate AD 3000
- 4: Voltage- and Current measurement
- 5: Conductivity measurement via potential probes
- 6: Pressure measurement
- 7: Spectroscopy
- 8: High Speed Camera



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Surge current generator EMC 2004

- Charging Voltage up to 10 kV
- Energy up to 1500 Ws
- Different impulse forms
- Surge currents up to 25 kA
- External Trigger available

→

BitGate System AD 3000 with measurement probes

High-resolution measuring system for simultaneous recording of electrical quantities

- 5 measurement probes
- 14 Bit resolution
- Sampling rate up to 100 MS/s

←

High speed camera Nova S6

High speed camera for analysis of the plasma distribution with precision mount

- Resolution up to 1024 × 1024 pixels
- Maximum frame rate of 800 kfps
- Minimum integration time of 200 ns
- External Trigger available

DC Demonstration Grid Laboratory

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TASKS AND SERVICES

- Investigation of dynamic load changes in the grid
- Development and testing of DC protection systems
- Investigation of the switching properties of commercially available DC switching devices
- Investigation of DC grid topologies
- Characterisation of different operating and fault scenarios in the variable grid structure
- Development of a novel DC protection system

SUPPORTED BY

Bundesministerium für Bildung und Forschung

aufgrund eines Beschlusses des Deutschen Bundestages

DC Demonstration Grid Laboratory

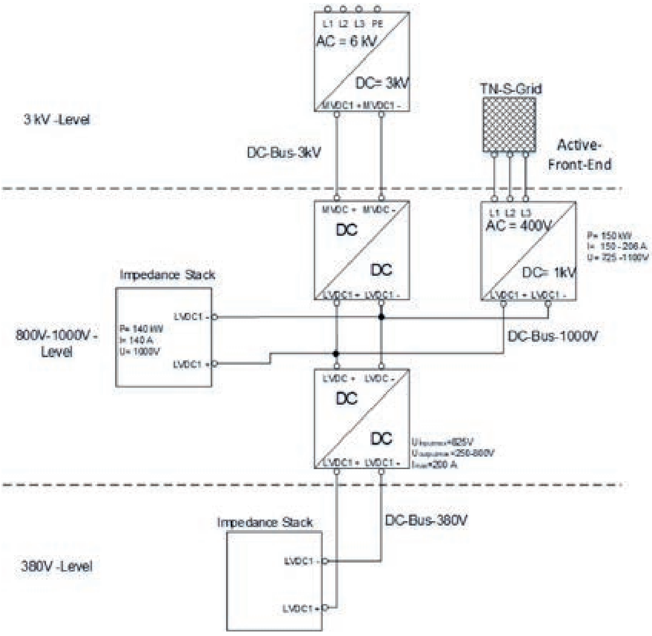
Introduction
The advancing energy transition in Germany and technical advances in power electronics mean that DC technology is becoming increasingly important in the industrial sector as well as in energy transmission and mobility. This technology offers a wide range of application advantages (efficiency, material savings, etc.) but also brings with it challenges and questions that need to be answered in order to ensure safe use.

The DC demonstration grid laboratory supports the investigation of a wide range of grid topologies through a flexible, rapidly adaptable setup and a large spectrum of different source and load types.

Two voltage levels (0–380 V and 1 kV) are already in use, and by mid-2022 the structure will be expanded to include a 3 kV voltage level.

Structure, components and object of investigation
The demonstration grid laboratory offers a wide range of tests for investigating DC grid topologies. The performance data, the planned overall setup including all voltage levels and the detailed description of the laboratory components can be found in the table on the next page. Currently, the demonstration grid laboratory is working on general grid characterisation and modelling for DC grids. The largest possible experimental space is achieved by a wide range of variable load impedances and active source and load components. In addition, a DC protection system is being developed and investigated in various failure scenarios. In addition to current and voltage, the time constant, network topology and internal regulation of selected sources and loads can also be adjusted. Another advantage is that additional equipment can be easily integrated into the existing structure. The performed measurements are recorded using the latest measuring technology. The network states during dynamic load changes as well as switching processes and the reaction of the protection system can thus be analysed precisely.

Outlook
In the future, the existing voltage levels will be supplemented by a further voltage level (3 kV). The spectrum of applications that can be simulated will thus be expanded once again. The test field in its design as a real structure spanning all voltage levels is a unique feature at elenia.



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Grid structure

- Connection of the test field directly to the 6 kV distribution network of the university
- Transformer: 220 kVA, 6 kV/2*780 V
- Behind the transformers is an AFE, which performs the rectification to 3 kV DC (± 1.5 kV)
- Further DC converters feed the 1 kV level from the 3 kV level
- In addition, the 1 kV level is fed from regulated DC sources and a second AFE, which are both connected to the three-phase AC grid
- The 380 V level is also realised via a DC converter (1 kV/380 V)
- By combining the equipment, a wide variety of applications can be simulated
- Both active and passive loads can be realised
- Rated current (on 3 kV level): 50 A
- Variable test duration and parameters adjustable through digital sequence control

→

The acquisition of electrical measurement data during the investigations is carried out for evaluation via an HBM system, probes and precision measuring shunts, and for the protection system via sensor boxes specially manufactured by the PTB

Transient recorder HBM Gen2i/Gen3T-2:

- 16 measurement channels (isolated, BNC and fiber optic)
- 12 bit resolution
- Up to 100 MS/s sampling

PTB sensors for the protection system

- Dual voltage divider for high-frequency and stationary signals and contactless current measurement
- Rated current of the sensors 200 A
- Voltage measurement up to 3.6 kV

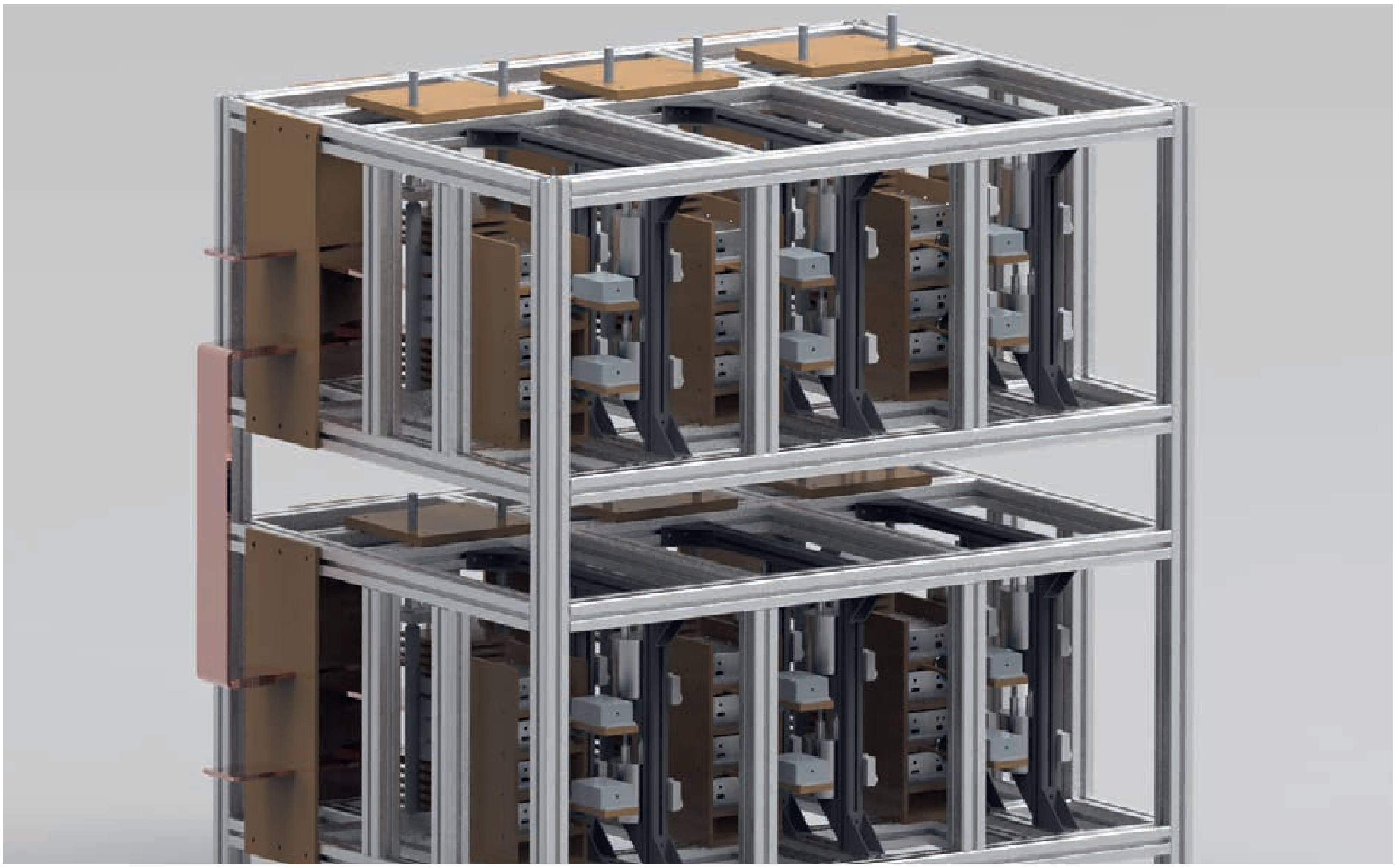
←

Wiring through plug-in system and internal components
A wide range of topics can be covered:

- Modelling of a wide range of DC on-board grids, industrial and distribution network structures
- Network characterisation and modelling of DC networks with the aid of Design of Experiments (Doe)
- Development, investigation and optimisation of novel DC protection systems with a focus on switchgear coordination in case of current faults

At present, re-strengthening tests are also being carried out after DC loads on various arresters and in switches

DC-Test Facilities



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TASKS AND SERVICES

- Development and optimization of DC switches and hybrid switching de-vices
- Research on switching characteristics of commercially available DC switching devices
- Evaporation behaviour of plastics based on thermal arc loading

SUPPORTED BY

Bundesministerium für Wirtschaft und Energie

aufgrund eines Beschlusses des Deutschen Bundestages

DC-Test Facilities

Introduction of the high-power DC test facilities with focus on the commissioning of the new DC.lab of the funded project UPS

The share of operating DC grids is increasing more and more, thus in research projects with our participation this is very well noticeable. DC Industry 2, SE2A, SMS 2 and UPS (see research project chapter 6) are examples of our research projects investigating these grid structures and its components. Current and future areas of application include distribution, industrial and on-board grids in electric vehicles, ships or aircraft.

In addition to our existing DC test laboratory with a maximum current of 5 kA and a voltage of up to 561 V (Fig. 1), a new high-power DC.lab test laboratory for DC high-current testing is being built at elenia as part of the BMWi funded project UPS. The design of the test field started with the start of the project in 2016. Different possibilities to provide the needed high DC current during high operation voltages have been investigated. The laboratory will be able to generate a maximum test voltage (DC) of 12 kV DC and a maximum test current of 30 kA in the next year. Due to the high power levels targeted, a new grid connection is being bulit up, in close cooperation with the relevant departments of the TU Braunschweig and the local grid operator BS|Netz.

The heart of the new laboratory is a controlled B12 rectifier. No phase angle control of the rectifier is used for the test parameters. The basic behaviour of the bridge was verified in simulations. The rectifier is supplied via two new test transformers installed in the basement of the institute (Fig. 2). Due to the 30° shifted output voltage of the two transformers, a particularly low residual ripple of the DC voltage is achieved. The actual test field (rectifier, measurement and test equipment) will be set up in the institute's high-voltage hall. The construction work within the framework of the UPS project has been planned with the building management of the TU Braunschweig and is currently being implemented.

The thyristor drivers independently send a firing pulse based on the control signal and voltage drop across the thyristor. Separate high-frequency converters were developed to supply the drivers with power (Fig. 3). They operate according to the transformer principle, but do not require an iron core.

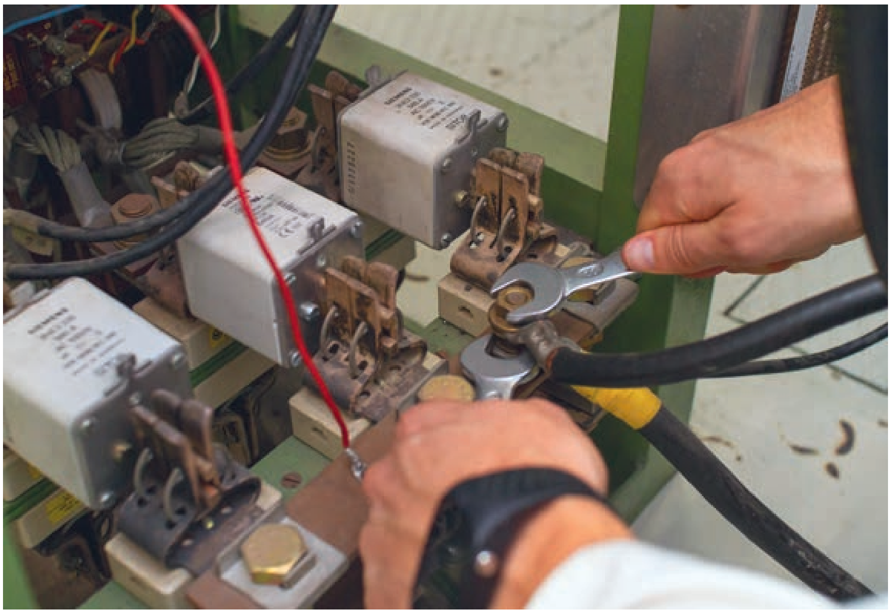
To ensure safe operation of the rectifier, the thyristor drivers check their connection to the sequence control frequently. If the supply or communication line to a driver fails, this is reported to the control system and the laboratory transits immediately into safe mode.

As semiconductor protection against short-circuit currents in a new approach a I_S-limiter was installed to protect the bridge due to the high power rating other technologies were not able to provide the protection area needed. The limiter is installed in the high voltage hall and interrupts the 20 kV power supply to the transformers if the maximum permissible current is exceeded.

An initial commissioning has been carried out already. For this purpose, the test transformers were supplied with 10 kV via a variable and medium voltage transformer.

The rectifier worked as intended during initial switching tests.

In the coming months, the medium-voltage switchgear will be built into the basement of the institute and the transformers will be installed there also. The institute will then be connected to the 20 kV medium-voltage grid via a new substation.



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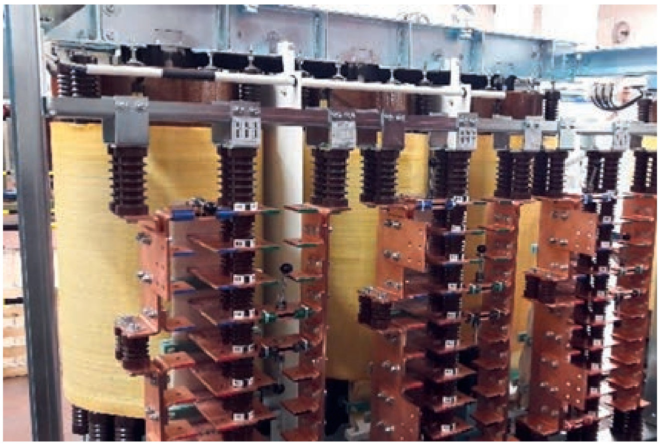
Connectors of the DC-laboratory at Okerufer
Generation of direct current from alternating current via:
- an active B6 bridge rectifier circuit
- Thyristor-based rectifier with fuses as back-up protection
- Max. DC test voltage: 561 V
- Max. DC test current: 5 kA Ignition
- Variable thyristor-angle setting
- Variable test duration due to digital sequence control

→

Transformers of the DC.lab
Generation of direct current from alternating current via:
- a B12 bridge rectifier circuit
- Thyristor-based rectifier with Is limiter as backup protection
- Max. DC test voltage: 12 000 V
- Max. DC test current: 30 kA
- Low residual ripple
- Variable test duration by digital sequence control



