Technische Universität Braunschweig

elenia
Department for High Voltage Technology and Electrical Power Systems

Department for High Voltage Technology and Electrical Power Systems - elenia

Annual Report

2019

Preface

Dear friends of the elenia,

The year 2019 was marked by intense public discussions about climate protection, Fridays for Future and the climate package of the Grand Coalition. Students and Scientists for Future were also active at the TU Braunschweig and, together with the Executive Committee, initiated the development of a new model for a sustainable, climate-neutral university.

Our research efforts fit into this period with more electromobility, increased use of renewable energies and storage facilities, and the expansion of power grids. That's why we're growing pleasingly well and many successful projects were submitted. From application-oriented contractual research to fundamental research funded by the Deutsche Researchsgesellschaft (DFG), we have a healthy balance of third-party funding from companies, federal and state ministries, and the DFG. This development is associated with growth in personnel, with the result that we now work closely together with a staff of over 50 employees.

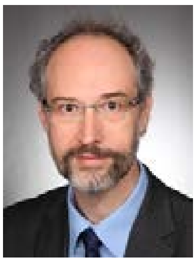
For the faculty, the elenia and Michael Kurrat will continue as Dean for two more years. With the main objective of structuring, the faculty met in February for its conference "Teaching" in the Wöltingerode monastery in order to seize the opportunities offered by the re-accreditation of electrical engineering and information technology for the development of the faculty.

The energy technicians of the TU strengthen the committee work of the Energietechnische Gesellschaft (ETG) in the VDE. Our colleague Regine Mallwitz from the Institute for Electrical Machines, Drives and Railways will take over as head of the ETG department Q1 "Power Electronics", Michael Kurrat will head the department Q2 "Materials, Insulation Systems, Diagnostics" and Bernd Engel has been re-elected to the ETG Executive Board as a representative of science.

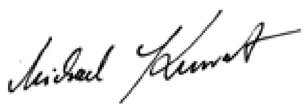
With the wish for a good and successful year 2020, we would like to thank you, our partners from companies and research institutions, the lecturers, the DFG, the project management agencies, the Federal Ministries, the Volkswagen Foundation and the Lower Saxony Ministries for Science and Culture as well as for the Environment, Energy and Climate Protection for supporting our work.

Braunschweig, December 2019

Bernd Engel



Michael Kurrat



Contents

6 Chronology

4 Teaching

5 Events

Contents

1 Portrait

2 Research

3 Labs & Workshops

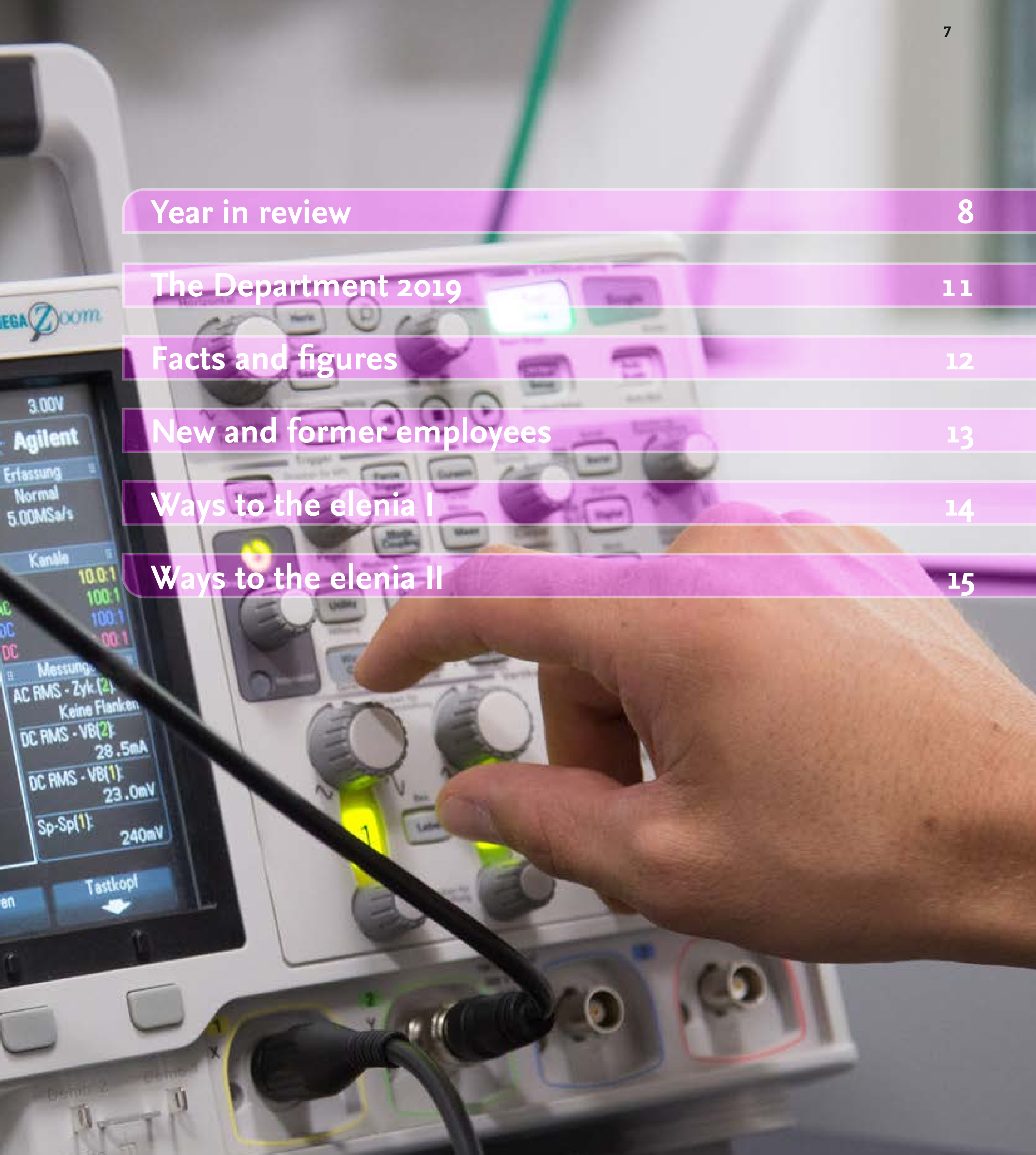
4 Teaching

5 Events

6 Chronology

Portrait

1



The Department for High Voltage Technology and Electrical Power Systems - elenia is part of the Faculty of Electrical Engineering, Information Technology and Physics at the Technische Universität Braunschweig. With more than 50 employees, we have grown considerably in recent years due to the growing need for research in energy technology. Our team works on joint projects in a technically profound, scientifically diligent and highly motivated manner and is the essential factor for the success of the elenia. Our interpersonal and professional approach is always based on our institute's canon of values.

Year in review

Review of the year 2019 at the Department for High Voltage Technology and Electrical Power Systems - elenia

There is much to report from research and teaching about the elenia in 2019. Our three main research groups were very active. The highlight was the Research Group Day on 14 May 2019, which took place this year at the Physikalisch-Technische Bundesanstalt (PTB). More than 30 posters were presented and eagerly discussed.

In our research group " Components of Energy Supply " (Mentor Prof. Kurrat) we work on developing new methods of high voltage technology as well as new devices. This enables us to gain a deeper understanding of the electrotechnical and physical phenomena and to describe them. This year new and challenging projects have been started. In the Smart Modular Switchgear 2 project, new switching concepts and fault detection algorithms are being developed and tested for medium-voltage DC networks. In this project, our scientific exchange with colleagues from IMAB, PTB and ETA is strengthened. In the field of vacuum technology, a DFG-funded project was started this year with the TU Darmstadt, which focuses on magneto-optical arc analysis.

Furthermore, we are working on the theoretical, optical and thermodynamic properties of plasmas in various fields of application from spark gaps to vacuum switches with our long-standing industrial partners. In the field of insulation systems, Mr. Nicholas Hill completed a dissertation this year in the field of cryogenic insulation materials. With this dissertation we were able to further improve the profile of the institute in the direction of the breakdown theory of gases.

The research focus group "Electromobility" (Mentor Dr.-Ing. Lienesch) was able to acquire the project DaLion4.0 funded by the BMWi immediately after the successful completion of the BLB lighthouse project DaLion at the end of 2018. Thus, significant work has already been carried out towards greater clarity regarding influencing factors in battery cell production. In addition to the development of controllable models, which aim to map cell production in cyber-physical systems, the focus lies on the integration of new measurement techniques and quality management. In addition, the activities in the NetProSum2030 project expanded the laboratory capacity for the investigation of battery modules and systems as well as building up valuable expertise in this field. In addition, the good cooperation with PTB was strengthened by NetProSum2030 and the BaSS project that started in 2018. At the beginning of the year, a small proposal team headed by BLB drafted the application for the "Research Production Battery Cell" for the Braunschweig/Salzgitter location. The battery research factory with its competitive battery production is embedded in the BMBF's battery research concept. At the end of June, the decision was made in favour of the Münster site. However, discussions are currently taking place between the BMBF and the other applicants in order to identify, promote and jointly implement the best concepts. The BLB International Battery Production Conference (IBPC) in Braunschweig was just as successful as last year and attracted over 230 battery experts from 17 different countries.