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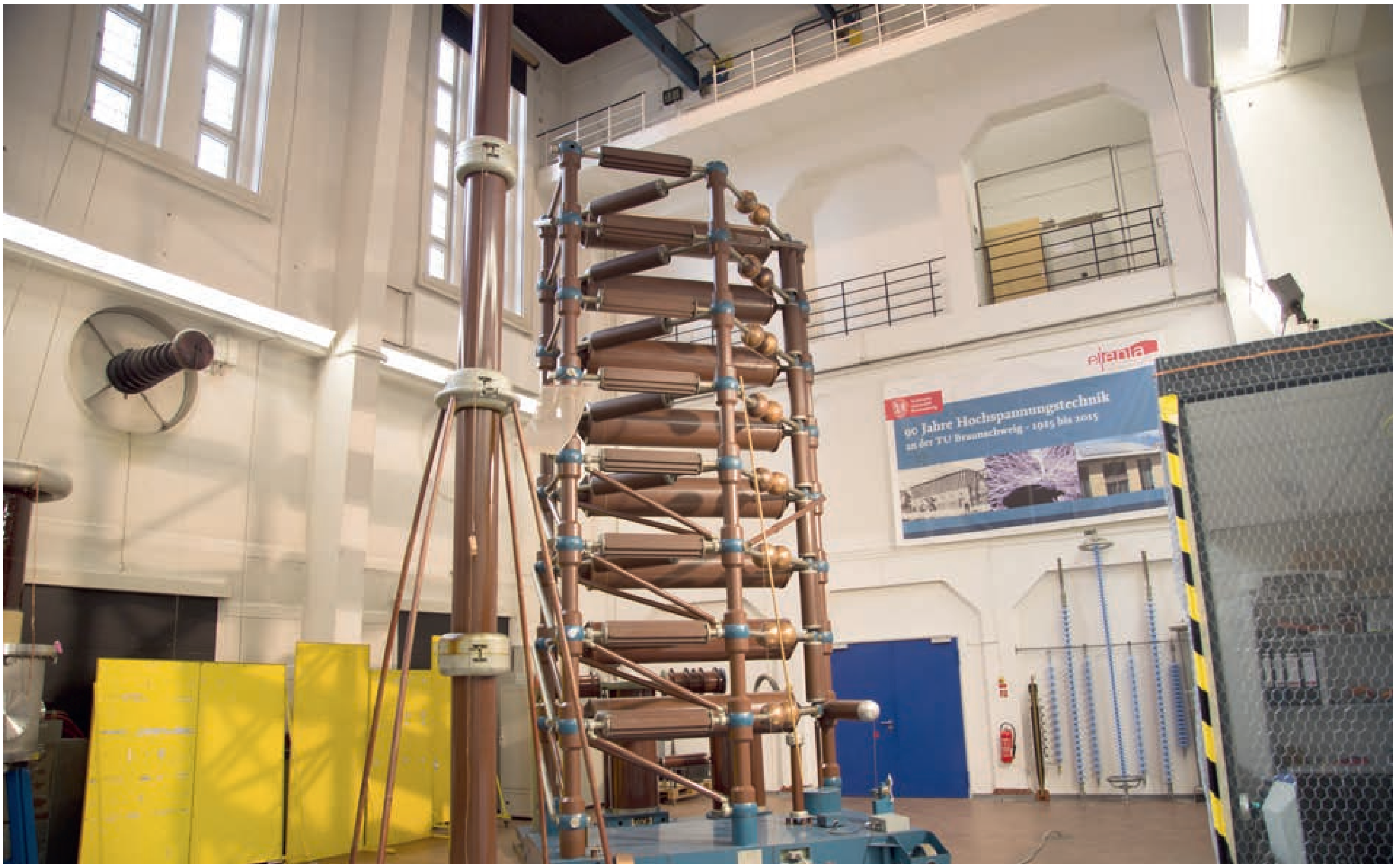
Transientrecorder HBM Gen3T
Acquisition of electrical and optical measurement data by:
- HBM Gen3T transient recorder
  - 4 measurement channels (fiber optic)
  - 4 measurement channels (differential)
  - 14 bit resolution
  - 100 MS/s
- High-Speed-Camera Redlake MotionPro X4:
  - Resolution 512 × 512 pixels
  - Black and white or color recording
  - Max. Frame rate of 200 fps
  - min. exposure time 1 µs

High Voltage Laboratory



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TASKS AND SERVICES

- High voltage measurements (flashover/breakdown) with alternating, lightning impulse and DC voltage on model assemblies or prototypes according to IEC 60060-1
- Partial discharge measurements and interpretation on models and components made for low-voltage, medium and high-voltage, if necessary according to IEC 60270
- Dielectric material tests such as loss factor, relative permittivity and transmission-resistances at variable frequencies and temperatures
- Various high-speed cameras are available for the visualization of discharging-phenomena

High Voltage Laboratory

Much space for experiments of medium and high voltage technology and for teaching at pandemic times

The high-voltage lab of the department is divided into three areas. There is the large test field with two systems for High voltage generation, alternating voltages and lightning impulse voltages, the DC power test field (detailed laboratory report separately) and the electrically shielded partial discharge measuring cabin.

The large test field offers various possibilities for testing, also due to the use of the Greinacher Cascade which generates a DC voltage of an input side alternating voltage, thus three voltage forms can be generated in the large test field. The achievable voltage amplitudes are up to 800 kV for AC and DC voltages and for lightning impulse voltage up to 2 MV. Furthermore various circuits in the voltage range of up to approx. 300 kV via the existing modular systems can be set up. In addition to the generation voltage dividers are also required. For every voltage form and amplitude a suitable divider, e.g. the up to 2 MV suitable damped capacitive (Zaengl) divider, various capacitive dividers up to 400 kV, ohmic dividers up to 200 kV or installed in the Greinacher cascade up to 800 kV is needed. Via measuring satellites from transient recorders, the voltages can also be transmitted floating and thus ensure the safety of employees.

In addition to the generation and measurement for measurement campagnes the appropriate experimental set-up is also required. Here, countless assemblies are already available and new ones can be manufactured in the workshop of the institute. Among other things a cryostat is available for measurement campagnes up to Û = 200 kV at temperatures of -190 °C in liquid and gaseous nitrogen with possibilities for visual Observation of the discharge, via high-speed cameras and sight glasses, as well as irradiation of the superstructure. Alternatively investigations in vacuum test vessels with up to 400 kV at 10^5 mbar can be done. Current investigations on this test vessel are performed to record X-ray radiation in experiments with lightning impulse voltages.

In the partial discharge measuring cabin, which is equipped with line filters to protect it against mains-side interference a partial discharge measuring system for partial discharge measurements from 1 pC and a parallel test system with 10 measuring stations are available. A setup for generating high-frequency voltages is also available in the TE-cabin. Especially due to the use of power electronics it is to be assumed that high-frequency interference will become more and more relevant in the future.

During the Covid 19 pandemic, the size of the high-voltage laboratory made it possible to carry out the “High-voltage technology” practical course in the presence of the students, as the required distances could always be maintained. Thus, the diverse and highly exciting experiments brought variety into the online studies and the enthusiasm for high-voltage engineering could be awakened in some students.

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AC voltage transformer

- Middle: 50 Hz alternating voltage transformer up to 400 kV / 400 kVA (up to 800 kV possible)
- Centre: Various modular components consisting of capacitors, resistors and diodes
- Left: Compressed gas condenser for voltage measurement
- Right: Cryostat to -190 °C and ~200 kV to 3 bar bsolute pressure

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Surge Generator

- Left: Surge voltage generator for lightning surge voltages with 400 kV / 50 kJ (up to 2 MV possible)
- Far right: load capacity and resistances adjustable for standard-compliant 1.2/50 pulses
- Right: Damped capacitive divider up to 2 MV

Partial discharge measuring cabin

- Front: Partial discharge measuring stand for alternating voltages up to Û = 100 kV and background noise level < 500 fC–1 pC, at temperatures up to 150°C
- In the back: Parallel testing system for breakdown tests in oil and air

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Greinacher cascade and vacuum test vessel

- Left: Greinacher cascade up to 800 kV at 0.05 A with integrated divider and changeable polarity
- Right: Vacuum test vessel up to 400 kV at 10^5 mbar with sight glasses

Insulating Materials Laboratory

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TASKS AND SERVICES

- Partial discharge measurements and interpretation on models and components of low, medium and high voltage, if necessary according to IEC 60270
- Dielectric material tests such as dissipation factor, relative permittivity and contact resistance at variable frequencies and temperatures
- Parallel test equipment for breakdown tests in oil and air

Insulating Materials Laboratory

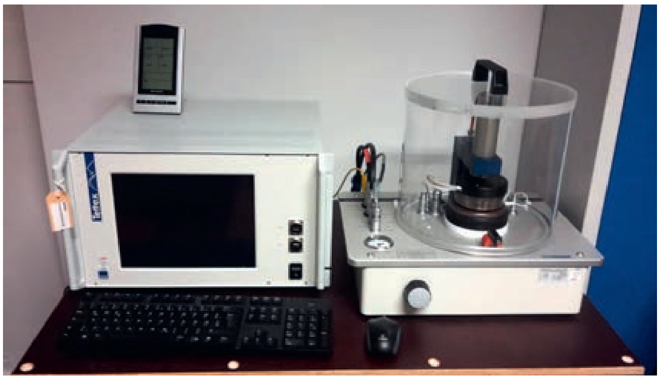
Qualification of a laboratory for research of new insulating materials and systems for DC systems and electric mobility

Insulating materials used in electric motors, for example, are subject to increasingly stringent requirements in the field of electromobility. In addition to the classic methods of testing insulating materials, new methods and approaches are needed to improve the evaluation and service life estimation.

In the past, various scientific studies have been carried out to assess the quality of insulating materials. For example, Frank Gerdinand examined mineral-filled epoxy resin molding materials in 2004, and Michael Budde conducted a condition assessment of electrical insulation using partial discharge diagnostics in 2009. The insulation condition of an insulating material is characterized by a large number of dielectric parameters and strength parameters. Currently, for example, the ε_r and tan (δ) measurements can be carried out in the rooms on the second floor. For partial discharge investigations, the electrically shielded partial discharge measurement cabin in the high-voltage hall has been used so far. The electrically shielded measuring cabin available on the second floor will be set up for the partial discharge tests in future finishing work. The new measuring cabin will enable highly precise, interference-free and effective measurement of partial discharges. This will enable the smallest weak points in the insulation to be detected and analyzed. The insulation laboratory in the basement of the elenia remained in storage for a longer period of time. The first steps towards re-commissioning the insulation materials laboratory have been initiated in recent months. The equipment of past research projects has been checked, overhauled or brought into working order. Future measurements should be able to take place under various environmental conditions, as temperature and humidity affect the measurements. For tests at higher temperatures, a vacuum drying oven with up to 180 °C is available. Conditioning of the insulating materials can be done in a desiccator or in water basins. A vacuum bell jar can be used for tests in a vacuum. The commissioning of the parallel test facility in the insulating materials laboratory makes it possible to perform four additional breakdown tests to the existing facility with ten samples in the high-voltage hall at the same time.

The aim of the reopening of the insulating materials laboratory is to conduct insulating materials research at the highest level and at the latest state of the art. In future research projects, the accumulated competences in testing and diagnostics of insulating materials will be further deepened. Furthermore, the research portfolio at elenia will be expanded. This will strengthen the interest in insulating materials research at elenia in order to ensure the promotion of young scientists in this field. To this end, new experiments for the high-voltage practical course are being created for teaching purposes and old ones are being revived. In the long term, this will result in a new practical course.

Photos: Maik Kahn/TU Braunschweig



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Schering bridge

- Measuring system for the determination of dielectric properties
- Haefely Tettex 2830/2831 with 2914 temperature measuring cell
- Relative permittivity (εr)
- Dielectric loss factor (tan (δ))
- Frequency range: 50 Hz
- Voltage range: 2.5 kV

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Impedance meter

- Dielectric characterization of solid materials in time and frequency range
- Omicron-Lab measuring system "Spectano 100" with sample holder "DSH 100"
- Relative permittivity (εr)
- Dielectric loss factor (tan (δ))
- Frequency range: 5 μHz – 5 kHz
- Voltage range: 0.1 V – 200 V

Shielded measuring cabin

- Partial discharge measurement (PD measurement)
- Voltages up to 100 kV AC
- Basic noise level <1 pC
- Inverter up to 20 kHz
- Temperature range: -40 °C to 200 °C at 50 Hz
- Data acquisition system

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Parallel test system

- Parallel test system for breakdown tests
- Breakdown tests in oil and air
- Four simultaneous tests
- Strength tests up to 100 kV, without parallel system up to 200 kV
- Automatic shutdown in case of breakdown

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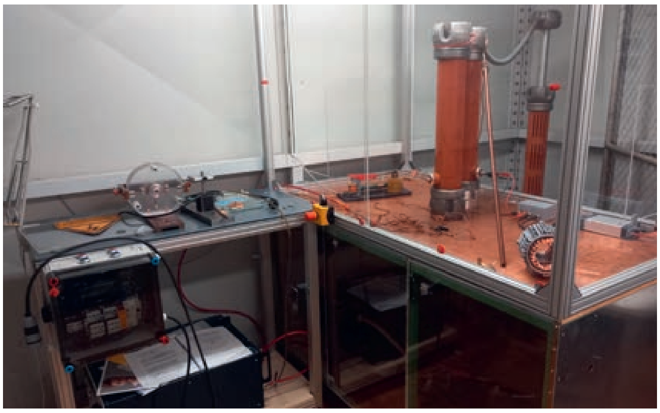

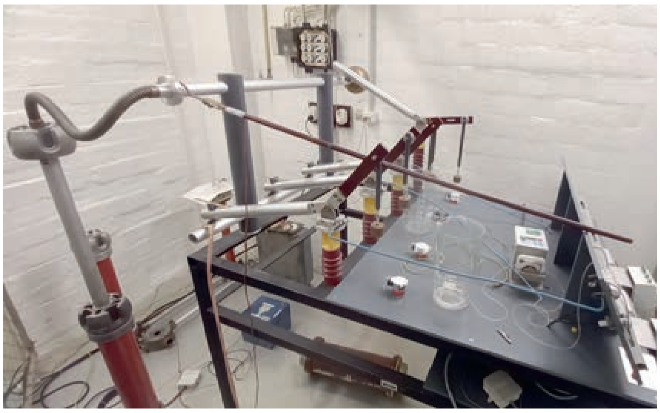

Joint Laboratory

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TASKS AND SERVICES

Validation of Meshed DC Systems with Real-Time Simulation Applications

- Hardware-in-the-Loop (HiL)
- Power-Hardware-in-the-Loop (PHiL)
- Rapid Control Prototyping (RCP)

Modelling and Simulation

- Operation, Control and Protection of MMC and DC Systems
- Control Theory in General

Joint Laboratory

Validation of laboratory-scale DC grids and converters with power-hardware-in-the-loop experiments

The validation of meshed HVDC grids is a challenging task due to the complexity of such systems. Main focus lies on validating concepts for operation, control, and protection, while especially the performance of converter technologies, with the Modular Multilevel Converter (MMC) as the main technology, is of significant interest.

A great demand for the proof-of-concept through laboratory-scale prototypes exists. The prototypes act as interfaces between plain simulation and the actual implementation. The experiments can be conducted harmlessly and under well-defined conditions, which is not possible with field studies. The experimental results support the credibility of simulations to a great extent.

Due to the complexity of DC systems, not all system elements can be represented in the laboratory as prototypes. Using Power-Hardware-in-the-Loop (PHiL) applications, some of the system elements can be simulated in real-time instead. The prototype then interacts with the simulated system elements, and vice versa. A power amplifier serves as the mandatory interface. Simulated logic level signals are converted to power level signals to stimulate the prototype.

As development with simulations of complex DC system topologies, and validation with laboratory-scale prototypes are strongly linked to each other, the elenia Institute for High Voltage Technology and Power Systems – together with the Institute for Electrical and Energy Systems (IfEA) of the Ostfalia University of Applied Sciences – initiated cooperative work.

At the IfEA, a suitable laboratory environment exists, which is used with emphasis on validation of DC systems with laboratory-scale prototypes, control and performance of MMC, as well as PHiL applications. The real-time simulators and power amplifiers at the facility play the most significant role component-wise.

A three-nodal and laboratory-scale HVDC system serves as the basis for both the prototype development and the development of suitable workflows for validation in general. Additionally, PHiL applications are being developed and validated with implementations of MMC components. To accomplish that, fields of competence include control theory, power electronics, modelling and simulation.

Photo: opal-rt.com

Photo: Marc René Lotz/TU Braunschweig

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Real-Time Simulator (OPAL-RT OP5707)

- Intel Xeon E5 series
- 16 Analog In, 16 Analog out
- 32 Digital in, 32 Digital out
- Ethernet, CAN, IEC 104, IEC 61850, SFP
- Real-time optical fibre link with power amplifier Triphase PM15

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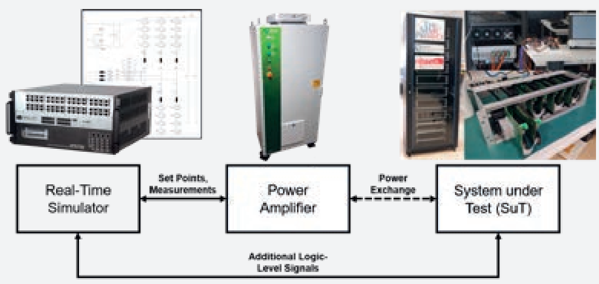
Power Amplifier Triphase PM15

- 15 kVA, ± 650 V
- Four-Wire AC Current Source
- Two-Wire DC Voltage Source
- Full 4Q Operation
- Both sources can be operated independently and simultaneously
- Real-time operation and communication with OPAL-RT OP5707



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Power-Hardware-in-the-Loop (PHiL) Setup

- MMC real-time simulation on Real-Time Simulator
- MMC components in the laboratory as System under Test (SuT)
- Set points sent from Real-Time Simulator to Power Amplifier, measurements are fed back
- Power exchange with SuT via Power Amplifier
- Simultaneous validation of controller designs and power electronics components

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MMC Components in the Laboratory

- MMC consists of many power electronics components, the commutation cells
- A cell stack is validated using PHiL
- Each cell consists of a half-bridge with an internal capacitor and an individual controller
- Four commutation cells with their corresponding controllers are shown

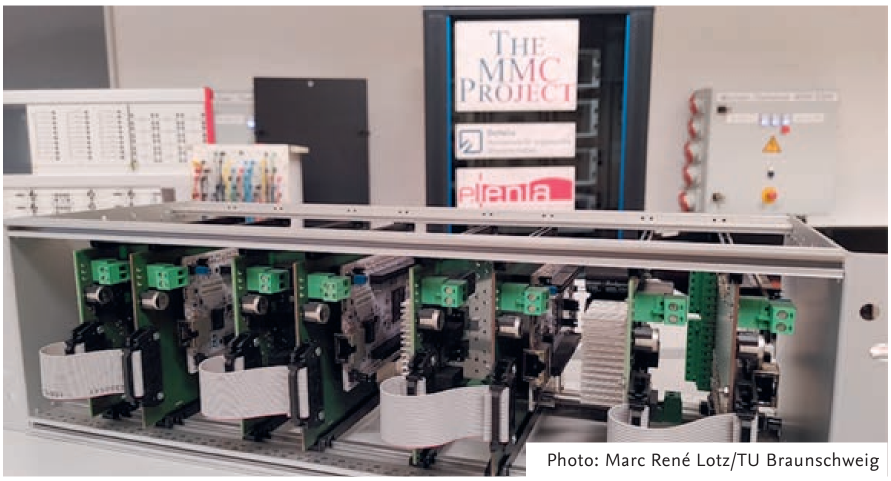

Photo: Marc René Lotz/TU Braunschweig

Performance Laboratory

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TASKS AND SERVICES

Performance testing

- Testing of circuit breaker up to U_N=72,5 kV
- Short-circuit single-phase

Contact geometry investigation

- Investigation of innovative contact geometries

Thermography investigation

- Investigation of surface temperatures of different materials

Performance Laboratory

Synthetic generation of test conditions for circuit breakers of the medium and high voltage level

The institute's synthetic test field is used to research vacuum circuit breakers for the high-voltage level. For this purpose, short-circuit conditions to be switched, which represent the maximum stress on circuit breakers, are simulated synthetically in the test field.

To establish the vacuum circuit breaker at the high-voltage level, various options with two vacuum interrupter chambers connected in series or variable contact gaps are being investigated. A special vacuum switch was designed that allows variable contact gaps. Breaking tests are carried out on this vacuum interrupter. For this purpose, the switch is first stressed by a high short-circuit current. The switch is opened during the current flow and a metal vapor arc is formed. After this arc is extinguished, the switch is subjected to a damped voltage oscillation (transient transient voltage). The short-circuit current and the transient voltage are generated during a disconnection process in the grid, which can be triggered by a grid fault. A high-current capacitor bank is used to generate the short-circuit current. This bank is charged with a maximum voltage of 3 kV and thus generates a half sinusoidal current oscillation of maximum 63 KA (RMS) at a frequency of 35 Hz / 50 Hz.

The high-voltage capacitor bank generates the transient voltage, which is switched via a triggered spark gap just before the current zero crossing. The capacitor bank can be charged up to 150 kV. For safety reasons, the bank is charged with a voltage up to 90 kV. This results in a peak transient voltage of 140 kV. The remaining elements of the high-voltage circuit are modular, producing different voltage slopes and frequencies. The frequency of the transient voltage is between 5 and 40 kHz, which corresponds to the frequencies in the medium and high voltage levels during the fault case and even beyond to generate a larger stress for the switch.

The metal vapor arc generated during the tests is observed through a observation glass and a high-speed camera. Through this process, the arc is characterized and various model ideas are verified. In many contact geometries, such as the transverse magnetic field (TMF) contact, the arc rotates at a very high speed up to 1000 m/s on the contact piece surfaces, resulting in different phenomena. These fast phenomena are displayed by the high resolution (1024 × 1024) and a maximal frame rate of 800 kfps of the camera.

In order to test new contact geometries as well as individual shielding and control arrangements for vacuum applications, temperatures up to 1200°C are generated in a hinged tube furnace under vacuum. Ceramics with diameters up to 200 mm can be soldered.

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High current (left) / high voltage (right) capacitor bank
Single-phase synthetic testing of circuit breakers

- Max. current 63 kA(RMS)
- Max. 140 kV TRV
- Circuit frequency: 35 Hz / 50 Hz
- TRV-frequency: 5 to 40 kHz

Vacuum test switch
Investigation of plasma phenomena between switching contacts possible

- Custom vacuum recipient
- Vacuum pump ($p < 10^7$ mbar)
- Variable gap up to 2 × 40 mm
- Series connection of 2 circuit breakers possible

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High speed camera Nova S6 by Photron
A high-speed camera is available for visual examination of the arcs:

- Resolution up to 1024 × 1024 pixel
- Black and white images
- Maximum frame rate 800 kfps
- Maximum integration time of 200 ns

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Soldering furnace for vacuum assemblies Carbolite Gero TS1
Free-standing hinged tube furnace for vacuum brazing of test assemblies and contact pieces

- Usable diameter 200 mm
- Temperature until 1200°C
- Temperature gradients freely selectable

Energy Management Laboratory

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TASKS AND SERVICES

- Carrying out storage efficiency measurement
- Testing of control methods and communication protocols
- Combined testing of hardware devices, simulation models and control systems with a modular control environment (HiL)
- Energy and power measurement
- Modular control environment ModSys-eelabs
- Control and evaluation tools for storage efficiency measurements
- Compatibility test for technical evaluation of the operation of battery storage systems with inverters of a leading manufacturer

Energy Management Laboratory

Sector coupling through efficient energy management and intelligent metering systems

The energy management laboratory provides a space for investigating innovative energy management concepts for electricity-only households and prosumer demonstrators. The research focuses on prosumer behaviour in the context of electromobility, the coupling of the heat and electricity sectors, load and storage management as well as newly developed metering and measuring concepts. For this purpose, numerous devices, such as various AC loads, DC sources, a charging infrastructure and a heat pump test stand consisting of an air-water heat pump, a climate chamber and a heating circuit can be used. The power and data technology coupling of the energy management laboratory with the grid dynamics laboratory also provides the option of measurements that extend beyond the laboratory. This makes it possible to work on new research questions and projects in the area of holistic laboratory-based research, such as the effects of a smart building on grid stability.

For the central control of the electronic and thermal components, all devices are currently being integrated into the modular control environment Mod-Sys-eelabs developed at elenia. With this control environment, the user should be able to realistically simulate a residential building that meets his or her requirements in just a few steps according to the modular principle.

Since the opening of the lab at the end of 2018, the construction of a prosumer demonstrator has already been realised in the NetPro-sum2030 project and investigations into various mobility concepts have been carried out in the EnEff Campus: blueMAP project. In the future, the flexess and MELANI research projects will be worked on in the energy management laboratory. In the flexess project, the targeted use of flexibilities of technical systems in the areas of households, commercial trade and electric mobility fleets is being investigated. Within this framework, households with different characteristics are simulated and measured in the energy management laboratory. In the MELANI research project, measurement methods and meter concepts for the multiple use of PV home storage systems are being developed. The laboratory environment of the energy management laboratory will be used to evaluate an image of the developed concept.

In addition to the research area, teaching also benefits from the expanded laboratory environment in the form of numerous student projects that can be carried out in the laboratories and the additional laboratory experiments offered parallel to the lectures. Furthermore, the extensive equipment of the energy management laboratory makes it possible to carry out efficiency measurements of PV storage systems according to efficiency guidelines and thus expands the service area of the institute.

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Efficiency measurement of PV storage systems

- Characterisation of the efficiencies, standby consumption and control efficiency of AC- and DC-coupled battery storage systems
- Automated control of the system components and evaluation of the measurement results

Simulation of a PV system

- Inverter: "SUNNY TRIPOWER STP 20000TL-30
- 2 DC sources: "Elektro Automatik EA PSI 91000-30

Simulation of loads

- 3 AC loads: "Höcherl & Hackl ZSACRV 9826" (9.8 kW each)

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Charging station at the Mühlenpford House

- Research in the field of generation-oriented charging and grid-oriented charging
- Physical coupling of the charging infrastructure with the energy management laboratory is possible
- The elias charging management system developed in the Fleets-Go-Green research project is used for information technology integration

Charging infrastructure of the elenia at the Mühlenpfordthaus

- Mennekes AC wall boxes with charging capacities of up to 22 kW
- smartPion charging pole with up to 2 × 11 kW
- Multicharger (CCS type 2 and CHAdeMO connection) for DC charging up to 22 kW

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Heating load emulation of the heat pump test stand

- Hardware-in-the-loop heat load emulation in combination with the TRNSYS building software for emulating the heating and cooling load of buildings
- Climatic chamber with temperature range from -5°C to 35°C, optional influence on air humidity
- Domestic hot water emulation by presetting tap profiles
- By embedding the system in the institute's own energy management system, it is possible to investigate different modes of operation of air-water heat pumps, including temperature-controlled, self-consumption-optimised and grid-serving modes of operation

Grid Dynamics Laboratory

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TASKS AND SERVICES

Investigations on topics such as:

- Behavior of components to frequency and voltage changes
- Overcurrent limitation and short-circuit behavior of distributed generation systems
- Contribution of conventional and fast frequency reserve
- Behavior and stability of voltage control inverters in stand-alone or grid-parallel operation
- Effects of variable voltages on controls such as Q(U) and P(U))
- Anti-islanding detection and oscillation circuit tests up to 33 kVAr according to DIN EN 62116
- Development and testing of novel control functionalities to provide system supporting characteristics for the interconnected power system
- Investigations on controllable local network transformers using our own simulation model

Grid Dynamics Laboratory

Power grid stability in times of converter-dominated power systems – Milliseconds matter

The "Grid Dynamics Laboratory", the name says it all: Here, current research topics on the integration of renewable energy generation plants into the low-voltage grid are investigated. The scientific focus is on highly dynamic, transient processes – target time: milliseconds to a few seconds.

A dedicated team consisting of scientific personnel, auxiliary scientific staff and our institute's own workshop work together energetically. The laboratory and its team introduce themselves:

About the laboratory – Central questions

The aim of the investigations in the grid dynamics laboratory is to think ahead to the energy transition. While the stability of conventional energy supply systems is based primarily on generator-based large-scale power plants from higher voltage levels, the feed-in structure is currently undergoing major changes. There is an increase in decentralized feed-in from converter-based, smaller plants from lower voltage levels. Renewable energy generation plants deliver their power to the grid via converters and thus differ from conventional thermal power plants, which provide power by means of large synchronous generators. The requirements for modern generation plants with regard to their behavior in a highly volatile, dynamic grid are manifold and subject to a high degree of complexity due to their power electronic characteristics, the communication structures and their regulation.

By examination of scenarios of this future power supply infrastructure which are already mapped in the laboratory today, opportunities as well as challenges in the supply with a high proportion of renewable energies and electromobility are to be identified and investigated in advance.

This means fundamental changes in the characteristics of future grid infrastructures, under which the interaction of conventional and new types of energy supply systems and regulations for ensuring grid stability must be continuously re-evaluated. The grid dynamics laboratory provides the appropriate infrastructure for this purpose: sources that can be flexibly arranged, grid simulations, loads, generation plants, freely parameterizable full converters and power hardware in-the-loop real-time simulators allow a wide variety of scenarios to be mapped, in particular critical situations: many things that one does not want to see in the real power supply infrastructure can be tested and run through here for the time being without any consequences.

The laboratory environment thus concentrates in particular on tests and scenarios that deal with special load situations of grid components and the grid-serving potential of decentralized generation plants.

The grid dynamics laboratory as a service provider for research and industry

Beyond the daily research routine, we also regularly work on external assignments for external partners – from start-ups to larger industrial customers.

For our clients, the main focus is on questions concerning the safe operation of equipment, software and/or hardware components in a mappable low-voltage environment.

Figure 1: PION AG charging station in 7-hour 44kW continuous load test

Typical external assignments include:

- The characterization of the behavior of devices, e.g. as a result of differently parameterized controls under reproducible scenarios.
- The recording of the robustness of developed devices in special load situations, such as short circuits, overvoltages, harmonics, etc.
- The initial assessment of the conformity of prototypes with (newly developed/existing) grid connection guidelines.

Presentation of laboratory components – coupled machine set

The central issue of our energy supply system in the next years will be the stable transition to a CO_2-neutral power supply. Technically, this means the transition from a grid primarily defined by synchronous generators of fossil power plants to a grid structure operated by the converters of regenerative plants. This changes the fundamental behavior of the energy supply infrastructure in many respects. Reason enough to test this transition in the laboratory. For this purpose, the grid integration laboratory offers a coupled machine set to test investigations in grid-parallel operation of converters and synchronous machines under laboratory conditions.

The machine set is currently being installed in the laboratory and subjected to initial test runs. A separate synchronization unit ensures that the machine set is connected to the laboratory network with phase and amplitude accuracy. The specially developed concept for the protection of persons and hardware, the control of the machine and the coordination of different components involved in the operation enable a safe laboratory operation for all future tests. For example, the current experimental focus includes the reaction of network components to rapid jumps in network phase and amplitude, usually caused by faults.

In these, machines tend to oscillate, but are able to stabilize the grid by delivering short-time high overcurrents. Inverters can act more flexibly, but are severely limited in overcurrent. Can these systems complement each other in transition? How can the grid be operated stably with different levels of penetration of converters and machines? How should converter controls be designed for this purpose? The network dynamics laboratory invites you to investigate these questions.

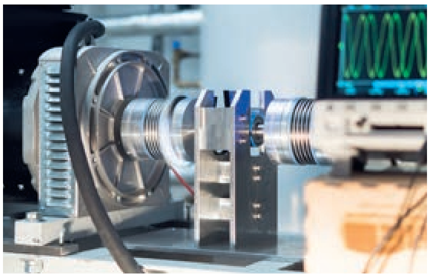


Figure 3: Coupled machine set in test operation after alignment and calibration of the shaft flange

Presentation of Laboratory Components – OPAL Real-Time Simulator

The tests in our laboratory offer a decisive advantage for our research: scenarios or behaviors that have been conceived in abstracted and necessarily simplified simulations can be verified under more realistic conditions. These experiments are often more meaningful, regulations can prove their correct operation for the first time in the real world. However, before implementing controls in hardware, it is useful to test their operation in more flexible embedding scenarios. In order to be able to map network errors and controller behavior in the millisecond range, the laboratory requires an integrated measurement and control option that works reliably and without delay in these ranges

Figure 4: Powerful OPAL real-time simulator with analog interfaces for controlling components in the laboratory

For this purpose, a computationally powerful real-time simulator was added to the laboratory. The real-time simulator enables hybrid use cases of simulation and hardware in “quasi” real time. This has several advantages: simulations can be transferred step by step to the laboratory. Part of the experimental setup is handled by laboratory equipment, the rest takes place in the real-time simulator. The devices and the simulation model work together in parallel and in real time. Analog measured values, such as voltage and current of individual devices, are fed via measuring devices to the real-time simulator, where they are calculated internally with the inclusion of various simulation parameters and output as new analog manipulated variables. This results in a so-called power-hardware-in-the-loop (PHIL) system – the combination of very fast simulations with electrical, mechanical hardware. In the power system dynamics laboratory, simulation step sizes of less than 100 us are achieved. In contrast to pure laboratory operation on hardware level, a real-time simulator enables the flexible representation of elements of the low-voltage network, e.g. lines with different inertias, batteries with different power ratings, networks with different arrangements, which would be difficult to simulate in the laboratory – all this can be changed here simply by mouse click. Failures in live elements can be simulated, which is an advantage for personal safety and equipment protection.

News from the laboratory – addition of a further grid simulator to the laboratory

With the procurement of the REGATRON TC.ACS.30 at the beginning of the year 2021, the already existing laboratory environment was supplemented by a powerful 4-quadrant voltage source in the function of an additional grid simulator. This simulator, like the already existing one, can be used either as a pure arbitrary generator or as an amplifier. This results in new use cases and scenarios for investigations in the context of network emulation in the already existing PHIL system of the network dynamics laboratory.

The addition of a further grid simulator allows exemplary operation of different converter systems at two “soft” network connection points with different variably adjustable voltages. These can be, for example, two different grid connection points within a low-voltage grid – interactions of individual grid sections and components with each other can thus be visualized. In addition, the grid simulator can electrically represent specially developed and parameterized converter and machine models in amplifier mode, thus increase the number and flexibility of interconnectable components.

Training and collaboration of student assistants

Several student assistants are regularly employed to support scientific staff in the laboratory. Among other things, they assist with tasks such as the software implementation and control of components in the laboratory using programs such as LabVIEW or MATLAB/Simulink, but also with the installation of electrical components or hardware – In the laboratory, students can gain practical experience in the field of electrical installations, as well as in the applicable theory of control and measurement technology.