In the field of grid integration of electromobility, active cooperation is being established with local companies. Two research projects on the electrification of the inner-city bus ring line have already been carried out in the recent past with the public transport company Braunschweiger Verkehrs GmbH. A study is currently underway to investigate the complete conversion to an electric bus fleet. As part of a cooperation with the local energy utility BS|Energy and the local grid operator BS|Netz, current issues relating to the grid integration of electric vehicles and associated challenges are being analysed.

In the research focus group "Smart Grids" (Mentor Prof. Engel), a number of challenging projects ended and started in 2019. In "PV Wind Symbiosis", the provision of reactive power from PV and wind turbines was investigated and a reactive power management system for distribution grids was developed.

Joint research group day of the elenia, 14 May 2019

The follow-up project "Q-Integral" will logically continue the work. The aim is to extend the management system to a cross-voltage and cross-grid operator approach. The U-Control project has also been succeeded by U-Quality. In this project, the influences of inverter-based components and heat pumps on voltage quality are investigated. The simulations will be validated in a comprehensive field measurement campaign. In the project consortium together with the RWTH Aachen, the TU Munich and the Researchsgemeinschaft für Elektrische Anlagen und Stromwirtschaft e.V., a FNN study on the subject of asymmetry was also acquired, which will be carried out in 2020 together with the TU Dresden.

In the recently concluded research project "NEDS" - Sustainable Energy Supply Lower Saxony, potential transition paths towards a power supply based on renewable energies in Lower Saxony by 2050 were developed and their sustainability and feasibility analysed. Over the course of four years, elenia investigated the technical and economic effects of a holistic grid integration of interconnected buildings with individual components at the low-voltage level as well as the coordinated and multi-criteria control via an agent-based, distributed optimization process. In the new research project Energy-4-Agri, elenia will focus on the electrification of the agricultural sector for a sustainable reduction of greenhouse gas emissions over the next few years.

In the department's own Project Management Office (PMO), the first successful developments from the change processes initiated in 2018 were continued. In a workshop, agile management methods were developed in order to optimize internal processes. Important topics are discussed quickly and unbureaucratically between the interested parties in the "Open Space ". With the aim of shortening decision paths, competence allocations were critically reflected at the department and defined in a new decision matrix.

The department's workshop in September 2019 had a unique scientific destination in the form of the Energy Research Centre Lower Saxony (EFZN) in Goslar. The day was topped off with a historical city tour. In October 2019, the EFZN, an institution of the five universities of Braunschweig, Clausthal, Göttingen, Hanover and Oldenburg, also reappointed the board of most of its functions. The TU Braunschweig will from now on be represented there by Prof. Engel.

Since 2019 new lectures and new lecturers have been added to elenia's extensive range of courses: "Structure and Function of Storage Systems" by Dr.-Ing. Frank Lienesch and the participation of Prof. Engel in "Regenerative Energy Technology", which is particularly aimed at students of sustainable energy technology.

The transformation of the elenia for research and teaching continues. The new high-performance DC test field was installed inside the high-voltage lab. In addition, the green light was given for a new student workroom in the south tower and the renovation of three rooms on the first floor for the electrical workshop. The renovations also include the renovation of the AudiMax at university level. For the construction phase, a large circus tent - nicknamed "TentoMax" - was installed on an empty site as a temporary replacement.

In 2019, 11 new employees started at elenia, while 6 employees left the department. After submitting their dissertation, 8 employees successfully completed their doctoral examinations this year. In contrast to this natural fluctuation, the administrative staff in the office is getting old together with the professors. With the induction of our new employee Mrs. Droemer, a new allocation of responsibilities in the administrative office was agreed upon. While Mrs. Droemer now takes over the day-to-day business, Mrs Schmidt and Mrs Thiele concentrate on the management of the numerous third-party funded projects. All in all, 2019 was once again a highly exciting year for elenia, but at the same time a year with a promising future, which we can look back on with great joy.

The Department 2019

Department For High Voltage Technology

1. Row (top-back, from left to right)
Jacqueline Schmidt, Christian Ryll, Dirk Bösche, Stefanie Čelan, Dr.-Ing. Ernst-Dieter Wilkening, Henrik Herr, Sören Meyer, Robin Drees, Frederik Tiedt

2. Row
Muhamet Alija, Kerstin Rach, Julia Musebrink, Nils Gräfer, Benjamin Weber, Florian Rauscher, Julia Seidel, Petra Thiele,

3. Row (middle)
Björn Oliver Winter, Timo Meyer, Benjamin Kühn, Edwin Rebak, Fabian Scholz, Jonathan Ries, Elke Droemer,

4. Row (front)
Prof. Dr.-Ing. Michael Kurrat, Julia Brockschmidt, Kerstin Ryll, Olga Pronobis, Louisa Hoffmann, Nicholas Hill, Frederik Anspach,

Not in Picture Mattias Hadlak, Reinhard Meyer, Alessa Damrath
Lecturers Dr.-Ing. Michael Hilbert (PTB), Dr.-Ing. Christian Schulz (TenneT), Dr.-Ing. Johannes Schmiesing (avacon)

and Electrical Power Systems - elenia

Lily Kahl, Lars Claaßen, Christian Reinhold, Enno Peters, Till Garn, Frank Soyck, Jonas Wussow, Oliver Landrath, Tobias Kopp,

Hartmudt Köppe, Merten Schuster, Frank Haake, Cornelius Biedermann, Lorenz Soleymani

Gian-Luca Di Modica, Melanie Hoffmann, Björn Osterkamp

Christoph Klosinski, Prof. Dr-Ing. Bernd Engel

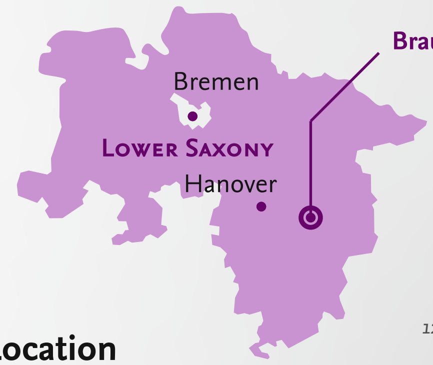
Facts and figures

The core values of elenia

Our Vision

- Reliability
- Practiced Integrity
- Independence
- High Scientific Standard
- Best Professional Training
- Diversity
- Open Dialogue

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



Technische Universität Braunschweig

elenia Institut für Hochspannungstechnik und Elektrische Energieanlagen

1 University
6 Faculites
75 Study Programmes
122 Departments

2000 Scientists
20.000 Students

Location

Braunschweig since 1925

The Department

The People at elenia in the year 2019

2 Professors
1 Academic Senior Counselor

3 Staff members of the office

5 Assistant Lecturers

5 Staff members of the mech. Workshop,
1 Staff member of the electr. Workshop, 1 Staff memberin in IT-Administration

47 Research Assistants in three Focus Groups

- Smart Grids
- Components of Energy Supply
- Electric Mobility

63 Student Assistants *(2019)*

Research at elenia

Three Focus groups

Electric Mobility

Smart Grids

Components of Energy Supply

19 Funded research projects were carried out in 2019 with

12 Million Euro Volume of third-party funding

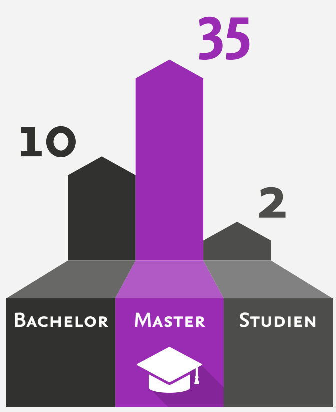
83,3 cups of coffee were consumed on average per day

Teaching at elenia

20 Lectures

4 Practical Courses

2 Study Seminars



Student Theses

Facts and figures on the department's year 2019

New and former employees

New employees hired in 2019:

Workgroup Energy Technologies

Focus group Electric Mobility

Oliver Landrath, B.Sc. Electrical Engineering
Project/Research Area
Fast EV, Electrolyte wetting,
Battery technology
Interests: Tennis, Bouldering, Guitar

Robin Drees, M.Sc. Elektromobilität
Project/Research Area
OptiZellForm
Forming and quick charging
Interests: Sports, Travel, Computer Games

Focus Group Components

Frederik Anspach, M.Sc. Electrical Engineering
Project/Research Area
Smart Modular Switchgear II
Switch-off behaviour of DC switchgear
Interests: Sports, History, Technology, Cooking

Lars Claaßen, M.Sc. Electrical Engineering
Project/Research Area
Smart Modular Switchgear II
Systems engineering and DC systems
Interests: Tennis, Soccer, Winter sports

Timo Meyer, M.Sc. Electrical Engineering
Project/Research Area
Investigation of a double interruption with TMF contacts in vacuum
Interests: Soccer, Running, Japanese culture

Workgroup Energy Systems

Focus Group Active Distribution Grid

Merten Schuster, M.Sc. Wi-Ing. Energy Management
Project/Research Area
Q-Integral - Active reactive power management
Forecasting of reactive power, Fallback-Strat.
Interests: -/-

Mattias Hadlak M.Sc. Environmental Engineering
Project/Research Area
Network and consumer-oriented integration
of storage systems in households
Interests: Guitar, Soccer, Bouldering, Fitness

Till Garn, B.Sc. Electrical Engineering
Project/Research Area
Research Project U-Quality
Grid simulations
Interests: Running, Bouldering, Hockey