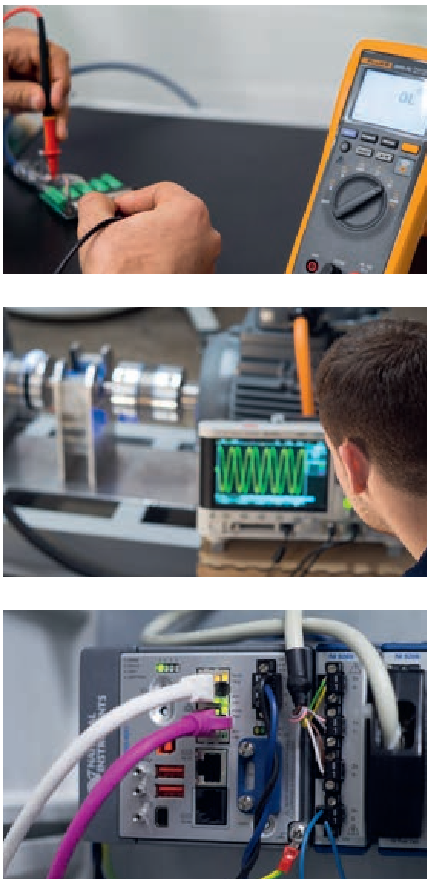


Figure 5: Diverse working and learning areas at different laboratory interfaces

Facts & figures about the grid dynamics laboratory

Various components such as inverters, AC and DC sources and loads, as well as a 50 kVA single line regulator, enable a complete low-voltage line to be simulated or reproduced in the laboratory. To complete the low-voltage environment, up to 1.8 km of low-voltage cables can be simulated using flexibly adjustable resistors and inductors.

A powerful and accurate measurement system with 16-bit measurement resolution and a sampling rate of 500 kS/s enables precise and accurate work. Voltages up to ±1400 V and currents up to 200 A can be recorded and processed at various measuring points in the laboratory environment. The core elements and test components, which however define the central core points of the laboratory can be found below:

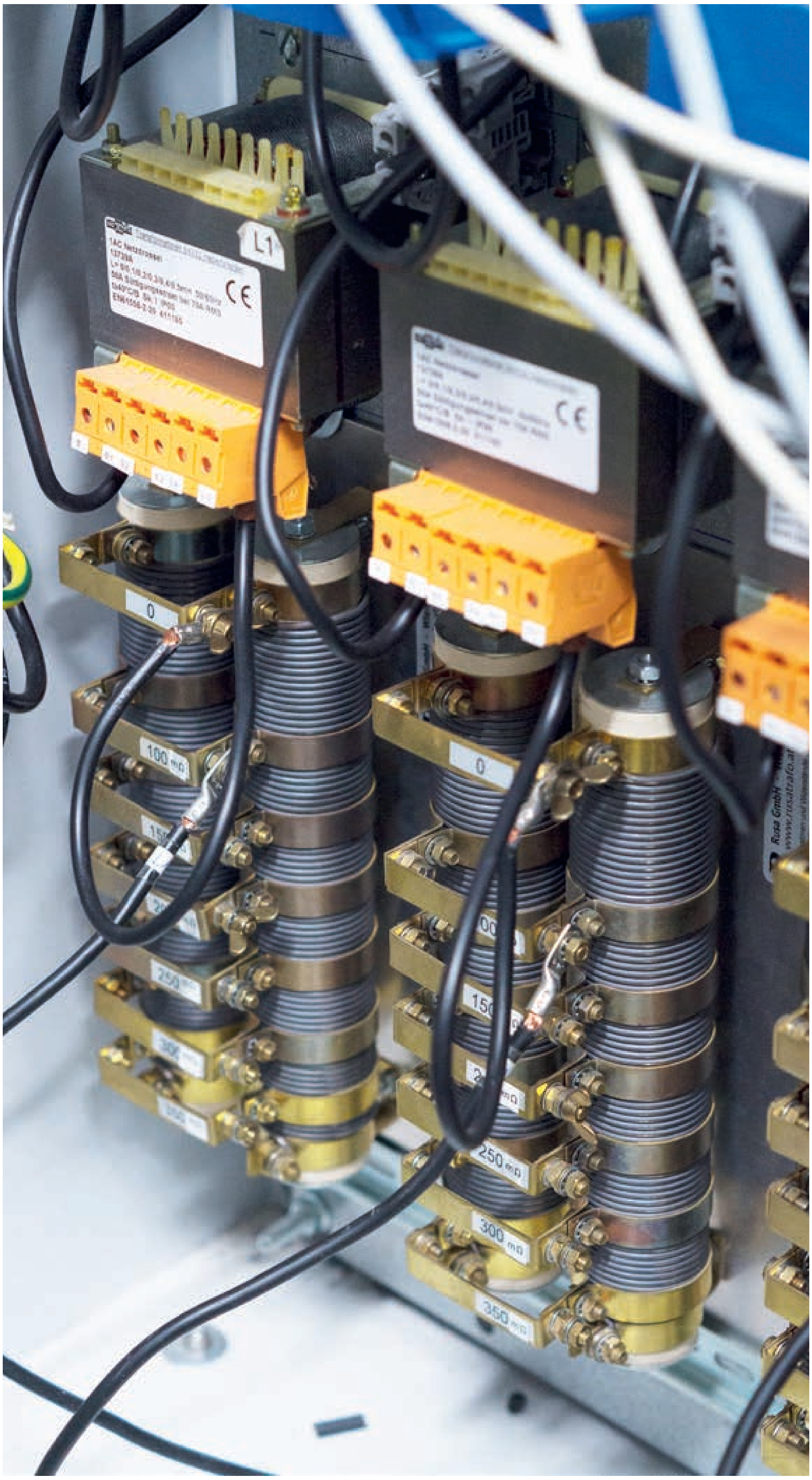


Figure 6: Line replicating elements correspond to up to 1.8 km of low voltage cable

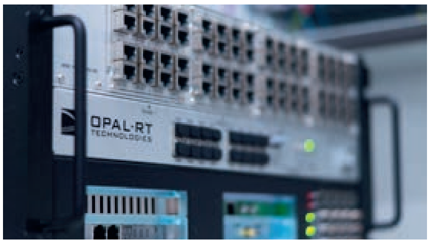
Photos: Frederik Tiedt/TU Braunschweig

Grid Simulator AMETEK MX-45
Fully regenerative grid simulator for simulating various grid states with variable grid parameters:

- 45 kVA nominal power
- Voltages up to 300 V_{RMS} and 400 V_{DC}
- Currents up to 50 A_{RMS}
- Frequency range 16–800 Hz
- 4-wire connection (unbalanced load)
- Integrated measuring system
- Analog interfaces for precise control of individual phases in amplifier mode

Grid Simulator REGATRON TC.ACS.30
Fully regenerative grid simulator for simulating various grid states with variable grid parameters:

- 30 kVA nominal power
- Voltages up to 305 V_{RMS} and 800 V_{DC}
- Currents up to 43 A_{RMS}
- Frequency range 16–1000 Hz
- 4-wire connection (unbalanced load)
- Integrated measuring system
- Analog interfaces for precise control of individual phases in amplifier mode
- Operation as simulated RLC-load
- Automated flow control using Python based scripts
- Fast slew rates of up to 4 V/us for investigation of transient events



OPAL 5700 Real-Time-Simulator
Real-time simulator with high computing power for power hardware-in-the-loop applications and low-latency laboratory control:

- Analog/digital inputs and outputs for coupling a wide range of laboratory components
- Communication interfaces via protocols such as MODBUS, EtherNet, EtherCAT, CAN, TimeStamp, GOOSE, etc.
- FPGA technology for faster command processing
- Working in the MATLAB/Simulink development environment
- Real-time capable simulations of hardware and electrical networks with simulation step sizes below 100 μs

TRIPHASE – Rapid Prototyping Inverters
Freely programmable full converters for implementation and investigation of own control models:

- Two full converters with 15 kVA nominal power each
- 1x 3-wire connection, coupled rectifier and converter, can be used as battery simulator
- 1x 4-wire connection, single-ended drive, zero-system embossing
- Control and parameterization via MAT-LAB/Simulink

30 kW coupled machine set (asynchronous machine and synchronous machine)
Coupled machine set consisting of asynchronous and synchronous machine with freely parameterizable converter:

- 30 kW connected load at 1500 rpm nominal speed and 150 Nm nominal torque
- Synchronization unit for connection of external sources to the machine set network
- Generator and motor operation possible
- Control via LabView and cRio system

Mechanical Workshop

CONTACT

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TASKS AND SERVICES

We are in the mechanical workshop support the research assistant and students in manufacturing components and systems for trainings, study projects, these as well as research projects.

Photos: Kerstin Rach/TU Braunschweig

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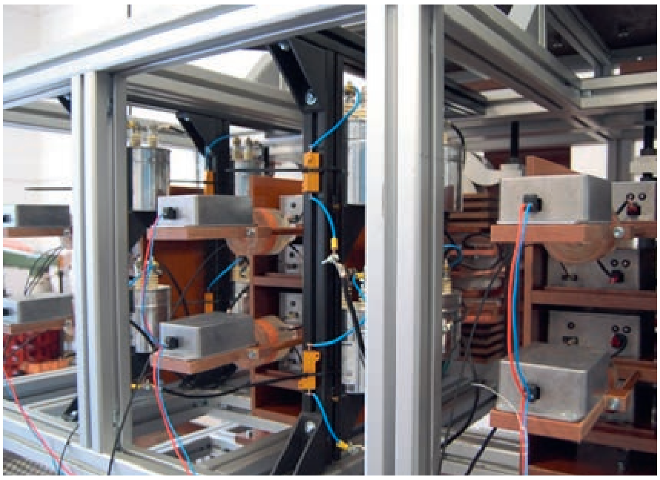
Mechanical fastening of the Driver Circuit of a B12 bridge



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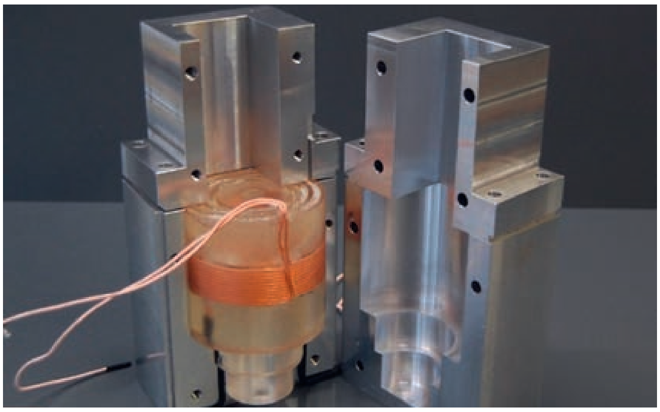
Mechanical assembly of a high-performance B12 bridge of 30kA



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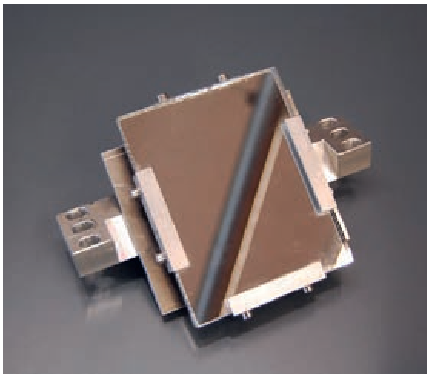
A mirror holder for an experimantal investigation of long switching arcs (Project: EU-laS)



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High frequency carrier
In the halved casting mould

→

Enclosure low-pressure

Insulation from the thyristors of a B12 bridge

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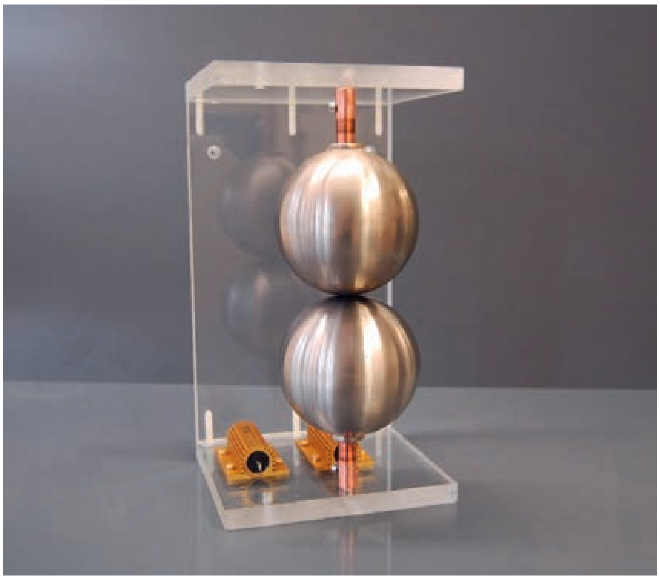
Spark gap holder:
Safety device for our capacitor bank, that used in the Weil-Dobke circuit.

↓



Electrical Workshop

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After extensive remodeling and renovation work, the electrical workshop has been operating in new facilities in the Mühlenpfordthaus since mid-2020.

- In addition to storage, work and office areas are separated from each other
- The new premises have their own expandable room distribution with sufficient reserves, various CEE three-phase current couplings, as well as individually switchable LED daylight
- The new workshop includes two extensively equipped electrical laboratory workstations with various laboratory power supplies, isolating transformers, oscilloscopes, current sources, as well as soldering and desoldering stations.
- Furthermore, there is a workstation for mechanical work with standard equipment for simple metal and plastic processing.
- The room also offers space for student or research assistants who can work here under supervision.

Photos: Christian Ryll/TU Braunschweig

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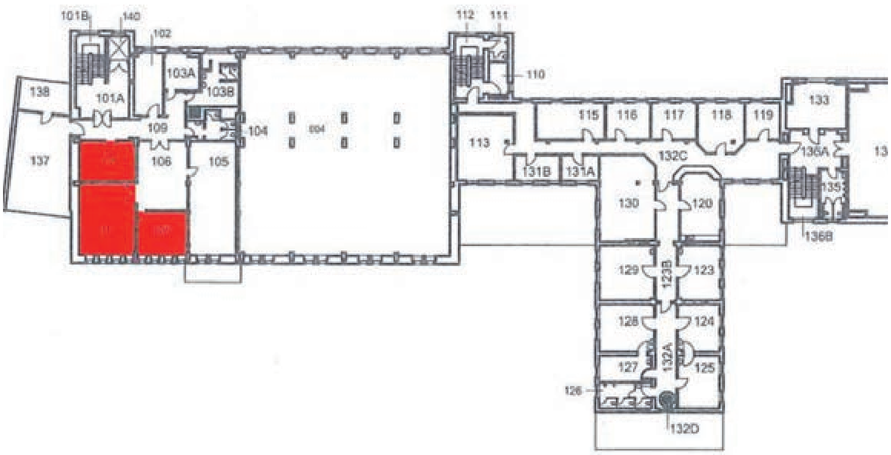
Area atlas 1st floor Mühlenpfordthaus

Moved from room 139 to rooms 107 and108 1st floor and enlargement of the workshop and office space from 21 m² to 65 m²



Workshop

↓

↑

Electrical lab workstations

Office

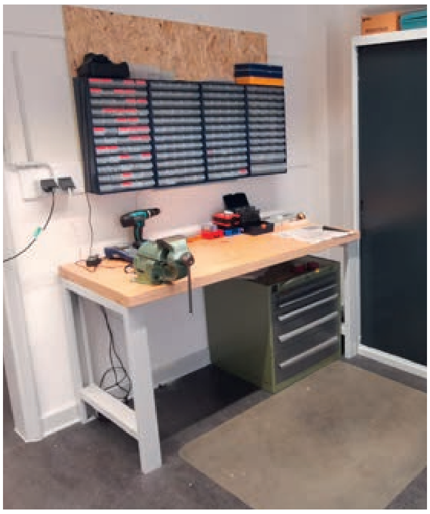
↓

↑

Storage

Small parts magazines

↓



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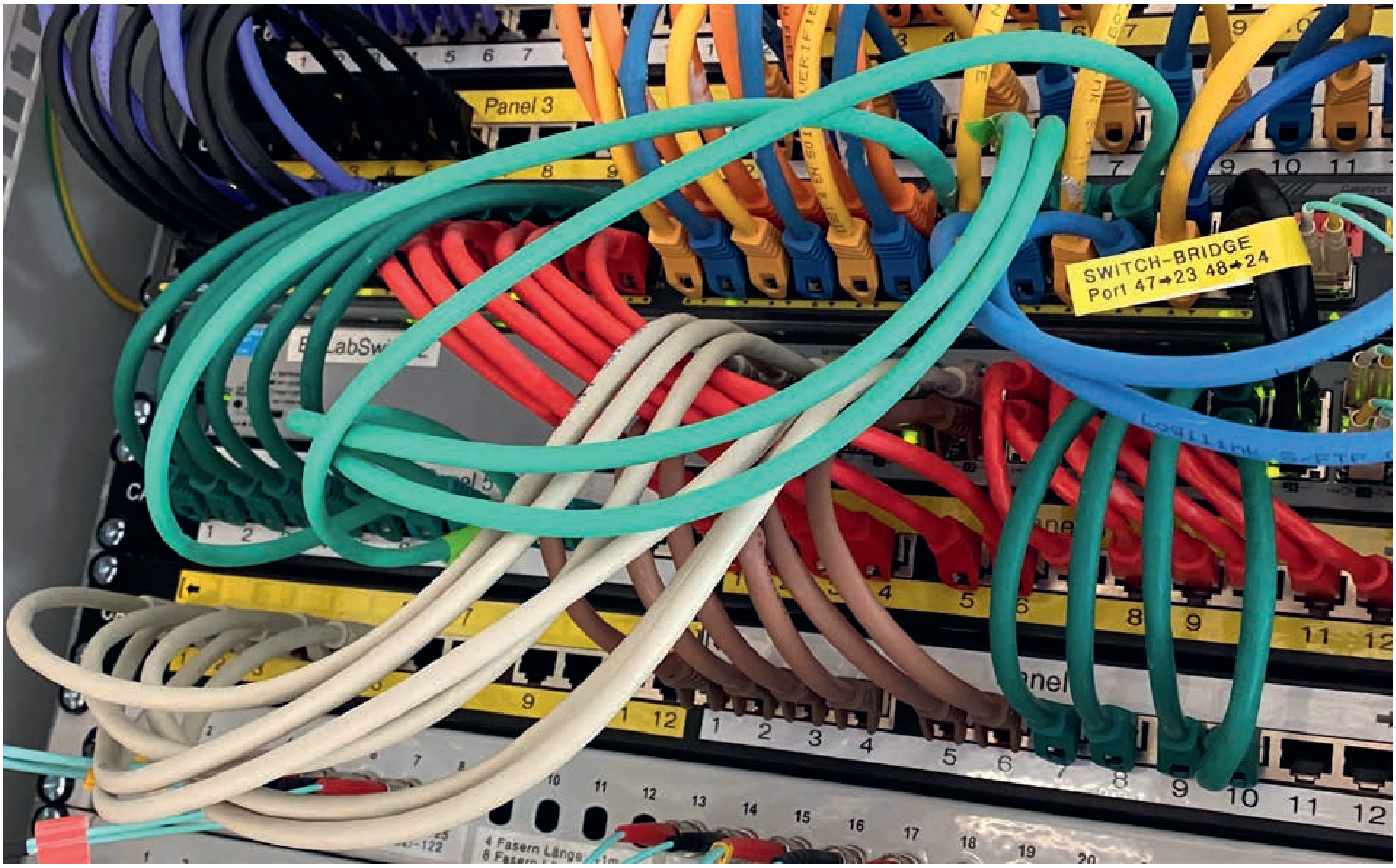
Workbench and component magazines

IT-Department



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TASKS AND SERVICES

- Procurement, maintenance and care of servers and clients
- Provision of workstations and software
- License procurement and administration
- Support and training of staff and students (service desk)
- Analysis and definition of the IT systems according to DSGVO
- Continuous monitoring and maintenance of the institute and research networks
- Setup and maintenance of special project-related IT systems
- Administration of institute and project websites

IT-Department

An overview of elenia's information technology (IT) systems in times of home office and remote support

Due to the continuously growing number of employees in elenia institute and the rapidly ongoing digitalization, an institute IT-department was established in 2017 by hiring Fabian Scholz. It supports all employees and students of elenia having questions and problems regarding elenia's and TU Braunschweig's IT systems. Other tasks include collaboration and planning of technical setups in the individual research projects, as well as maintenance and servicing of the general network and server structure to ensure uninterrupted work.

In the reported period1, more than 1200 inquiries were answered via e-mail and ticket system. The number of accounts to be managed amounts to 166, which work on and with the 381 systems provided.

Particularly noteworthy is the lockdown at the beginning of 2020 due to Corona pandemic. In a very short time, workplaces, meetings and events had to be moved to the home office. For this purpose, the possibility of network access via VPN connection was made possible in cooperation with the Gauss IT-Zentrum, and a platform for online meetings was created. In this way, all employees can continue to pursue their work in the home office.

In order to be able to continue offering examinations for prospective doctoral students, an audio system was purchased. This enabled professors, university staff and guests to follow the exciting lectures via livestream.

While most members of the institute were working from home, construction work was carried out in the institute to complete the new student workroom. With a corresponding concept of hygiene, it was officially opened on July 26, 2021.

Since July 2021, IT has been supported by the hiring Lukas Oppermann on a part-time basis.

↑

Example: monitoring of extinguishing systems of BLB
A network monitoring system for the fire alarm systems of the battery testers was set up for BLB (Battery Lab Factory Braunschweig). Here, the project supervisors can view the current status of the systems at any time. In the event of a fire, they receive a push notification on their smartphone so they can react quickly and initiate further measures.

This is just one of the many system examples that have been set up for research projects.

Photo: Fabian Scholz/TU Braunschweig

↑

Audio system for doctoral exams
In order to be able to perform digital promotional procedures, an audio system was procured. The most important part of the audio system is the mixing console, enabling individual control of the microphones. This ensures a high voice quality for the online events.

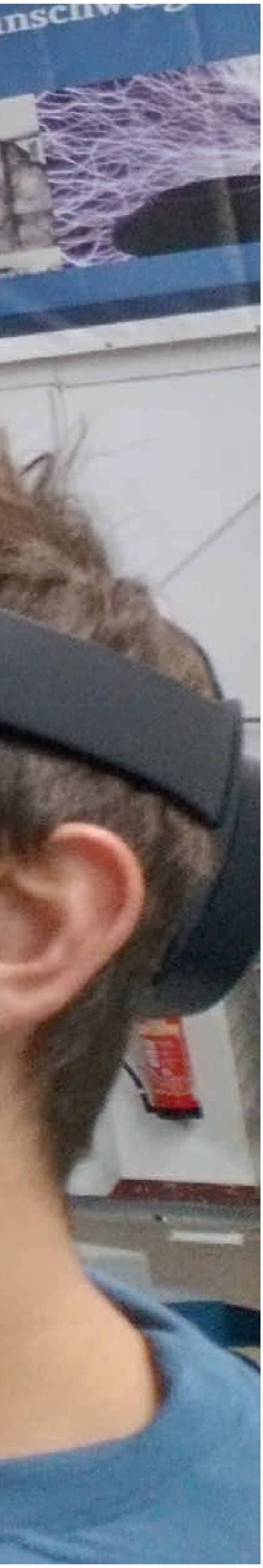
Photo: Fabian Scholz/TU Braunschweig

↑

New student workspace
After a two-year renovation phase, the new student workroom was opened on July 26, 2021. It offers space for a total of 28 students, who can write their theses or participate in computer-based courses here. An integrated media system and air conditioning are available in the modern room as well.

Photo: Laurenz Kötter/TU Braunschweig


an der TU Brau



Teaching

Courses

Lectures: Workgroup Energy Technologies

Lecture	Contents	Lecturer
Transmission grid technologies	Basics of transmission networks: structure, components, developments, operating methods, challenges; calculation of transmission networks with equivalent circuit diagrams: Overhead lines, cables, synchronous generators, transformers, compensation elements; Basic technologies of high voltage direct current (HVDC) transmission: converters, grid topologies, offshore wind farms.	Dr.-Ing. Christian Schulz
Numerical calculation methods	Basics for the numerical solution of systems of linear equations, DGL 1st order (initial value problems), partial DGL (finite difference method), computer exercises LT-Spice.	Prof. Dr.-Ing. Michael Kurrat
High voltage technology I	high-voltage grids, overvoltages, insulating systems, gas discharges, insulating materials, high-voltage direct-current transmission.	Dr.-Ing. Michael Hilbert
High voltage technology II	Introduction, fundamentals of high current and high voltage test engineering, quality assurance and measurement uncertainty determination, generation of high AC voltages, measurement of high AC voltages, generation of high DC voltages, measurement of high DC voltages, generation of high pulse voltages, measurement of high pulse voltages, generation of high currents (AC, DC, pulse), measurement of high currents (AC, DC, pulse).	Prof. Dr.-Ing. Michael Kurrat, Dr.-Ing. Johann Meisner
Design and function of storage systems	Charging infrastructure, storage characteristics, system design, storage technologies, double-layer capacitor, energy storage in the form of hydrogen, design and operation of lithium-ion battery storage, battery aging and diagnostics.	Dr.-Ing. Frank Lienesch
Electrical energy systems I	Transmission line and grid forms, equivalent circuit diagrams of equipment, synchronous machine, different transformer types, overhead lines and metrological, determination of the individual equivalent circuit diagram components, grid calculation methods for load flows node method, mesh method and superposition method, introduction of the symmetrical components for short-circuit current calculation. Calculation of symmetrical and unbalanced fault conditions in the grid, The dynamic stability of power systems, Physiological effects of current on the human body, Grounding topologies and protection criteria.	Dr.-Ing. Ernst-Dieter Wilkening
Electrical energy systems II	Thermal and mechanical load capacity of equipment, behavior of the mains voltage after the interruption of the current flow and the effect on the switching distance, design of various switching devices and fuses of the different voltage levels, design of switchgear, protection technology: differential protection, distance protection and overcurrent protection are dealt with.	Dr.-Ing. Ernst-Dieter Wilkening
Design and calculation of direct current systems	Calculation and design of DC grids, operation of DC grids, fault detection and location, systems engineering, components for power generation, distribution and storage, industrial grids, island grids, electrical system.	Prof. Dr.-Ing. Michael Kurrat

Lecture	Contents	Lecturer
Basics of electrical energy technology (Part 1)	Introduction to power transmission and distribution, three-phase systems: basics and calculation, transformers, generators.	Prof. Dr.-Ing. Michael Kurrat, Prof. Dr.-Ing. Markus Henke, Prof. Dr.-Ing. Regine Mallwitz
Electric Power Systems Engineering	Fundamental knowledge of Power Systems, Interpret / evaluate of texts and data from Power Systems, Formulate research problems, Select an adequate level of abstraction, Systematic approach, Use scientific theories and model concepts, Analyze social, economic or cultural consequences.	Prof. Dr.-Ing. Michael Kurrat
HVDC Technology	Introduction to HVDC transmission systems, Operation of LCC and VSC based HVDC systems, Main components of HVDC converter stations, Interaction between AC and DC systems, Basic principles of modeling, analysis and control of dynamic systems, Control theory applications on HVDC Systems, Principles of developing DC grids, Use PSCAD/EMTDC as a simulation platform for power system analysis, Simulate and design various basic converter topologies, Perform basic control tests on HVDC systems.	Dr.-Ing. Nasser Hemdan Melanie Hoffmann

Lectures: Workgroup Energy Systems

Lecture	Contents	Lecturer
Innovative energy systems	Framework conditions of the energy transition, expansion of power grids, participation of future generators in system services, innovations of conventional power plants, renewable forms of energy, virtual power plants and demand side management, future of electrical storage systems.	Prof. Dr.-Ing. Bernd Engel Dr.-Ing. Jonas Wussow
Electrical engineering I for mechanical engineering	Introduction and teaching of electro-technical basics, analysis and calculation of electrostatic fields, direct current circuits, magnetic fields, iron circuit, charging of electric vehicles, direct current machine, electrical safety, deepening of the course contents by experimental presentation.	Prof. Dr.-Ing. Bernd Engel Dr.-Ing. Frank Soyck
Distribution grid technologies	Role of distribution grids in energy supply, grid structures, operating equipment (cables, overhead lines, transformers, switchgear), protection concepts, system services, grid charges, future developments in the distribution grid (Smart + X).	Dr.-Ing. Johannes Schmiesing
Energy management and market integration of renewable energies	Energy industry, energy policy, laws and support systems, markets (electricity market 2.0, balancing power market), direct marketing / balancing group management, virtual power plant, large-scale storage facilities.	Prof. Dr.-Ing. Bernd Engel
Electrical railroads	Review of the relevant fundamentals of electrical engineering, introduction to rail vehicle technology, overview of electrical bus systems, traction current systems nationally and internationally, DC and AC, drives for electric railroads, brakes, auxiliary operations, signaling and safety systems, control technology on rail vehicles, passenger information and multimedia, executed vehicles, news and developments.	Prof. Dr.-Ing. Bernd Engel
Electrical equipment of rail vehicles	Electric traction, brakes, auxiliary systems, signaling and safety systems, control systems on rail vehicles, passenger information and multimedia, vehicles in service, future developments.	Prof. Dr.-Ing. Bernd Engel

Lecture	Contents	Lecturer
Basics of power engineering for environmental engineers Part 1 and 2	Electrical engineering basics: Basics of the electric and magnetic field, main features of direct and alternating current grids, basics of electrical power supply, complex alternating current calculation and three-phase current systems, grid equipment and electrical safety.	Prof. Dr.-Ing. Michael Kurrat, Prof. Dr.-Ing. Bernd Engel, Prof. Dr.-Ing. Markus Henke
Systems technology in photovoltaics	Introduction to photovoltaic system technology, system configurations, inverter topologies, inverter functions, other components of PV system technology, grid integration of PV systems, island grid systems, grid-connected PV systems with storage, future developments.	Prof. Dr.-Ing. Bernd Engel
Electrical facilities and grids	Introduction, Wire and grid forms, Stationary system analysis, Electrical parameters of equipment, Grid calculation, Grid control, Short-circuit current calculation, Unsymmetrical faults, Neutral point treatment, Stability of power supply, Protective measures, Exercise on symmetrical components and revision/question time, Exercise: Synchronous machine, Exercise: Short-circuit current calculation, Revision & question time.	Prof. Dr.-Ing. Bernd Engel
Regenerative energy technology	Basics of the structure of the German and European power supply system and components, such as transmission lines, cables and transformers, technical basics of grid operation by grid operators and their handling of system services, overview of the processes in the German electricity market and the influences of the German energy revolution, insight into the current and future challenges posed by the transformation of the energy supply system in Germany	Prof. Dr.-Ing. Bernd Engel
Public transport – operation and vehicles	Basics of energy technology, Basics of electrical machines, Mechanical drive train, Examples of executed vehicles, Regional light rail Braunschweig, Innovative electric buses.	Prof. Dr.-Ing. Bernd Engel
Control in the electrical power system	Equations for a balanced three-phase line, equivalent circuit, active and reactive current transmission, static and dynamic stability, simplified mathematical model and control of synchronous machine, grid control (active power, frequency, reactive power, voltages), control of current and voltage impressing inverters, system dynamic models.	Dr.-Ing. Stefan Laudahn

Internships

Internship	Contents	Lecturer
Analysis, simulation and planning of grids	Introduction to grid calculation and introduction to PowerFactory, static load flow calculation, short circuit calculation, connection test of distributed generation units, load flow calculation with profiles, creation of a simulation model for dynamic grid calculation, power quality calculations.	Prof. Dr.-Ing. Bernd Engel
Electromobility	Battery diagnostics, electrode manufacturing, electrode packaging, power electronics and electrical machines, powertrain simulation.	Prof. Dr.-Ing. Michael Kurrat
High voltage technology	High voltage measurement technology, insulating material technology, generation of high DC and AC voltage, lightning impulse voltage, breakdown testing, use of augmented reality.	Prof. Dr.-Ing. Michael Kurrat
Innovative energy systems	Photovoltaic cells, PV inverters, island grid systems, heat pump, energy management.	Prof. Dr.-Ing. Bernd Engel

Seminar: For students

Seminar	Contents	Lecturer
Energy systems seminar	Lecture series and presentation training on energy technology and energy industry topics	Prof. Dr.-Ing. Michael Kurrat, Prof. Dr.-Ing. Bernd Engel
Seminar basic of power engineering for environmental engineers	Technology Impact Evaluation	Prof. Dr.-Ing. Michael Kurrat, Prof. Dr.-Ing. Bernd Engel, Prof. Dr.-Ing. Markus Henke

Seminar: For PhD students

Seminar	Contents	Lecturer
PhD seminar	Know and understand systems thinking, understanding systems theory, sustainable energy systems.	Prof. Dr.-Ing. Michael Kurrat, Prof. Dr.-Ing. Bernd Engel

Laboratory: High Voltage

New innovative experiments with augmented reality

In many of elenia's laboratories, high-voltage components are used and investigated. In this case, all necessary safety measures and equipment must be understood and operated in order to ensure hazards for people and the environment. The handling of such components and the corresponding safety measures are taught to the students in an application-oriented manner in the practical course on high-voltage technology. The basics of voltage generation and measurement as well as insulating material technology are carried out in practical experiments.

Detecting the Risks

High electric fields depend on the geometry of the electrodes and the voltage of the experimental equipment. Electric fields are not visible and therefore the risks in high-voltage technology often remain undetected. In the experiments of the practical course on high-voltage technology, typical dangers are described and illustrated by means of investigations. Due to the complexity of electric fields, they are difficult to understand. For this reason, augmented reality glasses are used in a new practical course attempt, which make the electrical fields visible and thus give the students a didactic understanding of the dangers of high voltages. The team of Jun.-Prof. Dr. Oliver Bodensiek from the Institute for the Didactics of Natural Sciences helped to support the experiment.

New experiment content

In the new experiment, a voltage is increased on a classic high-voltage component, the spark gap (see Figure 1), until a visible and acoustic breakdown occurs, in order to demonstrate the dangers.

In high-voltage engineering, such breakdowns must be avoided in order to protect the surrounding area. The prediction of such breakdowns is only possible with complex calculations and simulations. In order to create an application-oriented understanding of such phenomena, the electric field is to be made visible. In this way, risks can be detected and predicted. A pair of Hololens glasses from Microsoft has been acquired through study quality funds to make this possible. The glasses are implemented live with the information of the voltage measurement and the geometry of the test facility and can visualise the electric field lines and the equipotential lines on the basis of these factors, as shown in Figure 2. This enables an otherwise invisible hazard to be detected and countermeasures to be set up. Furthermore, in the new experiment, capacitors are charged and their dangerous charging behaviour is visually pointed out by displaying the voltages on the complete experimental equipment with the glasses. Due to the discharge behaviour of capacitors, a certain residual voltage can be present even after immediate disconnection, which represents a life-threatening hazard for people. In view of the first successful applications and tests, further experiments are to be developed that can be made visible through the augmented reality glasses.