Frederik Tiedt, B.Sc. Wi.-Ing. ET
Project/Research Area
Integration and installation of laboratory and Software in EEL and NDL
Interests: Sports, Playing guitar, Hiking

Cornelius Biedermann, M.Sc. Wi.-Ing. ET
Project/Research Area
U-Quality: Effects of future
low voltage grid usage cases
Interests: Sports, Satire

Following employees left the department in 2019:

Dr.-Ing. Nasser Hemdan, Dr.-Ing. Michael Hilbert, Björn Osterkamp, Ole Marggraf, Lorenz Soleymani, Christoph Klosinski

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These students worked as assistants at the department in 2019:

Abolaila, Saleh
Azimzade, Ibrahim
Bardachev, Dmitry
Beste, Justus
Brüggemann, Max
Cherni, Ahmed
Chung, Gaseng
Clausen, Steffen
Dabash, Ahmad
Falinski, Marcel
Feldt, Felten
Flügel, Karen
Gerig, Joel
Gengatharan, Garsan
Gitin, Ilja
Goldschmidt, Robert
Hasse, Henrik
Haßelmann, Tobias
Hemme, Tom
Herman, Robin Frederik
Himstedt, Luca
Hölk, Jan
Jannasch, Ian Oswald
Jäger, Jan
Kahn, Maik Kevin
Korff, Felix
Körte, Christian
Kreft,Gloria
Kruse, Marvin
Köhler, Heiko
Krüger, Jan
Lakaw, Josia David
Lütge, Chris
Mai, Thanh
Marquard, Lena
Moayedi,Kamyab
Moeilsiahrodkoloai, Behrooz
Niemann, Sönke
Neumann, Shivananda
Neumann, Kai
Özdemir, Okan
Rabe, Ann-Katrin
Rahn, Alexander
Rehbock, Andrè
Ribel, Anton
Riechelmann, Nina Marie
Reimers, Felix
Sauer, Timo
Shaheen, Heeba
Suchorukov, Vjacelsav
Studt, Julian
Schneider, Chris Aaron
Themelis, Alexandros
Torunoglu, Kenan
Van Ohlen, Nils
von Kölln, Kristina
Vieth, Patrick
Vu, David
Walter, Hendrik
Weinmann, Simon
Weymann, Emil
Xu, Zexuan
Zeumer, Till

Ways to the elenia I

My path from student to employee of elenia

Background

My name is Frederik Anspach, I completed my bachelor's degree in electrical engineering as a dual study in Koblenz. I wanted to study my master's degree with a focus on energy technology. Braunschweig and the TU offered ideal conditions in all areas of life. I started my master's degree in the summer semester 2017.

Frederik Anspach, M.Sc.
at elenia since May 2019

Who I am?

The first master's semester was just around the corner and the first courses had to be selected. More or less the courses were selected by module name. On my first day, I didn't know much about the TU yet because there was no introductory week in the summer semester, not to mention that I had no social contacts in my course yet. After a quick search I finally found SN. 23.3 at the elenia and found myself in the lecture High Voltage Technology II. To be honest, the time went by very fast until now, when I was sitting here on this chair writing my report.

Back to the day of the first lecture. The first lecture room was found, the lecture was fun. The initial fear that I wouldn't understand a thing, since I had completed my bachelor's degree at a college, subsided quickly. But the next big issue was already there. Where is the next lecture? I was looking for the Hans-Sommer-Straße 66. After a brief investigation on my smartphone it was definitely not nearby. In a short break I asked my fellow studens sitting next to me. My first social contact had taken place and still continues today. One of them even calls himself an office colleague these days.

Studies and thesis

The first contact with the department's staff took place through oral examinations. After the examination, open discussions were held about my interests and future plans. In addition, I was told about employees who offer jobs in my areas of interest. In the end I decided to take a Hiwi job in the simulation team "Comsol Multiphysics". Working on this job I made many contacts at the department. These contacts led to further employments. The working environment in all of my jobs was always instructive. The cooperation with the employees was at par with each other. The appreciation of the work I received was always a motivation boost for my entire academic work. I can only recommend to every student to start a job as a student assistant, you will gain a lot of fascinating knowledge and train scientific methods. These advantages will help with the exam preparation and the final thesis. Due to the good networking at the department, I was able to quickly find my Master's thesis topic and contribute to shaping it. During the master thesis I was extensively supervised. In addition to my supervisor, I was able to discuss my results with many other employees and always felt taken seriously. The elenia enables the student to write a very interactive thesis. During that time you will learn a lot more than just writing a good master thesis.

Employment at the Institute

Already in the run-up to my master's thesis, there was a mutual interest in working together beyond my degree. The masters thesis was tailored to my possible future field of work. Furthermore, I was allowed to dive into some different fields of research. Thus I could ensure whether the scientific work fits me. What can I say, it suited me. At the end of my master thesis I officially applied for a position as a research assistant. The interviews with Prof. Dr. Kurrat were very open and informal: In conclusion, I began my work as a research assistant on 1. May 2019.

Ways to the elenia II

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

The time before the elenia

After the Abitur I had to think about my future path. It was important for me to find a job that I liked and enjoyed. After extensive research, I decided to combine my interest in the natural sciences and my passion for languages in the career of a patent attorney. For this I first needed a degree in engineering. So I decided to study electrical engineering in Braunschweig. I started my bachelor studies with a vague plan to become a patent attorney in the distant future. And when you felt you had only just arrived, you had to look for a specialization in the fifth semester. At first, I saw this as an unexpected challenge. During my undergraduate studies, you hardly got to know many of the specializations and because of my career aspirations, I was not predestined for any specialization. So at first I simply attended lectures that interested me. Here I came across my first lectures at elenia.

Why the elenia?

There is a large number of electrical engineering institutes at the TU Braunschweig. However, elenia stood out in the lectures that I attended at first. On the one hand, because of the close thematic connection to the energy transition and the close relationship of lectures to the challenges posed by this issue. On the other hand, because of the structure of the lectures and the effort that is put into them.

As I liked the department in terms of the field and teaching style I decided to write my bachelor thesis here. Therefore I wrote to a employee whom I knew from the exercise. Unfortunately she didn't have a suitable topic for me. However, she passed on my request and so I got two responses that were similar enough thematically to combine them in a bachelor thesis. This way I had the benefit of two tutors.

From the final thesis to employment

I already worked very closely with my tutors in my bachelor thesis. There were a lot of meetings and I had a very interesting subject. Since I liked the tasks during my bachelor thesis, I accepted the offer to continue working at elenia as a student assistant. As a student assistant, I was able to directly build on the knowledge I gained during my bachelor thesis. I became more familiar with the simulation tools that I had previously used through new assignments and, together with my supervisor, I refined the results of my bachelor thesis to be published as a congress paper. After the bachelor's degree I specialized in energy technology and continued with my HiWi activity. My supervisor slowly entered the final phase of his dissertation and there were many things to work on. I continued to perform a lot of simulations and visualized the results graphically, but I also gained my first experience in the laboratory. In November 2018, I was asked if I could imagine working part-time at elenia during my studies. Since I liked the work very much and I could also imagine doing my doctorate after my studies, I applied for the proposed position.

Till Garn, B.Sc.
at elenia since April 2019

Work and study

During my interview it was already a question of how studies and a part-time job could work together. It was also made clear that studying would still be my main occupation. On 01. April of this year I started to work 20 hours a week at the elenia, alongside my studies. Of course this was a challenge at first, but you grow with your tasks. The experiences and the deeper insight into the research I can get now is worth it in any case.