COURSE

Internship High voltage technology

TYPE

Internship

PROJECT RUNTIME

Every winter session

CONTACT

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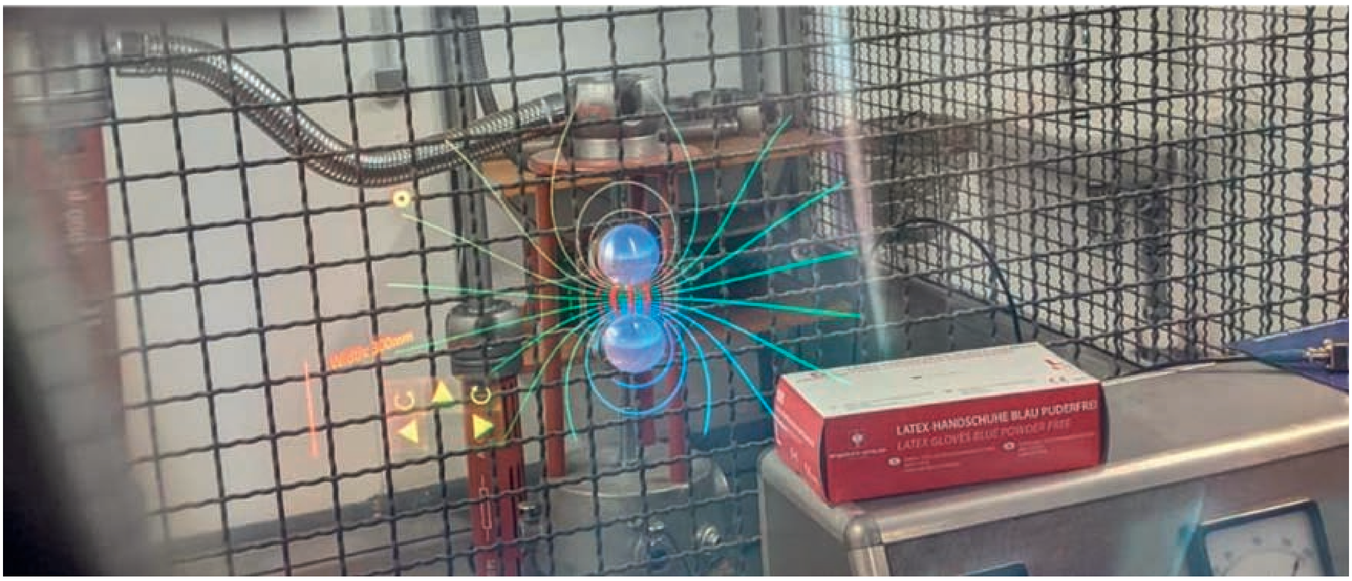
Figure 1: Risks of electric fields on a spark gap
Figure 2: Photography through augmented reality glasses



Student Work 2020

Student Research Thesis

Author	Titel
Chao Wei	Requirement Analysis for the Connection of Offshore Wind Farms in SysML with a subsequent Concept Study
Emil Weymann	Entwicklung und Vergleich von Regelungskonzepten zur Verringerung von schnellen Spannungsänderungen, Unsymmetrie, Flicker und Oberschwingungen im Niederspannungsnetz
Franca Dömer	Ansätze zur Modellierung von spannungsebenenübergreifenden Netz- Und Simulationsszenarien Im Kontext zukünftiger Netzentwicklungen in Deutschland
Kerstin Wetjen	Untersuchung rechtlicher und regulatorischer Rahmenbedingungen eines spannungsebenen- und netzbetreiberübergreifenden Blindleistungsmanagements
Lea Tesch	Steady-State-Modell für die thermische Gebäudesimulation nach DIN EN ISO 13790 (2009)
Marcel Lüdeck (BS|Netz)	Konzept und Aufbau von Messwerterfassungen in Ortsnetzstationen – Übertragung, Speicherung, Auswertung und Erstellung eines Monitoring Systems

Bachelor Thesis

Author	Titel
Ahmed Madiouni	Erstellung von Prognosen für ein dynamisches Flottenlademanagement
Daniel Rausch (pe-systems)	Potentialabschätzung von Kleinwindkraftanlagen im internationalen Kontext und simulative Bewertung von möglichen Anwendungsbereichen
Felix Korff	Untersuchung der Effizienz der flächendeckenden Blindleistungsbereitstellung durch erneuerbare Energieanlagen in den unteren Netzebenen
Florian Pröpsting	Prüfung, Inbetriebnahme und Erprobung einer AC-Ladesäule in Laborumgebung
Frederike Paul	Entwurf und Evaluierung einer Methodik zur Modellierung von Einspeise- und Last-Zeitreihen aus aggregierten Messzeitreihen
Henrik Buhl	Preisbildung bei simultaner Mehrfachnutzung von Batteriespeichern in Mehrfamilienhäusern
Jannik Pohl (avacon)	Identifikation und Bewertung von Anwendungsfällen für die Nutzung detaillierter Verbrauchswerte von Haushaltskunden
Julius Rieckmann	Untersuchung der alterungsabhängigen Schnellladefähigkeit von Lithium-Ionen-Batterien mithilfe eines Batteriemodells
Kai Neumann	Anforderungsanalyse und Inbetriebnahme eines Blockierschalters für einen Weil-Dobke-Prüfkreis zur Prüfung von Leistungsschaltern
Karsten Laaken	Validierung der Qualitätsbewertung von Lithium-Ionen Batteriezellen im Wareneingang durch zyklische Alterung
Lia Stücke	Identifikation und Modellierung von PV-, PV-Batteriespeicher und Elektromobilitätsszenarien in hochintegrierten Quartiersenergiesystemen
Muhammad Kemal Ichwandi	System Structure Definition Including Component Analysis for HVDC Transmission System Development
Sarah Schnetzke	Entwicklung and Bewertung von Szenarien für eine nachhaltige Energieversorgung in der Landwirtschaft
Sönke Niemann (PTB)	Echtzeitsimulation der Zündfähigkeit eines explosionsfähigen Gasgemisches für den semi-empirischen Konformitätstest von eigensicheren elektrischen Geräten

Author	Titel
Valentina Tognoli Gonzalez	Verification of Technical Requirements for a HVDC Grid Connection Topology as part of the Systems Engineering Methodology
Yvon Gouné	Sensitivitätsanalyse eines statischen Flottenlademanagements

Master Thesis

Author	Titel
Alexander Stefani	Elektrochemische Untersuchung und Modellierung von Lithium-Ionen-Batte-rien mittels der Elektrochemischen Impedanzspektroskopie
Annika Stein	Untersuchung verschiedener Methoden zur elektro-thermischen Charakterisierung von Lithi-um-Ionen-Batterien
Chang Zhao	Entwicklung einer Methode zur Optimierung von HGÜ Netzanschlusskonzepten anhand eines Fallbeispiels
Christian Körte	Modellbildung von PEM-Brennstoffzellen für den Einsatz in All-Electric-Aircraft
Christoph Rempe	Analyse der Herausforderungen für induktives Laden und Entwicklung von Zukunftsszenarien
Clemens Schmidt	Analyse und allgemeingültige Bewertung der Spannungsqualität (schnelle Spannungsänderun-gen, Flicker, Unsymmetrie, Oberschwingungen) im Niederspannungsnetz
Daniel Kehl	Anpassung eines PXI basierten Batteriemanagementsystems für Lithium-Ionen-Batteriemodu-le zur Integration in einer Second-Life-Anwendung
Dawei Huang	Anwendbarkeitsstudie der Clusteranalyse zur Klassifizierung von Lithium-Ionen-Batteriezellen mittels Kenngrößen der Formierung
Demian Kufeld	Entwicklung und Validierung einer Methodik zur Prognose von Blindleistungsbedarfen in elek-trischen Energieversorgungsnetzen
Fabian Herdle	Vergleich und Erhebung von entwicklungs- sowie nutzungsrelevanten Parametern von All-So-lid-State-Batterien und Lithium-Ionen-Batterien
Fabian Katschewitz	Untersuchung des Kapazitätsnutzungsgrads von Lithium-Ionen-Batteriezellen unter verschie-denen Ladebedingungen
Felix Klabunde	Energetische Modellierung, Analyse und Bewertung landwirtschaftlicher Versorgungsstruktu-ren im Kontext der deutschen Energiewende
Franca Dömer	Untersuchung der Steigerung der Ressourceneffizienz im Bilanzsystem von abwassertechni-schen Anlagen durch Sektorenkopplung
Gloria Kreft	Sektorenkopplung: Entwicklung eines Modells zur technisch-ökonomischen und praktisch um-setzbaren Konzeption eines Systems aus Photovoltaikanlage und Ladeinfrastruktur für gewerb-li-che Unternehmen
Heeba Shaheen	Optimierung der Begrenzungsspannung einer Multicarbon-Funkenstrecke mit niedrigem Schutzpegel für 48 V DC- Anwendungen
Heiko Köhler	Vermessung eines DC-Netzes und Analyse des transienten Verhaltens der elektrischen Größen zur Bestimmung des Fehlerortes unter Beeinflussung von leistungselektronischen Komponen-ten
Henning Köhler	Wirtschaftlichkeitsuntersuchung von Flexibilitätsoptionen im Kontext der Bilanzkreisbewirt-schaftung
Joke Frerichs	Optimierte Bereitstellung von Flexibilität im Querverbund thermischer und elektrischer Erzeu-gungs- und Verbrauchseinheiten
Jonathan Ahrens	Charakterisierung von Li-Ion-Batterien aus Elektrofahrzeugen für Second-Use-Anwendungen

Author	Titel
Justus Friedrich	Methodenentwicklung und Parameterbestimmung zur elektrochemischen Simulation von Lithium-Ionen-Zellen
Kenan Torunoglu	Investigation of a method for increased efficiency of the operation of large PV plants utilizing tap-changing transformers
Marcel Lüdecke (avacon)	Bewertung der Auswirkungen ausgewählter strombasierter Technologien auf den Sektor bezogenen Energieverbrauch und deren Treibhausgasemissionen im ländlichen Raum
Mariem Bedoui	Entwicklung eines dreiphasigen EV-Lademodells mit netzorientierten Funktionen in Python
Okan Özdemir	Spannungshaltungsverfahren eines netzbildenden Umrichters im Parallelbetrieb mit einem Synchrongenerator
Patrick Vieth	Untersuchung und Bestimmung von Optimierungspotentialen von Hybridschaltgeräten im Spannungsbereich bis 3 kV
Robin Langemann	Einsatzmöglichkeiten von Windenergieanlagen im Kontext von regenerativen Wärmeversorgungen
Simon Weinmann	Untersuchung des Parallelbetriebs von Strom- und spannungseinprägenden Umrichtersystemen zur statischen Spannungshaltung
Sitong Lu	Entwicklung eines elektro-thermischen Batteriemodells zur Ableitung von Schnellladeprofilen
Tianzhu Cang (PTB)	Measurement uncertainty determination of novel high-voltage impulse dividers
Torben Jennert	Charakterisierung von Lithium-Ionen-Batteriemodulen mittels elektrochemischer Impedanzspektroskopie
Yvonne Bruchmann	Verfahren zur Verbesserung der Spannungsqualität insbesondere der Unsymmetrie in der Niederspannung- Analyse und wirtschaftliche Einordnung

Student Work 2021

Internship Thesis

Author	Titel
Manuel Wagner, Dimitry Suhanov	Entwicklung eines Ladekonzepts für alle Mitglieder der TU Braunschweig

Student Research Thesis

Author	Titel
Christian Schläger	Entwicklung eines Softwaretools zur Bestimmung des elektrischgen Flexibilitätspotenzials von thermischen Anlagen auf Haushaltsebene
Duc Anh Nguyen	Analyse und Modellierung regenerativ versorgter Elektrolyseure
Johann Fetköter	Entwicklung von Anreizmechanismen für netzdienliches Verhalten privater Ladestationen im Verteilungsnetz auf Basis von Netzdaten
Justin Herdegen	Elektrochemische Modellierung und Simulation von Lithium-Ionen-Zellen

Bachelor Thesis

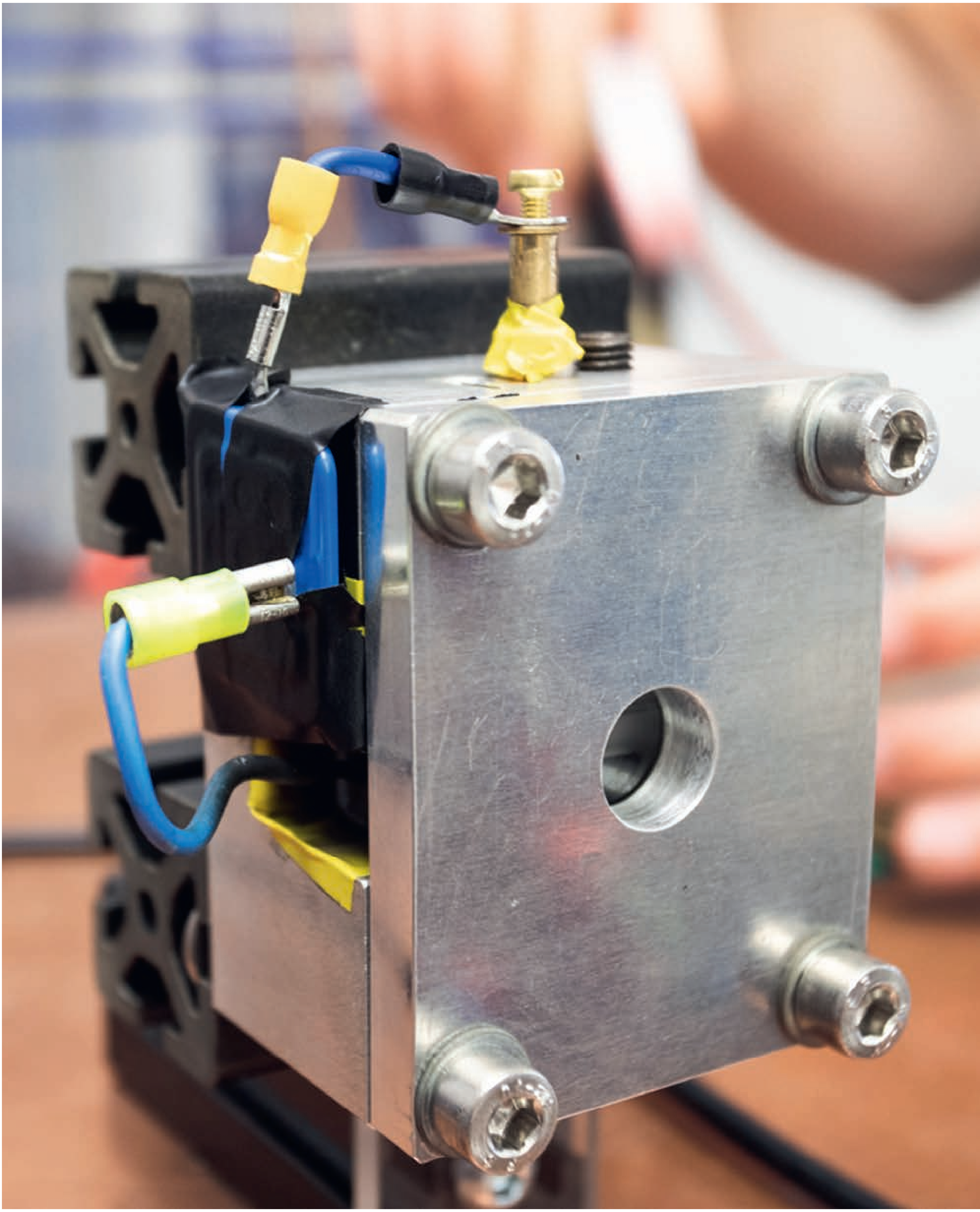
Author	Titel
Alexandra Düe	Sanierung eines denkmalgeschützten Nicht-Wohngebäudes und Bewertung unterschiedlicher Versorgungsvarianten am Beispiel des Kreishauses Heide (Holst.)
Artur Schmidt	Modellierung und Analyse eines Brennstoffzellensystems im Gebäude
Chris Aaron Schneider	Entwicklung eines Messaufbaus zur Reduzierung der magnetischen Einkopplung durch Impulsströme
David Skorupa	Erstellung und Ansteuerung eines Laboraufbaus zur Validierung von Ladealgorithmen
Emmanuel-Wilson Bauni Kamga	Implementierung einer State Estimation im Kontext einer spannungsebenenübergreifenden Netzführung
Eray Cinkaya	Entwicklung eines Referenzmodells einer vermaschten HGÜ-Topologie für die Simulation von Betriebs-, Schutz- und Regelungskonzepten
Felten Feldt	Synchronisation, Messung und Digitalisierung der Emissionsspektren von Metalldampfplasmen in Abhängigkeit von Zeit und Stromstärke
Firas Jmili	Lag bei Redaktionsschluss noch nicht vor
Frederike Paul	Entwurf und Evaluierung einer Methodik zur Modellierung von Einspeise- und Last-Zeitreihen aus aggregierten Messzeitreihen
Gengatharan, Garsan	Untersuchung des Zündverhaltens von Modellfunkenstrecken zur Bestimmung von Leitwert und Zündenergie
Huize Cheng	Planung und Konzeptionierung einer Schaltung zur optischen Strahlungsmessung
Julius Trützschler	Entwicklung eines Tools zur datengetriebenen Analyse und Auswertung von spannungsebenen- und netzbetreiberübergreifenden Netzdaten
Kevin Preißner	Entwicklung und Untersuchung eines breitbandigen Referenzspannungsteilers für 1400 V
Leonie Maria Brümmer	Entwicklung eines Fachkonzepts für eine digitale und kollaborative Forschungsplattform zur Stärkung der Energieforschung in Niedersachsen

Author	Titel
Manuel Hernandez Manas	Requirements Engineering for Scaled Laboratory MTDC Systems
Maximilian Jantos	Technische und wirtschaftliche Analyse der Power-to-X-Nutzung im Kontxt einer 9 MW Photovoltaikanlage
Merle Heinrichs	Analyse von netzdienlichen Betriebskonzepten eines Batteriespeichers bei der Herstellung von grünem Wasserstoff
Philipp Barner	Marktuntersuchung aktueller Wärmepumpensysteme auf Haushaltsebene mit Fokus auf die Beeinflussung des Spannungsbandes
Redlich, Daniel	Methodische Entwicklung und Analyse zukünftiger Netzszenarien für ein Modell eines realen Hochspannungsnetzes
Rico Wosnitza	Analyse von transienten Überspannungen im DC-Netz
Sebastian Brauer	Verwendung von Open-Source- Ansätzen zur Umsetzung von Betriebsstrategien zur simultanen Mehrfachnutzung von Speichersystemen in Mehrfamilienhäusern und Quartieren
Stefanie Walujski	Umsetzung einer geeigneten Netzlast für dynamische Laboruntersuchungen in einem Echtzeitsystem
Timo Haakert	Untersuchung dynamischer Öffnungskurven von Vakuumschaltern mittels eines regelbaren Servomotors
Xuan Thien Le	Ermittlung der Betriebscharakteristik eines Batteriespeichers
Yu Zhang	Untersuchung der elektrischen Festigkeit einer Vakuum-Modellanordnung

Master Thesis

Author	Titel
Andre Rehbock	Lag bei Redaktionsschluss noch nicht vor
Anna-Lena Müller	Erstellung eines regenerativen und nachhaltigen Energiekonzeptes für ein Bestandsgebäude mittels Systems Engineering
Behrooz Moeilsiahrodkolai	Untersuchung möglicher Beiträge zur Frequenzhaltung durch stromgeregelte Umrichter im Netzwiederaufbau
Chao Wei	Requirement Validation of a Grid Connection System for Offshore Wind Farms as part of the Systems Engineering Methodology
Christopher Prange	Zeitabhängige Computersimulationen zur Untersuchung der Vorgänge eines Lichtbogenplasmas in Luft
Dennis Uhde	Umsetzung und Untersuchung von Regelungen zur Verbesserung der Spannungsqualität insbesondere der Unsymmetrie im Niederspannungsnetz
Fabian Kabus	Methodenentwicklung zur effizienten Ermittlung von elektro-thermischen Eigenschaften von Lithium-Ionen-Batterien
Guannan Xin	Entwicklung einer kompakten Ladeschaltung für einen Weil-Dobke.Schwingkreis
Marvin Hugo	Quasistationäre Beschreibung einer örtlichen Leitfähigkeitsverteilung und weiterer Plasmaeigenschaften in einer Modellfunkenstrecke unter Stoßstrombelastung
Jens Brüggemann	Untersuchung der Frequenzstabilität mittels eine Power Hardware-in-the-loop Systems
Julian Studt	Modellierung und Evaluation statistischer und maschinell lernender Methoden zur Prognose von elektrischen Spotmarktpreisen
Julian Wehr	Untersuchung der Beeinflussung von Inselnetzerkennungsverfahren von Bestandsumrichtern im Verbundbetrieb mit netzbildenden Wechselrichtern

Author	Titel
Keno Brüning	Analyse der geographischen Verteilung von Wind- und solarer Einspeisung und deren Einflüsse auf das elektrische Energienetz
Kerstin Wetjen	Entwicklung und Untersuchung von Fallback-Strategien im Falle von Kommunikationsunterbrechungen in elektrischen Energieversorgungsnetzen
Lars Groppe	Konzeptionierung, Entwicklung und Erprobung von erzeugungsorientierten Ladealgorithmen
Lenard Faber	Modellbasierte Entwicklung und Erprobung verschiedener Schnelladestrategien im Rahmen der Formierung von Lithium-Ionen-Batterien
Maik Kahn	Methodische Entwicklung zur Etablierung des High Potential Tests als Qualitätstest in der Batteriezellproduktion
Mariem Bedoui	Entwicklung eines dreiphasigen EV-Lademodells mit netzorientierten Funktionen in Python
Marius Matern	Entwicklung und Validierung einer Methodik zur Vorhersage der Blindleistung in elektrischen Energiesystemen unter Anwendung eines maschinell lernenden Prognoseverfahrens
Mike Stefan Skroch	Erstellung typischer Fahrprofile von Kraftfahrzeugen und Hot-Spot-Analyse von Ladepunkten und -Zeiten auf Basis empirischer Daten
Niklas Bestian	Unsymmetrie in verschiedenen Niederspannungsnetzen unter Berücksichtigung der Elektromobilitäts- und der Wärmeentwicklung — technische und wirtschaftliche Simulation und Analyse
Nils Menebröker	Entwicklung von Formierungsstrategien für Hochenergiebatteriezellen und Evaluierung der elektrochemischen Performance
Oliver Landrath	Theoretische Untersuchungen der Plasma Elektrodenkopplung eines Lichtbogenplasmas in Luft mit Computersimulationen
Paul Hendrik Sasse	Optische und messtechnische Untersuchung der Wiederkehrspannung einer gekapselten Modella-nordnung nach Strombelastungen im Betriebsbereich eines LVDC Hybridschalters
Rene Schilling Johnson	Entwicklung von Verfahren zur Inselnetzerkennung durch spannungseinprägende Umrichter im Verbundbetrieb mit Bestandsanlagen
Robin Herman	Messung, Auswertung und Bewertung der Auswirkungen von Komponenten auf Spannungsqualitätsmerkmale im Niederspannungsnetz
Saleh Abolaila	Entwicklung und Validierung eines Evaluationsschemas für Bereitstellung von Systemdienst-Services durch umrichtergekoppelte Erzeugungsanlagen
Tim Göttert	Technisch-wirtschaftliche Bewertung der Bereitstellung von Momentanreserve durch leistungselektronische Systeme
Timo Sauer	Strombegrenzung von spannungseinprägenden Wechselrichtern in Netzfehlersituationen mittels eines Power Hardware-in-the-Loop Systems
Tom Hemme	Vergleich von Formierungsstrategien für Lithium-Ionen Batteriezellen hinsichtlich der elektrochemischen Performance
Xiaoyu Li	Bewertung gezielter Binderanteilsvariation in mehrlagigen Silizium-Graphit-Anoden und Evaluierung des Einflusses auf die elektrochemische Performance und Tortuosität
Xin Cheng	Modellbildung eines 1 kV DC Labornetzes mittels Systemanalyse und statistischer Versuchsplanung
Ziang Wang	Identifikation, Analyse und Umsetzung von Betriebsstrategien zur simultanen Mehrfachnutzung von Speichersystemen in Mehrfamilienhäusern und Quartieren



Chronology

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Biedermann, C., Simon, S., Vanselow, A., Przibylla, J., Golobart, M., Modica, G., Garn, T., Willenberg, D., Witzmann, R., Engel, B.:
Spannungsqualität vor dem Hintergrund des Anstiegs an Photovoltaik, Elektrofahrzeugen, PV-Batteriespeichersystemen und Power-to-Heat
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Reinhold, C., Ries, J., Kahl, L., Hadlak, M., Engel, B.:
Einsatz netzdienlicher Flexibilität im koordinierten Verteilnetzbetrieb aus elektrischen und thermischen Anlagen in Gebäuden
ENERGY FOR FUTURE – WEGE ZUR KLIMANEUTRALITÄT, ENINNOV2020–16. SYMPOSIUM ENERGIEINNOVATION, GRAZ/AUSTRIA, GRAZ: VERLAG DER TECHNISCHEN UNIVERSITÄT GRAZ, 12.–14. FEBRUAR 2020, S. 307-308. ISBN 978-3-85125-734-2

Ries, J., Reinhold, C., Engel, B., Roos, M.:
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Transient Overvoltage Protection Solutions for Drive Inverters operating on an Open Industrial DC Grid
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Further developments of metrological and simulation-based characterization of the non-contact measurement of electrostatic charge by means of electric field meters
PROCEEDINGS OF THE 21ST INTERNATIONAL SYMPOSIUM ON HIGH VOLTAGE ENGINEERING VOLUME 1, 21ST INTERNATIONAL SYMPOSIUM ON HIGH VOLTAGE ENGINEERING, BUDAPEST, HUNGARY, SWITZERLAND: SPRINGER NATURE SWITZERLAND AG, 25.–29. AUGUST 2019, S. 55-66. ISBN 978-3-030-31675-4

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Modelling and Simulation of All-Electric Machines and Renewable Electric Power Systems in Agricultural Operations
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IBPC 2020 – INTERNATIONAL BATTERY PRODUCTION CONFERENCE, BRAUNSCHWEIG, 2.–4. NOVEMBER 2020

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Anspach, F., Claaßen, L., Wilkening, E., Kurrat, M.:
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Experimental validation of current limitation methods for grid forming inverters
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Qudaih, M., Engel, B., Truijen, D., De Kooning, J., Stockman, K., Hoffstädt, J., Jarquin-Laguna, A., Ansorena Ruiz, R., Goseberg, N., Bricker, J., Fahlbeck, J., Nilsson, H., Bossi, L., Joseph, M., Zangeneh, M.:
THE CONTRIBUTION OF LOW-HEAD PUMPED HYDRO STORAGE TO A SUCCESSFUL ENERGY TRANSITION, DECARBONIZATION OF ENERGY SECTORS
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Lotz, M., Kurrat, M.:
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Schierding, C., Thedens, M., Beyer, M.:
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Bösche, D., Wilkening, E.:
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Hoffmann, M., Chamorro, H., Lotz, M., Maestre, J., Rouzbehi, K., Gonzalez-Longatt, F., Kurrat, M., Alvarado-Barrios, L., Sood, V.:
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M. Alija, Y. Cressault, P. Teulet, M. Kurrat:
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Rauscher, Florian; Winter, Björn Oliver; Seidel, Julia; Engel, Bernd (2020):
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ENINNOV2020 TU GRAZ (HG.): 16. SYMPOSIUM ENERGIEINNOVATION 2020. 16. SYMPOSIUM ENERGIEINNOVATION 2020. GRAZ, 12.02.–14.02. ONLINE VERFÜGBAR UNTER HTTPS://WWW.TUGRAZ.AT/FILEADMIN/USER_UPLOAD/TUGRAZEXTERNAL/4778F047-2E50-4E9E-B72D-E5AF373F95A4/FILES/LF/SESSION_H6/866_LF_RAUSCHER.PDF.

M. R. Lotz, M. Kohn, T. Öznur and M. Könemund:
Hardware-in-the-Loop Setup for Low Voltage Modular Multilevel Converter Control Development
2020 IEEE 29TH INTERNATIONAL SYMPOSIUM ON INDUSTRIAL ELECTRONICS (ISIE), 2020, PP. 126–133, DOI: 10.1109/ISIE45063.2020.9152270

M. R. Lotz, M. Hoffmann and M. Könemund:
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PCIM EUROPE DIGITAL DAYS 2020; INTERNATIONAL EXHIBITION AND CONFERENCE FOR POWER ELECTRONICS, INTELLIGENT MOTION, RENEWABLE ENERGY AND ENERGY MANAGEMENT, 2020, PP. 1–8.

M. R. Lotz:
Power-Hardware-in-the-Loop Tests of DC Systems in Scaled Laboratory Environments
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Simulative Untersuchung der Netzintegration vollelektrischer Landmaschinen in ländliche Verteilnetze
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Biedermann, C., Modica, G., Przibylla, J., Engel, B.:
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M. Alija, Y. Cressault, P. Teulet, M. Kurrat:
Calculation of thermophysical properties and computational modeling for higher temperature and pressure air plasma
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Kehl, D., Lienesch, F., Kurrat, M.:
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ADVANCED BATTERY POWER, DIGITAL, 28. – 29. APRIL 2021

Drees, R., Kurrat, M.:
Model-based Design and Assessment of optimized Fast Charging Strategies for the Formation of Lithium-Ion Batteries
ADVANCED BATTERY POWER 2021, DIGITAL, 28. – 29. APRIL 2021

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Regulatory Framework for Sales Options of Flexibilities at Distribution Grid Level
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VDE ETG KONGRESS 2021, DIGITAL, 18. – 19. MAI 2021

Anspach, F., Vieth, P., Claaßen, L., Bösche, D., Wilkening, E., Kurrat, M.:
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PROCEEDINGS ICEC 2020, 30TH INTERNATIONAL CONFERENCE ON ELECTRICAL CONTACTS, ST. GALLEN / RORSCHACH, 7. – 11. JUNE 2021, S. 141 – 148. ISBN 978-3-907255-11-7

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29TH INTERNATIONAL SYMPOSIUM ON DISCHARGE AND ELECTRICAL INSULATION IN VACUUM (ISDEIV), PADOVA, ITALIEN, 26. SEPTEMBER – 1. OCTOBER 2021

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XXIX INT. SYMP. ON DISCHARGE AND ELECTICAL INSULATION IN VACUUM, ISDEIV, PADUA, IEEE, 26. SEPTEMBER–1. OCTOBER 2021

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Electrical Characterization of Li-Ion Battery Modules for Second-Life Applications
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Drees, R., Lienesch, F., Kurrat, M.:
Fast charging lithium-ion battery formation based on simulations with an electrode equivalent circuit model
JOURNAL OF ENERGY STORAGE 0. JG.(2021), H. 102345, S. 1–10. DOI: DOI.ORG/10.1016/J.EST.2021.102345

Klabunde, F., Reinhold, C., Engel, B.:
Modelling and Simulation of All-Electric Machines and Renewable Electric Power Systems in Agricultural Operations
SNE SIMULATION NOTES EUROPE 31. JG.(2021), H. 2, S. 57–64. DOI: 10.11128/SNE.31.TN.10562. E-ISSN: 2306-0271. P-ISSN: 2305-9974

Hoffmann, L., Kasper, M., Kahn, M., Ventura Silva, G., Gramse, G., Herrmann, C., Kurrat, M., Kienberger, F.:
High Potential Test for Quality Control of Separator Defects in Battery Cell Production
BATTERIES 2021 JG.(2021), 7, 1–12. HTTPS://DOI.ORG/10.3390/XXXXX, E-ISSN: 2313-0105

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Enhanced Contribution of Photovoltaic Power Systems to Frequency Control in Future Power Systems
IET RENEWABLE POWER GENERATION 2021

Modica, G., Choi, W., Dietrich, T., Ebbert, L., Effenberger, R., Meins, J., Schillingmann, H., Wussow, J., Engel, B., Henke, M.:
LISA4CL – Development and Grid Integration of an Inductive Charging System for City Logistics
NEIS 2021 — CONFERENCE ON SUSTAINABLE ENERGY SUPPLY AND ENERGY STORAGE SYSTEMS, DIGITAL, 13.–14. SEPTEMBER 2021

Rauscher, F., Nuschke, M., Engel, B.:
Determination of the damping and inertia time constant of grid forming inverters by laboratory measurements
NEIS 2021, HAMBURG, 13.–14. SEPTEMBER 2021

Schuster, M., Kufeld, D. N., Koeppe, H., Engel, B.:
Development Approach for Short-term Forecasting of Reactive Power at the Interface Distribution and Transmission Grid
ETG KONGRESS, DIGITAL, 18.–19. MAI 2021, S. 222–227. ISBN 978-3-8007-5549-3

Wagner, Henrik; Eckhoff, Sarah; Fayed, Sarah; Penahherrera V., Fernando; Ofenloch, Annika; Werth, Oliver et al. (2021):
Analysis of the Grid Capacity for Electric Vehicles in Districts with a Major Need for Sustainable Energy Refurbishment: The Case of a District in Lower Saxony
GESELLSCHAFT FÜR INFORMATIK (HG.): ENVIROINFO 2021. BERLIN, 27.–29. SEPTEMBER 2021

Anspach, F., Vieth, P., Bösche, D., Claaßen, L., Wilkening, E.D., Kurrat, M.:
Presentation of a novel and laboratory proved method to determine efficiently the minimum deionization time in hybrid circuit contactor
2021 IEEE 67TH HOLM CONFERENCE ON ELECTRICAL CONTACTS (HLM)

Ryll, K., Hoffmann, L., Landrath, O., Lienesch, F., Kurrat, M.:
Key Figure Based Incoming Inspection of Lithium-Ion Battery Cells
BATTERIES 2021. JG.(2021), S. 1–22. DOI: HTTPS://DOI.ORG/10.3390/BATTERIES7010009

Winter, Björn Oliver; Torunoglu, Kenan; Hussain, Waqas; Vielhauer, Armin; Engel, Bernd (2021):
Increasing energy yield of PV Parks by controlling On-Load Tap Changers to optimize inverter utilization
INTERNATIONAL ASSOCIATION ON ENVIRONMENT AND ELECTRICAL ENGINEERING (HG.): 21ND INTERNATIONAL CONFERENCE ON ENVIRONMENT AND ELECTRICAL ENGINEERING (EEEIC2021). EEEIC2021 BARI. BARI, ITALY, 07.09.2021. IEEE.