Energy Management

Grid dynamics and system stability

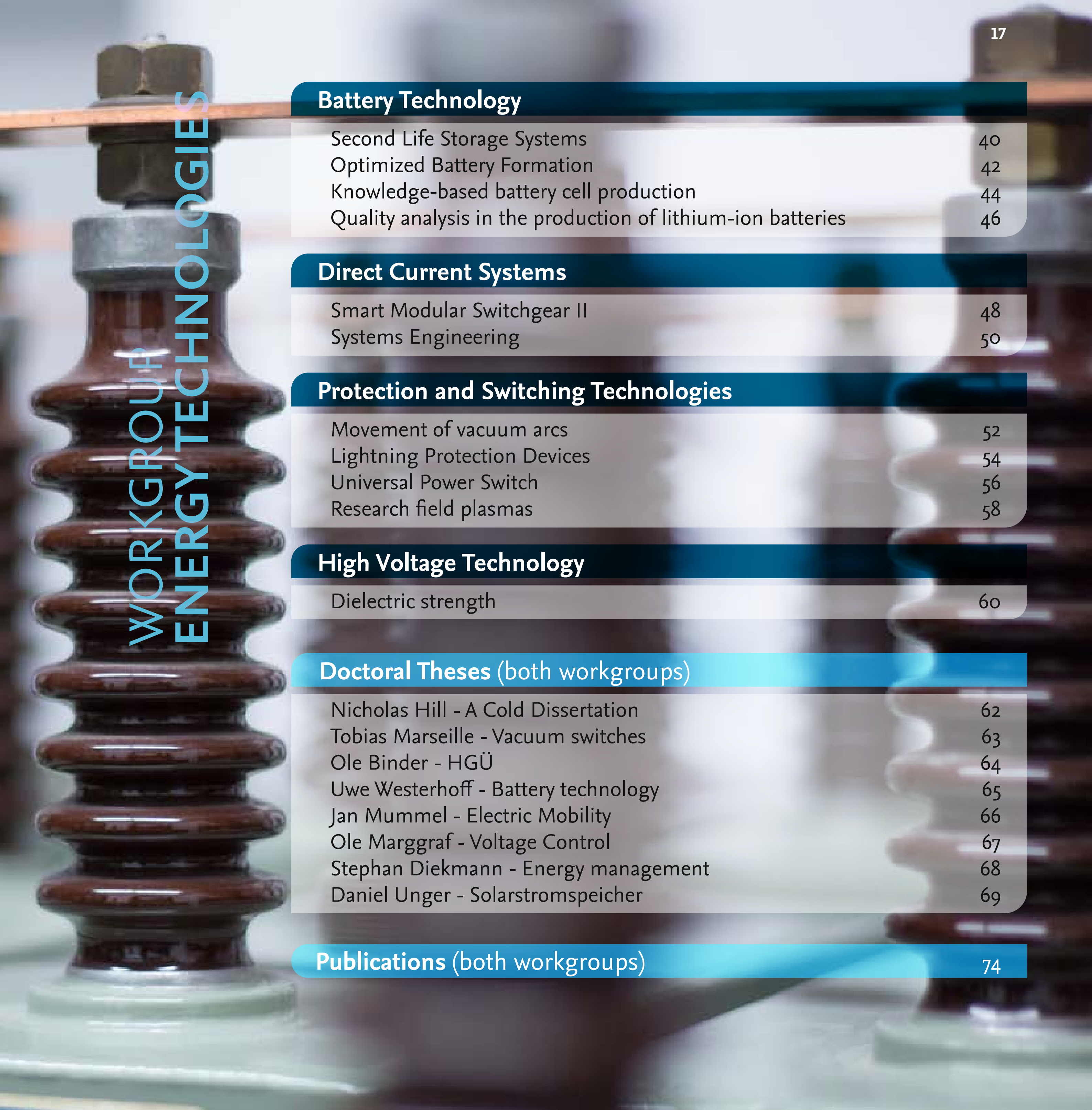
Operation and Planning of Grids

Electric Mobility

WORKGROUP
ENERGY SYSTEMS

Research

2



WORKGROUP ENERGYTECHNOLOGIES

Battery Technology

Direct Current Systems

Protection and Switching Technologies

High Voltage Technology

Doctoral Theses (both workgroups)

Our research projects and topics form the core of our work at elenia. In two working groups and three main research groups - Smart Grids, Electromobility and Components of Energy Supply - we are constantly facing new challenges in the energy system transformation. The focus group Smart Grids focuses on research topics such as prosumer households, energy management, dynamic behavior of converters or reactive power management. As an intersection between the two working groups, the focus group Electromobility covers both the grid integration of electric vehicles and battery technology. In the focus group Components of Energy Supply, research is carried out on direct current systems, vacuum arcs, as well as on switch and high-voltage technology. In addition, eight employees successfully completed their doctorates this year.

Energy Management for Prosumers

Development of gridsupporting operational strategies to determine the grid behaviour of future prosumer households

In an energy system with at times 100% energy input from renewable energies, generation plants installed at household level, supplemented by battery storage concepts such as (2nd-use) batteries play a decisive role from the grid's point of view. The technical components (see Figure 1) can, for example, be used to limit the replacement capacity at the grid connection point even with high connected load of e-mobility (20 kW and more) and thus avoid or delay grid expansion. On the other hand, prosumers can support the grid by providing ancillary services for grid stability such as voltage-dependent reactive power supply, short-circuit power in the event of a fault or flexibility offers for use by aggregators. The prerequisite is the coordination of power flows both internally (between generating plants and connected consumers) and towards the grid by means of intelligent and interconnected control and energy management systems (EMS). By interconnecting EMS via an intelligent measurement system (iMSys), for the first time the grid operator is given the opportunity to implement individual and targeted grid-compatible specifications at the lower voltage levels (e.g. by specifying "grid-compatible target profiles").

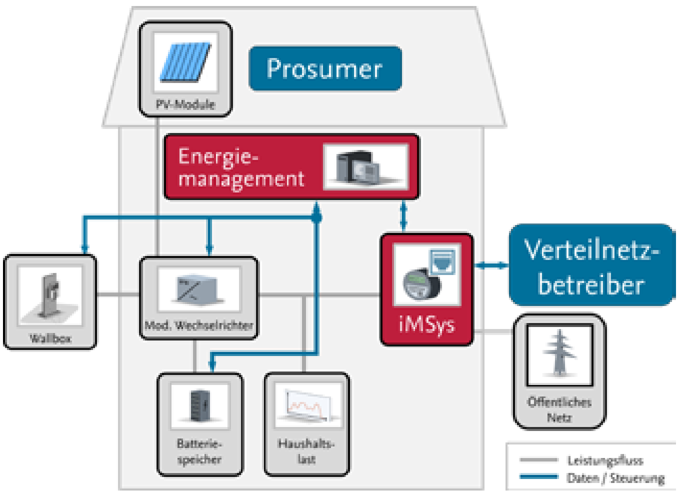


Figure 1: Components of the project NetProsum2030 considered prosumer household

Dimensioning of the PV system and the storage facility

For the dimensioning of the components (PV system, battery storage) and thus also for the technical possibilities to act network-suitable, the profitability of the investment made is of decisive importance from the system operator's point of view. Using the eSE simulation environment developed at elenia and the models integrated into it for the generation components and stored load and irradiation profiles, the active power curves between the components were simulated on a total of nine type days during self-consumption optimisation and then combined to annual profiles. Based on this, a calculation tool developed as part of a student research project was used to calculate the capital values over 20 years for different PV system and storage configurations (see Figure 2). The net present value is an indicator for the profitability of the total investment compared to a conventional investment option. For the considered prosumer household and under the assumed boundary conditions, an optimum of 9.9 kWp for the PV system (PVA) and 12.5 kWh usable capacity for the battery storage could be determined. In the project, the economically optimal capacity serves as the input variable for the design of an innovative 2nd-

Figure 2: Iterative process to determine an economic optimum for PV system and storage system

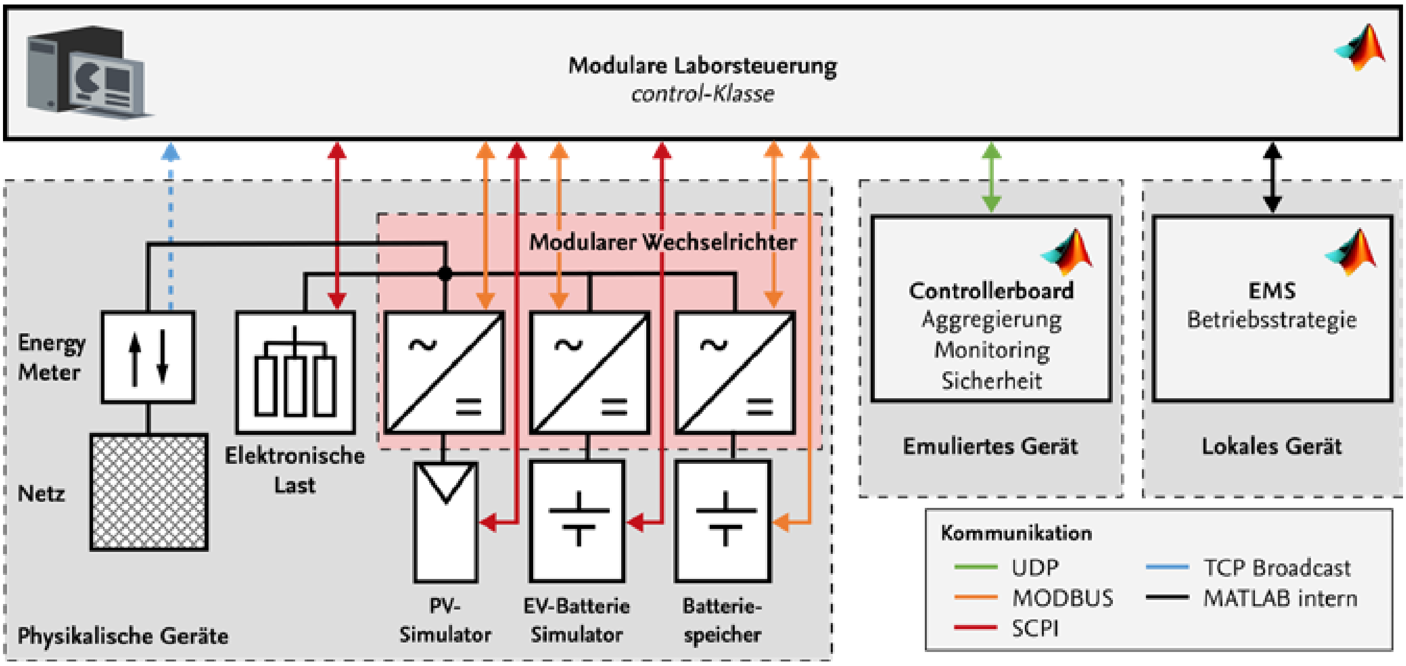


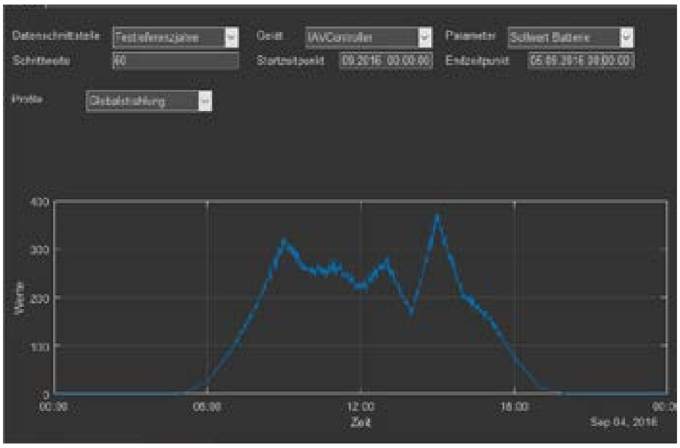
Figure 3: Emulation of a prosumer household in the energy management laboratory

use storage system, which is used in the practical simulation of the prosumer household at laboratory level.