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Islanding Dependencies and Detection in low-Voltageg rids with grid forming Inverters
THE IET (HG.): RENEWABLE POWER GENERATION CONFERENCE (RPG DUBLIN). RPG DUBLIN, 01.03.2021.

M. R. Lotz and M. Kurrat:
Evaluation of Temporary Overvoltages Considering Current Standards and Regulations with Extensive Renewables Integration
ETG CONGRESS 2021, 2021, PP. 1–6.

M. R. Lotz and M. Könemund:
Challenges of Commutation Cell Tests with Voltage Source Inverters in Power-Hardware-in-the-Loop Simulations
PCIM EUROPE DIGITAL DAYS 2021; INTERNATIONAL EXHIBITION AND CONFERENCE FOR POWER ELECTRONICS, INTELLIGENT MOTION, RENEWABLE ENERGY AND ENERGY MANAGEMENT, 2021, PP. 1–8.

M. R. Lotz and M. Könemund:
A System-in-the-Loop Methodology for the Validation of DC-Connected Converters
2021 IEEE FOURTH INTERNATIONAL CONFERENCE ON DC MICROGRIDS (ICDCM), 2021, PP. 1–8, DOI: 10.1109/ICDCM50975.2021.9504636

M. R. Lotz et al.:
Potentials and Technical Requirements for the Provision of Ancillary Services in Future Power Systems with Distributed Energy Resources
NEIS 2021, CONFERENCE ON SUSTAINABLE ENERGY SUPPLY AND ENERGY STORAGE SYSTEMS, SEPTEMBER 2020, IEEE CONFERENCE.

Events 2020

07.01.2020
"Possible applications of a battery-electric multiple unit in the Braunschweig area", VDI-AK Bahntechnik lecture series (WS2019/2020) at TU Braunschweig "Future of mobility in Lower Saxony"
B. ENGEL

08.01.2020
VDE board and advisory board meeting
M. KURRAT

13. and 14.01.2020
Doctoral Student Symposium (PTB)
B. ENGEL, M. KURRAT

22.01.2020
VDE New Year's Reception
B. ENGEL, M. KURRAT

22.01.2020
Campus day
B. ENGEL, M. KURRAT

28.01.2020
Business reception, Laboratory for Emerging Nanometrology LENA
M. KURRAT

29. and 30.01.2020
Meeting Advisory Board "Future grids"
B. ENGEL

03.02.2020
Exhibition on the Study Seminar "Consequences of the Energy Transition-Mobility Transition"
B. ENGEL, M. KURRAT

03.02.2020
Poster Session Study Seminar "Consequences of the Energiewende – Mobilitätswende"
M. KURRAT

07.02.2020
Pupils Day Physics
M. KURRAT

19.02.2020
"Centralized and decentralized elements in the energy system" ETG Department V1 in Frankfurt.
B. ENGEL

03. and 04.03.2020
Conclave EITP, Wöltingerode Monastery
B. ENGEL, M. KURRAT

05.03.2020
Kick-Off SiNED
B. ENGEL, F. SOYCK, J. WUSSOW, M. R. LOTZ, M. HOFFMANN, L. KAHL, S. CELAN

05.03.2020
"Why do we need hydrogen for the energy transition in Lower Saxony?" 1st Annual Conference of the EFZN Research Network Hydrogen Lower Saxony March 5 and 6, 2020, Goslar.
B. ENGEL

05.03.–06.03.2020
ZIEHL Conference, Berlin
M. KURRAT

02.–03.04.2020
Kick-Off ALPHEUS
B. ENGEL, M. QUDAIH

03.04.2020
Program Committee VDE High Voltage Technology
M. KURRAT

15.04.2020
Board meeting + MV Future City
M. KURRAT

29.04.2020
Annual General Meeting VDE Foundation Erwin-Marx
M. KURRAT

26.05.2020
"Experiences as E-Mobilist and Prosumager", Scientists for Future Braunschweig, Digital Lecture Series Climate Protection – Answers from Science
B. ENGEL

27.05.2020
VDE board and advisory board meeting
M. KURRAT

10.06.2020
Board meeting + MV Future City
M. KURRAT

18.06.2020
New BA program ET
B. ENGEL, M. KURRAT

23.06.2020
NFF Annual General Meeting
B. ENGEL, M. KURRAT

24.06.2020
New BA program ET
B. ENGEL, M. KURRAT

24.06.2020
WG Global underspending
B. ENGEL, M. KURRAT

07.07.2020
Kick-Off LISA4CL
B. ENGEL, G.-L. DI MODICA, J. WUSSOW

07.07.2020
WG Global underspending
B. ENGEL, M. KURRAT

18.08.2020
WG Excursion
M. KURRAT

19.–20.08.2020
AG-Workshop Energy technologies
M. KURRAT, ARBEITSGRUPPE ENERGIETECHNOLOGIEN

26. and 27.08.2020
WG Retreat
B. ENGEL

30.08.2020
Workshop HZB/TUBS
M. KURRAT

01.09.2020
"PV + Battery + X -Future inverter-fed grids" Photovoltaic Symposium (online)
B. ENGEL

04.09.2020
VDE board and advisory board meeting
M. KURRAT

18.09.2020
Externe Promotionsprüfungen als Zweitgutachter: Farina Wille (Faculty of Life Sciences)
B. ENGEL

07.10.2020
Kick-Off FastChargeLongLife
M. KURRAT, F. KATSCHEWITZ

15.10.2020
Program Committee VDE High Voltage Technology
M. KURRAT

16.10.2020
Colloquium + Awarding of Gauss Medal
M. KURRAT

20.10.2020
"Photovoltaics: expansion paths and perspectives for technological advancement," ETG Online Symposium: Electric Energy Generation and Storage
B. ENGEL

20.10.2020
Board meeting + MV Future City
M. KURRAT

26.10.2020
Cluster Symposium 2020 – Sustainable and Energy Efficient Aviation
M. KURRAT

27.–28.10.2020
Industry Day and Research Colloquium Battery Cell Production Competence Cluster (ProZell)
M. KURRAT, R. DREES, L. HOFFMANN

02. and 03.11.2020
International Battery Production Conference 2020 (IBPC)
M. KURRAT, R. DREES, L. HOFFMANN, D. KEHL

06.11.2020
"Grid-forming converters-why?" Online Workshop FNN Grid Control
B. ENGEL

10.11.2020
VDE panel discussion on Energiewende: Hydrogen/fuel cell vs. battery
B. ENGEL, M. KURRAT

10.11.2020
VDE-ETG Q2 meeting
M. KURRAT

11.11.2020
VDE board and advisory board meeting
M. KURRAT

19.11.2020
"Status report FNN workshop 11/6/2020 – from research to rulemaking" Digital meeting FNN steering committee system issues and grid codes.
B. ENGEL

24.–27.11.2020
European Conference on Battery Cell Manufacturing
R. DREES, L. HOFFMANN, F. KATSCHEWITZ; D. KEHL

02.12.2020
elenia General Meeting
M. KURRAT

08.12.2020
Board meeting + MV Future City
M. KURRAT

11.12.2020
ETG Congress 2021 Program Committee
B. ENGEL, M. KURRAT

Ongoing
Power Engineering Society (ETG) in the VDE, Board meeting
B. ENGEL

Ongoing
Energy Research Centre of Lower Saxony (EFZN), Board meeting
B. ENGEL

Ongoing
Scientist for Future
B. ENGEL

Without Date
Meeting Advisory Board "Photovoltaics Symposium"
B. ENGEL

Ongoing
General Meeting Energy Research Node Braunschweig (1 × per semester)
B. ENGEL

Ongoing
BWG (class meeting, plenary meeting) (monthly)
M. KURRAT

Events 2021

05.01.2021
VDE board and advisory board meeting
M. KURRAT

20. and 27.01.2021
Lecture series Batterieforum 2021
R. DREES, L. HOFFMANN, F. KATSCHEWITZ; D. KEHL

20.01.2021
FSP-Metrology Board Meeting
M. KURRAT

27. and 28.01.2021
Meeting Advisory Board "Future grids"
B. ENGEL

02. and 09.02.2021
Lecture series Batterieforum 2021
R. DREES, L. HOFFMANN, F. KATSCHEWITZ; D. KEHL

03. and 04.02.2021
Meeting Advisory Board "Future grids"
B. ENGEL

17.02.2021
Board meeting FSP Future City
M. KURRAT

23.02.2021
"Grid-forming inverters for TSOs" SMA Innovation & Technology Day 2021 (online)
B. ENGEL

26.02.2021
Laboratory Experience Exchange accredited
M. KURRAT

01.03.2021
85th NFF board meeting
M. KURRAT

02.03.2021
VDE board and advisory board meeting
M. KURRAT

03.–04.03.2021
Competence cluster battery utilisation concepts (Battutilisation)
M. KURRAT, R. DREES, L. HOFFMANN, F. KATSCHEWITZ

16.–17.03.2021
Kick-Off BMBF-Competence Cluster Intelligent Battery Cell Production (InZePro)
M. KURRAT, R. DREES, L. HOFFMANN

19.03.–25.03.2021
Retreat EITP
B. ENGEL, M. KURRAT

23.–24.03.2021
Research colloquium BMBF-Competence Cluster Battery Cell Production (ProZell)
M. KURRAT, R. DREES, L. HOFFMANN

14.04.2021
Board meeting FSP Future City
M. KURRAT

21.04.2021
"Research Roadmap "Ancillary Services"" Research and Innovation Platform of the Research Network Energy of the BMWi (online).
B. ENGEL

27.04.2021
elenia Open Research Day (online)
B. ENGEL, M. KURRAT

28.–29.04.2021
Kraftwerk Batterie
R. DREES, L. HOFFMANN, F. KATSCHEWITZ; D. KEHL

29.04.2021
Meeting BMWi Research Area: High Temperature Superconductivity
M. KURRAT

29.04.2021
General Meeting ivSupra
M. KURRAT

30.04.2021
Annual General Meeting VDE Foundation Erwin-Marx
M. KURRAT

30.04.2021
VDE Prof.Date
M. KURRAT

18.05.2021
ETG Poster Key Comp.
M. KURRAT

19.05.2021
Chair ETG Session D5
M. KURRAT

26.05.2021
"Target image climate-neutral energy supply 2045", VDE Prof.Date 2021 (online)
B. ENGEL

07.06.–11.06.2021
ICEC Conference
M. KURRAT

08.06.2021
External PhD examinations Second assessor: Christian Aigner (TU München) – online
B. ENGEL

11.06.2021
Kick-Off BMWi-Projekt NEWBIE
L. HOFFMANN, D. KEHL

15.06.2021
VDE board and advisory board meeting
M. KURRAT

15.06.2021
"PV self-consumption as a driver of the energy transition" 4th Lower Saxony Solar Energy Forum (online)
B. ENGEL

23.–24.06.2021
11. Braunschweiger Energy Seminar
M. HOFFMANN, T. MEYER

24.06.2021
Energy Seminar
M. KURRAT

30.06.2021
"Neighborhood energy systems for the energy transition", EFZN research workshop 2020/21 part 2 (online)
B. ENGEL

02.07.2021
Board meeting FSP Future City
M. KURRAT

22.07.2021
External PhD examinations Second assessor: Florian Rewald (TU Dortmand)
B. ENGEL

09.09.2021
External PhD examinations Second assessor: Tim Plößer (TU Darmstadt)
B. ENGEL

14.–15.09.2021
AG-Workshop Energietechnologien
M. KURRAT, ARBEITSGRUPPE ENERGIETECHNOLOGIEN

21.09.2021
VDE board and advisory board meeting
M. KURRAT

22.09.2021
"Welcome and Introduction by the EFZN", Göttingen Energy Days of BNetzA and EFZN
B. ENGEL

22.09.2021
Board meeting FSP Future City
M. KURRAT

23.09.2021
"System splits and other system disturbances – Do grid-forming inverters solve the challenges of future power grids – Introduction to the topic" , Workshop: Grid-forming inverters for stable grid operation, 22nd Forum Neue Energiewelt, Berlin.
B. ENGEL

24.09.2021
"The Smart Home for the Prosumer as a Key to the Energy Turnaround" Autumn Conference 2021 of the Expert Group Electrical Engineering and Information Technology (online).
B. ENGEL

27.09.–01.10.2021
ISDEIV Conference, Padova/Italy
M. KURRAT

Ongoing
Power Engineering Society (ETG) in the VDE, Board meeting
B. ENGEL

Ongoing
Energy Research Centre of Lower Saxony (EFZN), Board meeting
B. ENGEL

Ongoing
Scientist for Future
B. ENGEL

Without Date
Meeting Advisory Board "Photovoltaics Symposium"
B. ENGEL

Without Date
General Meeting Energy Research Node Braunschweig (1 × per semester)
B. ENGEL

Without Date
Appointment committee TU Clausthal, successor Prof. Beck
B. ENGEL

Ongoing
BWG (class meeting, plenary meeting) (monthly)
M. KURRAT

Participation in self-administration 2020

University

MICHAEL KURRAT

- Dean's meeting (web conference) 19.01. | 20.03. | 24.03. | 26.03. | 31.03. | 21.04. | 05.05. | 07.05. | 27.05. | 25.06. | 11.06. | 14.05. | 19.05. | 02.07. | 16.07. | 28.07. | 19.08. | 24.09. | 17.12.
- Presidential Search Committee 01.06. | 13.11. | 14.12.
- Spokesperson for WG Candidate Selection in Appointment Procedures 23.04. | 19.05. | 04.06. | 06.07. | 21.07. | 27.08. | 06.10. | 25.11.
- Senate meeting (web conference) 20.01. | 17.02. | 17.03. | 22.04. | 13.05. | 17.06. | 08.07. | 26.08. | 16.09. | 09.12.

BERND ENGEL

- Energy Advisory Board 05.03. | 18.06. | 05.11.
- WG Sustainability

Faculty

MICHAEL KURRAT

- Dean of Faculty EITP
- Speaker planning board EITP since May 28, 2020
- Planning board Faculty (FK EITP) 28.05. | 12.06. | 03.07. | 28.08. | 29.10. | 20.11.
- Faculty Meeting 17.01. | 07.02. | 23.04. | 14.05. | 28.05. | 18.06. | 16.07. | 05.11., | 03.12.

BERND ENGEL

- Faculty Council Meeting 20.01. | 27.4. | 18.5. | 22.6.
- Subject Representative Meetings

elenia Institute

MICHAEL KURRAT

- Institute board (Managing board) (monthly)
- Plenary meetings (Staff assembly) (monthly)
- Project Management Office (if required)
- Team leader meetings (monthly)
- Novice group (doctoral student seminar, monthly)
- Mentor meetings 15.01. | 28.04. | 19.05. | 28.10. | 25.11.
- First semester welcome 28.10.2020

BERND ENGEL

- Status meetings (staff assembly) – meeting dates (1 × per month)
- Team leader meetings of the WG Energy Systems
- Mentor meeting (1 × per semester)

Participation in self-administration 2021

University

MICHAEL KURRAT

- Dean's meeting 28.01. | 02.02. | 25.03. | 20.05.
- Presidential Search Committee 29.01.2021 | 10.03.2021
- Spokesperson for WG Candidate Selection in Appointment Procedures 10.02.2021
- Senate meeting (web conference) 20.01. | 08.02. | 17.02. | 17.03. | 16.06.

BERND ENGEL

- Senate meeting video conference public part, 20.01.
- Energy Advisory Board
- WG Sustainability

Faculty

MICHAEL KURRAT

- Dean of Faculty EITP until March 31, 2021
- Advisor Faculty Council EITP as associate dean since April 1, 2021
- Speaker planning board EITP as associate dean since May 28, 2020.
- Planning board Faculty (FK EITP) 08.01.2021 | 05.02.2021 | 21.05. | 25.06. | 16.07. | 17.09

BERND ENGEL

- Subject Representative Meetings

elenia Institute

MICHAEL KURRAT

- Executive head of the institute since April 1, 2021
- Institute board (Managing board) (monthly)
- Plenary meetings (staff assembly) (monthly)
- Project Management Office (if required)
- Team leader meetings of the working groups (monthly)
- Novice group (doctoral student seminar, monthly)
- Mentor meetings 27.01. | 12.07.
- First semester „Elektromobilität" welcome 13.04.2021

BERND ENGEL

- Institute Round Table (Board of Directors)
- Projektmanagement Office (weekly)
- Status meetings (staff assembly) - meeting dates (1 × per month)
- Team leader meetings of the WG Energy Systems (2 × per month)
- Mentor meeting (1 × per semester)

Imprint

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Design: Jakob Piest
Photos: Unless otherwise noted: elenia/TU Braunschweig

Reporting period: 01/2020 – 10/2021

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