Practical implementation in the energy management laboratory

In the final phase of the project, an overall system test at laboratory level is planned to demonstrate the network-related behaviour of the prosumer household in different net situations. The laboratory or demonstrator structure (see Figure 3) comprises the EMS developed at elenia, a modular inverter developed at IMAB, which offers higher efficiency and more possibilities in controlling power flows than conventional inverters, as well as the possibility of charging an electric car in accordance with standards. The measured value aggregation within the structure as well as safety-relevant functions such as switching off individual power modules in the event of overload etc. are taken over by a controller board developed by the Project Partners IAV. By specifying irradiation and load profiles, different power flow situations can be specifically caused and the reaction of the EMS (based on the selected operating strategy) can be evaluated. The time-coordinated control of the load and the PV simulator is carried out via the developed modular laboratory control system ModSys.

To carry out a first test, ModSys was used to emulate the controller board, which is currently not yet available as a prototype. Through the emulation, the message matrix, which was created to exchange the aggregated measured values of the controller board and the power setpoints calculated by the EMS, could be implemented and successfully tested in advance.



Outlook

Development of grid-supporting operating strategies
Within the next few months, the focus will be on the (further) development and implementation of network-related operating strategies. This includes the integration of a load and generation forecast that can be used to minimize control losses from the plant operator's point of view and to smooth feed-in and load peaks from the grid operator's point of view. In addition to forecasting and feeding active power into the grid, it will also be analyzed which options the use of a modular inverter offers with regard to offering flexibility and the reactive power management used for voltage maintenance.

Project Description

Project Name
NetProsum2030

Project Duration
September 2017 – August 2020

Project Partners
IMAB – Institut für Elektrische Maschinen, Antriebe und Bahnen, IAV (Ingenieurgesellschaft Auto und Verkehr), SMA Solar Technology

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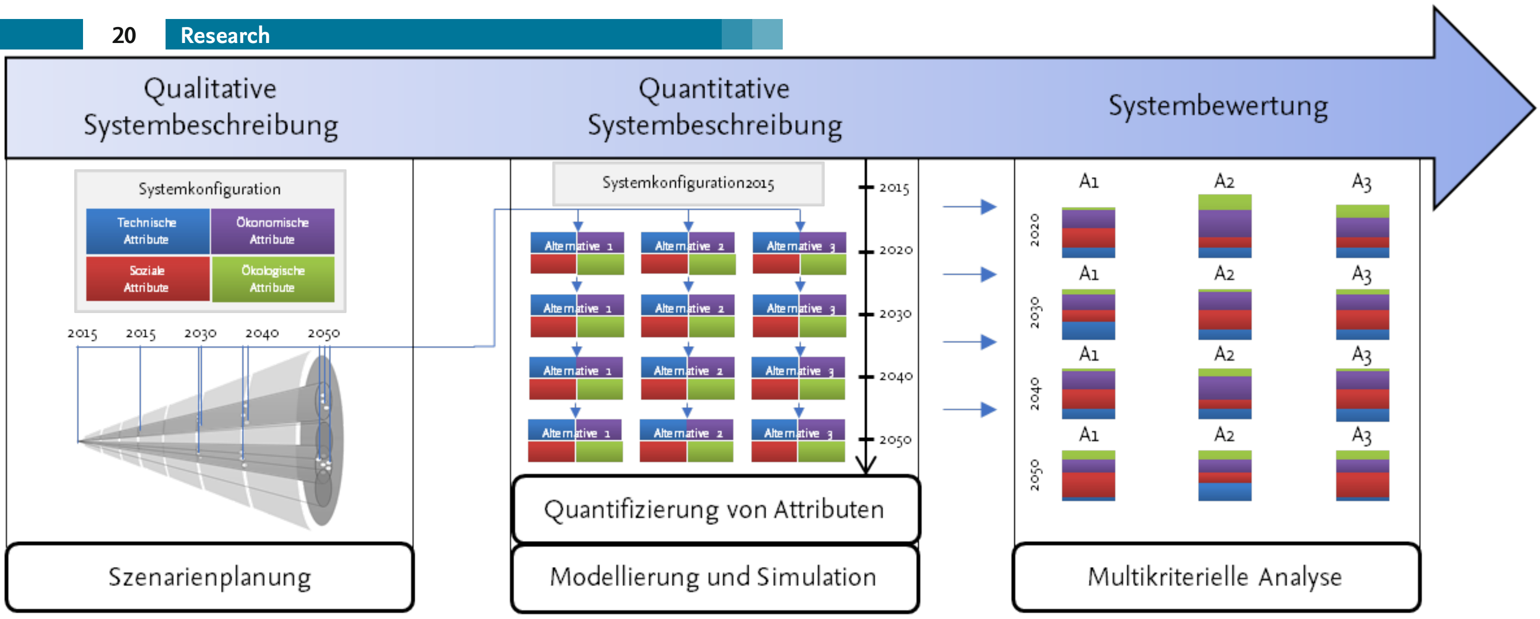
Gefördert durch: Bundesministerium für Wirtschaft und Energie aufgrund eines Beschlusses des Deutschen Bundestages



Simulation environment eSE

Simulation environment for electrical and thermal components within interconnected systems

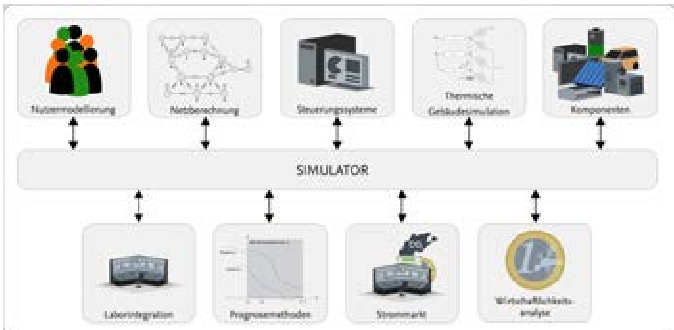
NEDS - Sustainable Energy Supply Lower Saxony

The research project NEDS - Nachhaltige Energieversorgung Niedersachsen aims to develop potential transition paths towards a renewable energy-based power supply in Lower Saxony by 2050 and to investigate their sustainability and feasibility as part of an interdisciplinary research team. In order to answer the diverse questions, a cross-sector system model for the Lower Saxony power supply system was developed within the consortium.

Over the four years, elenia investigated the technical and economic effects of a holistic grid integration of interconnected buildings with components, such as electric mobility, heat pumps and electrical and thermal storage systems at the low-voltage level, as well as the coordinated and multicriterial control via an agent-based, distributed optimization process. As part of an extensive exchange with the Department of Psychological Methodology and Biopsychology (IPMB) at Technische Universität Braunschweig a detailed user model including an empirical database was developed, which enables heterogeneous behavior of different user groups to be parameterized and to be scientifically sound. In addition, the team has succeeded in establishing an interface between the eSE simulation environment, developed as part of the research project, and the OFFIS co-simulation platform mosaik. This enables the investigation of complex simulation scenarios on the low-voltage level and coordination mechanisms between different control levels with high temporal resolution. In particular, the application possibilities of flexibilities from building systems for grid- and market-oriented purposes were considered. As a key result, it can be stated that technologies without a high degree of user interaction can be used cost-effectively for a secondary use at the grid level.

eSE - elenia Simulation Environment

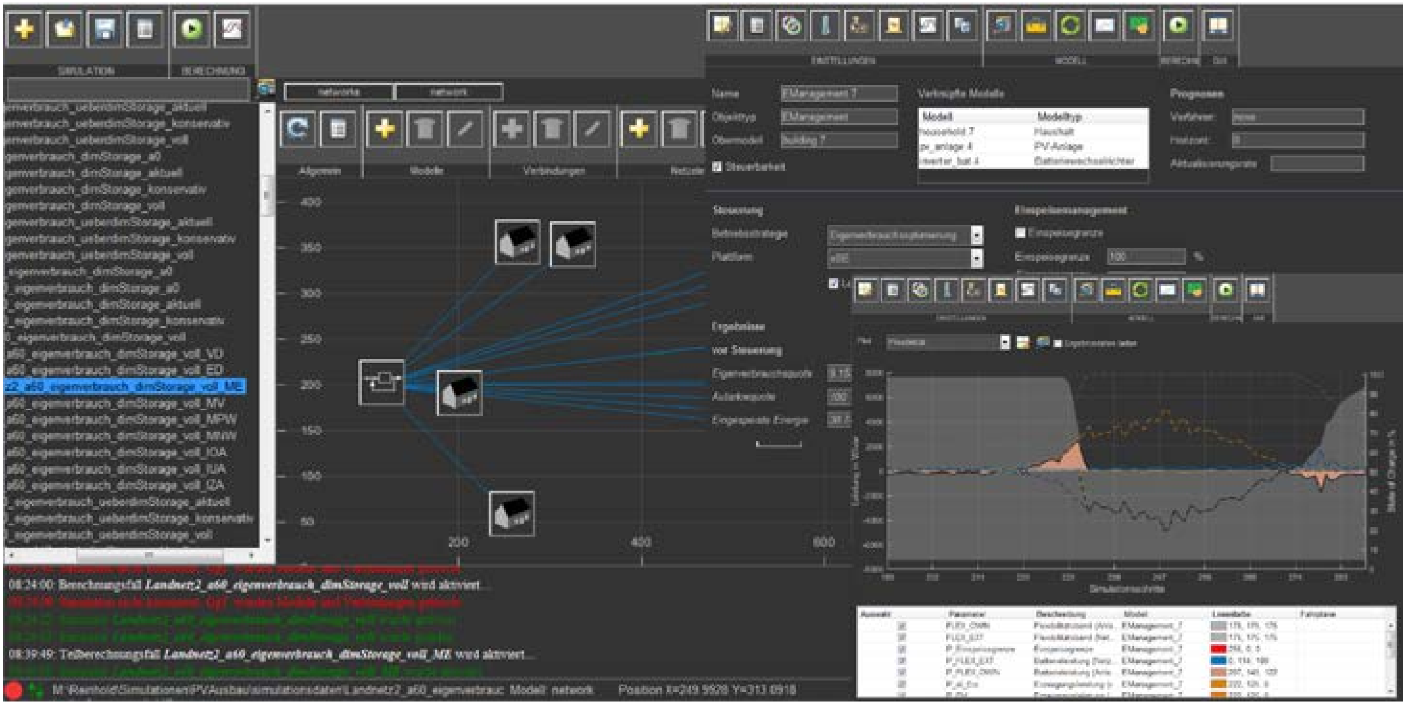
The modular simulation environment eSE - elenia Simulation Environment was developed by elenia for investigations and connections with other platforms such as mosaik. The primary task is the energetic simulation of steady-state models of electrical and thermal systems at different system levels and the interconnection to complex systems. Furthermore, interfaces to other modules, such as a grid calculation based on MATPOWER or a thermal building simulation, were developed beyond the requirements of the project. Based on this, it is possible to



Modular structure of eSE

develop and investigate control and coordination mechanisms for different levels. The so-called simulator, which manages the data flow and the process sequence, acts as the central unit between the modules. For a user-friendly operation of eSE, a MATLAB-based graphical user interface was implemented, which manages methods and structures of the respective modules and the simulator. In addition, the interface allows for a short familiarization time for students and researchers, as well as the generation of highly scaled simulation scenarios using customized views. The visualization of time series and the calculation of key indicators of the calculated simulation can be performed through an integrated evaluation module.

Besides the work in the research project, the environment was used and further developed in a large number of student projects, as well as tested in the dissertation of Mr. Stephan Diekmann with the focus on scalable energy management



Grafische Benutzeroberfläche der elenia Simulation Environment eSE

systems in apartment buildings for tenant flow concepts. Furthermore, the system simulations in the research project NetProsum2030 with eSE were successfully carried out for a prosumer household with a multifunctional inverter.

ModSys-eelabs

Outside the NEDS research project, the eSE Laboratory Integration module was developed by Henrik Herr, Christian Reinhold and Jonathan Ries in a joint effort to develop the modular control environment ModSys-eelabs. It was designed for the purpose of virtually automating the complex and time-consuming experiments in a laboratory environment. In a master-slave architecture in MATLAB, a control class can communicate with the hardware devices in the eelabs laboratory. The programmed protocol interfaces convert the sent messages into the protocol format of the device, such as MODBUS, UDP or TCP/IP. Through the flexible linking of signals in ModSys, interrogated measured values can also be sent to other devices and derived variables can be formed to implement self-programmed control systems.

The aim is to integrate all available devices, such as inverters, DC sources and AC loads, into the environment, so that a usability of the devices can be guaranteed without a long training period. In addition to the implementation of the hardware devices, structures and methods have been developed to use the simulation models from eSE directly in combined investigations in the laboratory. The concept and first investigations with ModSys were presented at this year's ETG Congress in Stuttgart-Esslingen.

Future work

The simulation environment eSE and the modular laboratory control ModSys-eelabs extend the portfolio of tools in the field of simulation and modelling technology at elenia. In the years to come, the range of functions will be successively expanded in order to be able to investigate a broad spectrum of research questions. Fortunately, the experiences and developments made can be used in future research projects flexess, Energy-4-Agri, SiNED and Future Laboratory Digitalization Energy.

gefördert durch das Niedersächsische Ministerium für Wissenschaft und Kultur im Rahmen des Niedersächsischen Vorab

Project Description

Project Name
NEDS
Nachhaltige Energieversorgung Niedersachsen

Project Duration
April 2015 – Juli 2019

Project Partners
TU Braunschweig, Carl von Ossietzky Universität Oldenburg, Universität Duisburg-Essen, Leibniz Universität Hannover, OFFIS e.V.

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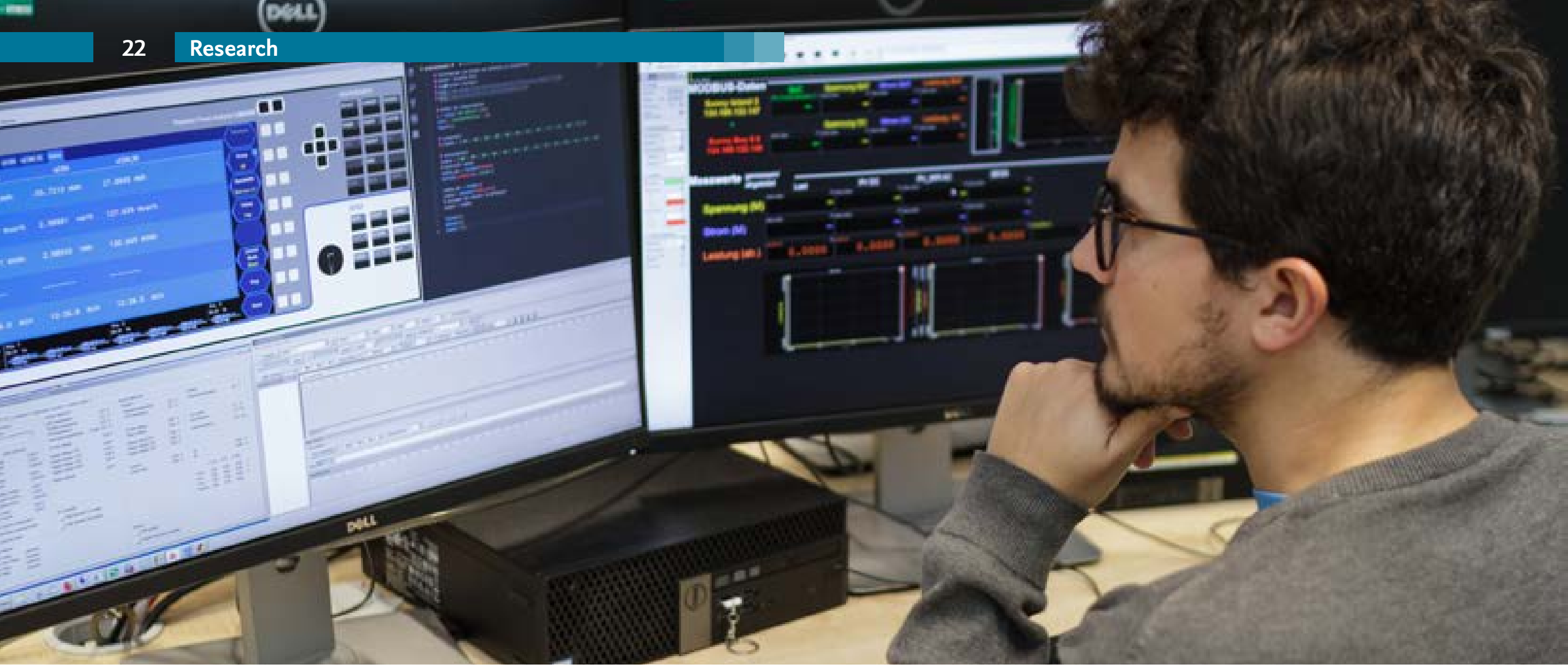


Robust grid operation

High-availability distribution grid operation in the event of disruption of the ICT infrastructure in the Smart Grid

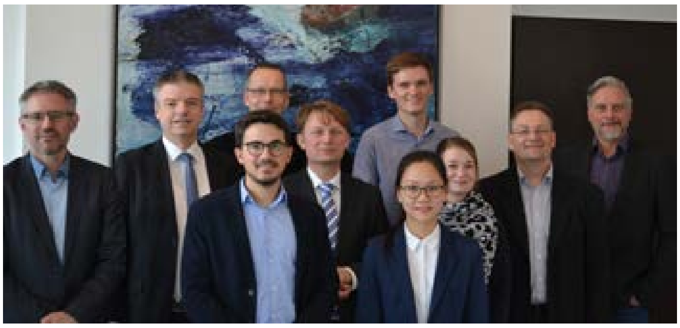
The distribution grids of the future will be characterised by a large number of renewable energy systems and decentralised components such as electric vehicles, storage facilities and controllable loads. A large number of new players, such as operators of virtual power plants or smart meter gateway administrators will also form diverse interfaces to this fine-granular system structure. This is accompanied by increasing networking using information and communication technology (ICT). This is necessary for the envisaged Smart Grid and for the coordination of heterogeneous technologies with mostly volatile behaviour and a multitude of new market players and market processes. The behaviour of weather-dependent systems can still be predicted with some degree of accuracy. In the case of complex market processes with heterogeneous actor diversity, however, it is all the more important to be able to use networked sensors and actuators in view of the basic functional principles of the current energy supply system. In addition to the traditional goal of security of supply, the aspect of information technology security is becoming increasingly important.

The IKTfree project and its contribution to the energy transition

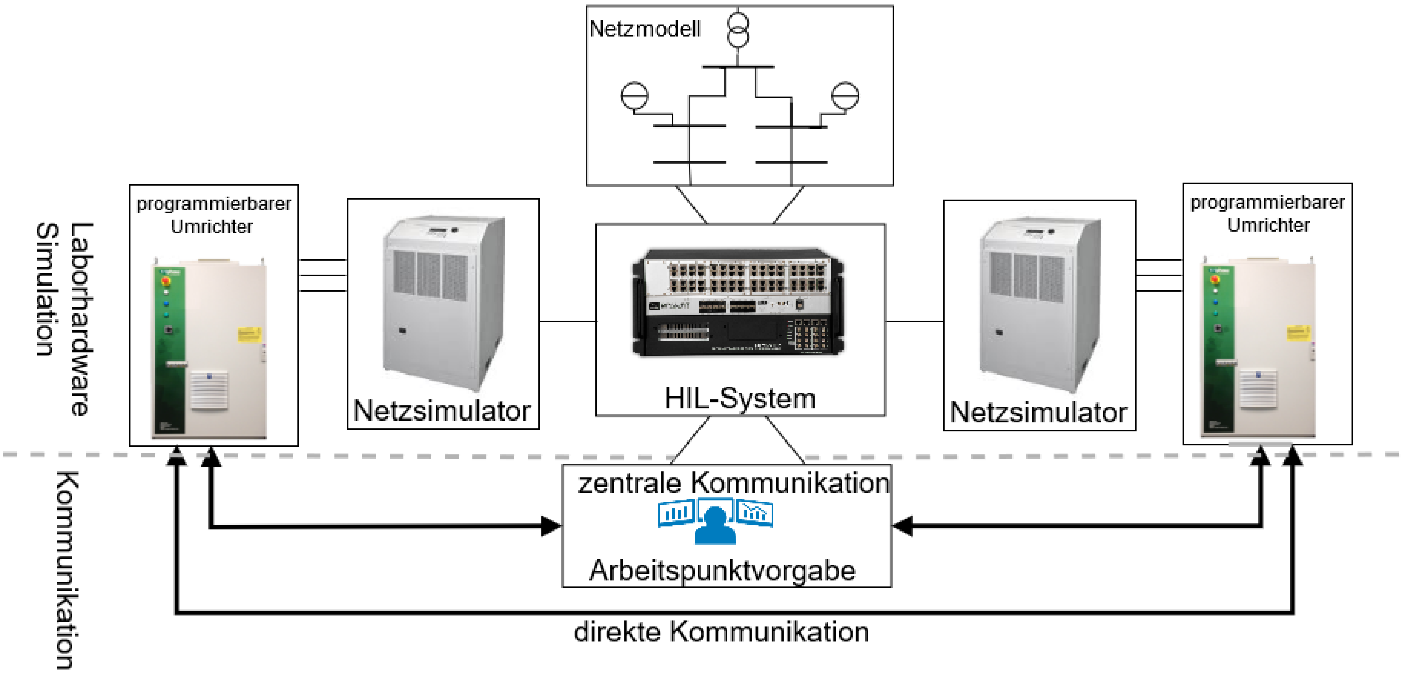
The project IKTfree, funded by the Federal Ministry of Economics and Energy (BMWi), deals with the contribution of distributed resources in the electrical distribution grid in order to provide measures that enable a stable operation over the longest possible period in the event of a failure of the communication infrastructure. In view of the higher number of decentralized generators and components in the distribution grid and the greater dependence on the information and communication infrastructure through the implementation of smart meters, this topic plays an increasingly important role at the energy policy level. For this reason, the DLR Institute of Networked Energy Systems, together with the Institute of High Voltage Technology and Electrical Power Systems (elenia) as a Project Partners, are investigating the behaviour of various equipment in the event of a disrupted ICT connection and drawing up recommendations for action for stable grid operation. In addition, the IT risk in the distribution grid is analyzed. So far, security of supply and ICT security in the Smart Grid have mostly been dealt within the research landscape for critical infrastructure and components with robust ICT. The presented project is supposed to carry out an analysis of the components of the last mile of the distribution grid in order to develop an emergency operation mode in the event of an ICT failure and thus contribute to an optimization of the distribution grid operation.

What happened in 2019?

In the last few months there have been major activities related to the organization and coordination of the project. During the kick-off meeting the different partners got to know each other personally and exchanged experiences, points of view and expectations regarding the project results. Periodically planned working meetings and telephone conferences offered the opportunity to coordinate the processing of the various work packages and to follow the development of the project. Different grid states were identified by means of a Failure Mode and Effect Analysis (FMEA) and weighted by means of risk priority figures and their threat potential described.
Two training courses were planned for 2019: Training on the software to be used and on a new real-time simulation labora-



The project team at the project kickoff in Oldenburg



Schematic representation of the laboratory test

tory device enabled project workers to deepen their knowledge and skills in these areas.

During an expert workshop at the VDE-FNN in Berlin, the project and its status were presented to FNN members. The resulting discussions enabled an exchange with the participants and valuable input for the project could be collected.

In regard to the promotion of the project, it was presented on the 19th February 2019 at the EFZN Research Day at the TU Braunschweig. Another important step was the acceptance of the poster "Scenario development for the investigation of safety-critical conditions in ICT-supported distribution grids", which will be presented at the upcoming conference "Future electricity grids 2020". In order to achieve greater dissemination, a project website was designed which contains all relevant data of the project as well as the various publications resulting from it (www.iktfree.de).

What lies ahead?

The project team is eagerly looking forward to the year 2020. After identifying the relevant scenarios, components and parameters in the previous work packages, the team plans the first simulations for the coming months. The interest in these simulations is to evaluate the effects on the distribution grid due to a failure in the ICT infrastructure.
It is also planned for the next months to develop measures for error avoidance and troubleshooting in order to avoid or mitigate the error effect. With the development of these measures into a control system and their implementation into the simulation environment, it is possible to evaluate their effectiveness. The results will subsequently be validated through laboratory tests.

Project Description

Project Name
IKTfree

Project Duration
Oktober 2018 – September 2021

Project Partners
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)

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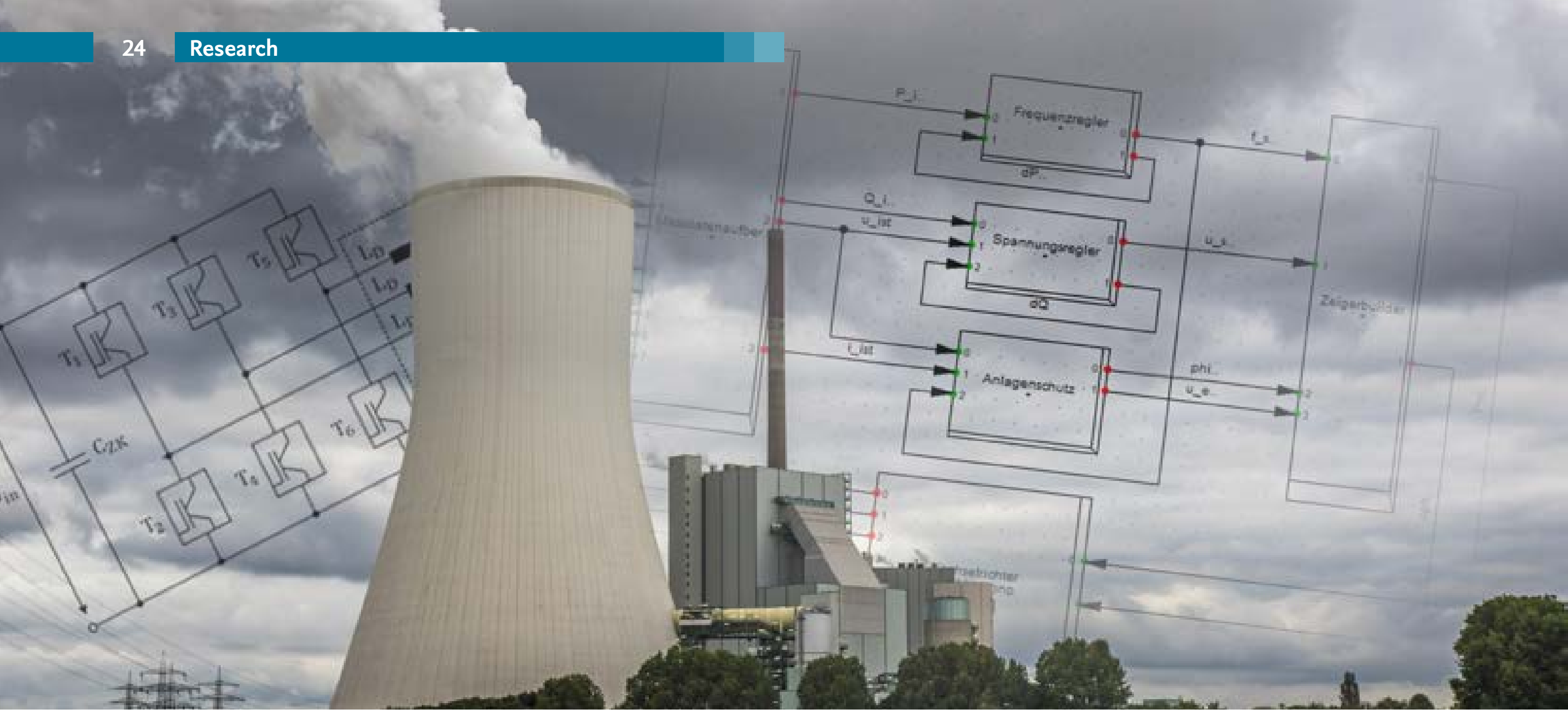
www.iktfree.de



Grid control with inverters

Stable grid operation with 100% renewable energies

Motivation

The electrical power supply and in particular the control of the electrical network 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 to generate electricity. Feed-in scenarios in which more than 90% of the load is covered by renewable energies are already occurring in Germany today. In order to ensure system stability, however, 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 and in grid operation will entail a far-reaching transformation. This is where the "Netzregelung 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 masses or the dominance of converter-based generation in grid sections. Fault scenarios and system services, accompanied by safe and stable operation of the grids, are the focus of this research project.

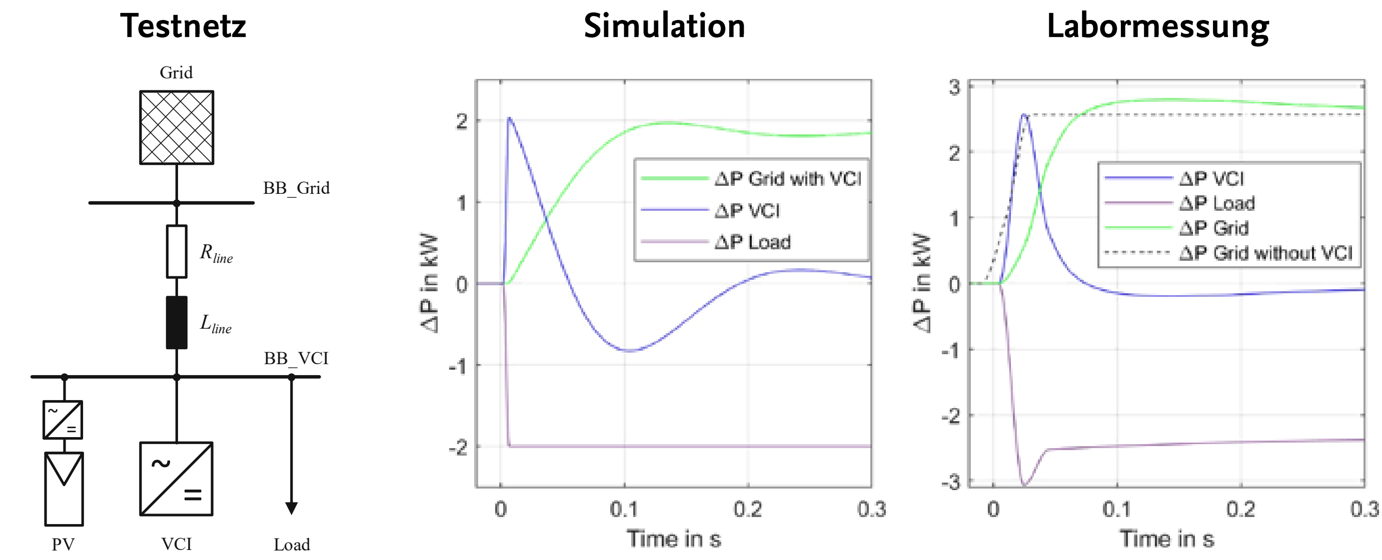
Aims of the project

The overall objective of the research project "Netzregelung 2.0" is to demonstrate that the electrical interconnected system in Germany can be operated safely and in a stable manner with a very high proportion of power converters. To this end, concrete control procedures will be developed and tested and validated both in the laboratory and in the field. Today's electrical interconnected system has grown historically and is therefore geared to the characteristics of synchronous 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 described independently of the respective technologies. Subsequently, control procedures can be developed for power converters that meet these requirements. It is examined which technologies have to fulfil which requirements in order to function in the overall system at any time. In the research project "Netzregelung 2.0" not only medium- and long-term scenarios with a high converter-based power generation are considered. In addition, transition paths from the current system, which is often still dominated by conventional generation, to a system that is almost exclusively supplied by converters will be investigated.

Research at elenia

As part of the joint project, elenia is working on the integration of voltage-controlled power converters into the distribution grid. In this context, the focus is on the provision of instantaneous reserves and their effect on the superimposed grid levels. The aim of the investigations is to investigate the contribution of these converter systems to the stabilisation of the supply network 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-controlled converter technology on the distribution networks, in particular on local voltage quality and network protection measures. Provision of instantaneous reserve from battery storage units instantaneous reserve refers to the energy that compensates for short-term power imbalances between generation and consumption without delay. Currently, this is provided by the kinetic energy of the rotating generators in large power plants. With the increasing displacement of conventional generation and thus of synchronous generators from the electricity mix, the amount of available instantaneous reserve in the electricity grid continues to decrease. This leads to strong fluctuations in the grid frequency, which endanger the system stability.

The provision of instantaneous reserve can also be made using voltage-controlled battery inverters and has already been tested in various laboratory and island grids. With a control system that simulates the basic behaviour of a synchronous generator, these can also provide instantaneous reserve for the interconnected grid. In order to investigate



Provision of instantaneous reserve from inverters in the low-voltage level in simulation and laboratory in grid parallel operation

the ability of wide-area provision, various network studies were carried out in 2019 in simulations in order to demonstrate the principle feasibility of provision from distributed systems. However, on the component level this procedure is limited by the maximum available power. While an inverter is usually limited to its rated power, a synchronous machine can provide a multiple of its rated power in the short-term range. Therefore, the challenge for a voltage-controlled inverter is to provide the necessary torque reserve during normal operation and, in the event of an overload, to limit the power in such a way that the maximum achievable torque reserve is still provided and the system limits are not exceeded at the same time. For this purpose, the control system was therefore extended to include a power limitation function in order to ensure stable behaviour on the network even in fault situations.

Integration into the distribution network

In order to be able to integrate large areas into the distribution network, voltage-controlled converter technology must exhibit behaviour that is compatible with the existing requirements, systems and protective equipment in the network. Against this background, the integration of inverters in different constellations into distribution network models is simulated and tested. The interaction between classical components and various inverter control systems, during normal operation as well as in the event of a fault, is in the focus of the investigations at elenia. Based on the knowledge gained, the behaviour of voltage-controlled inverters is optimised so that it supports the functionality of the distribution network, also with regard to current changes such as a stronger penetration of new consumer classes such as electric vehicles. Voltage-controlled plants are particularly suitable for this, since they work directly oriented to the mains voltage at the respective connection point and can support this if necessary. To this end, it is examined how the inverter should act in the event of high line loads, asymmetrical loads and generators or in the event of tripping of protective devices in the grid, in order to make the best possible use of the strengths of voltage-controlled generaton with respect to stable grid operation.

Project Description

Project Name
Netzregelung 2.0

Project Duration
Dezember 2016 – November 2021

Project Partners
Weitere Researchsinstitute:
Fraunhofer IEE, Uni Kassel

Anlagenhersteller:
Siemens, SMA Solar Technology AG

Übertragungsnetzbetreiber:
50Hertz, Amprion, TenneT, Transnet BW

Verteilnetzbetreiber:
EWE Netz, innogy, MITNETZ Strom, Westnetz

Verbände und Netzwerke:
VDE | FNN, DERlab, dena

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Control reserve with PV systems

How PV inverters contribute to frequency stability

The changes in the electrical energy supply system in Germany over the past 20 years have brought not only great opportunities but also new challenges. The most important aspect remains the assurance of system stability, which has to be guaranteed at all times, even with high fluctuations in generation. Today, this task is largely performed by conventional or controllable power plants by providing system services. In the future, however, wind turbines and photovoltaic (PV) systems will also have to contribute to this as part of the existing power plant infrastructure.

Frequency stability represents a significant part of system stability. The frequency in the German power grid is in equilibrium at 50 Hz as long as generation and consumption remain in balance. In the event of deviations, control reserve is activated to avoid disruptions to the grid and damage to components. In the joint research project PV-Regel, elenia, together with SMA Solar Technology AG and GEWI AG, developed a holistic concept for the provision of control power with PV systems. The results of the research project, which has now been successfully concluded, are presented below.

Challenges for control power with photovoltaics

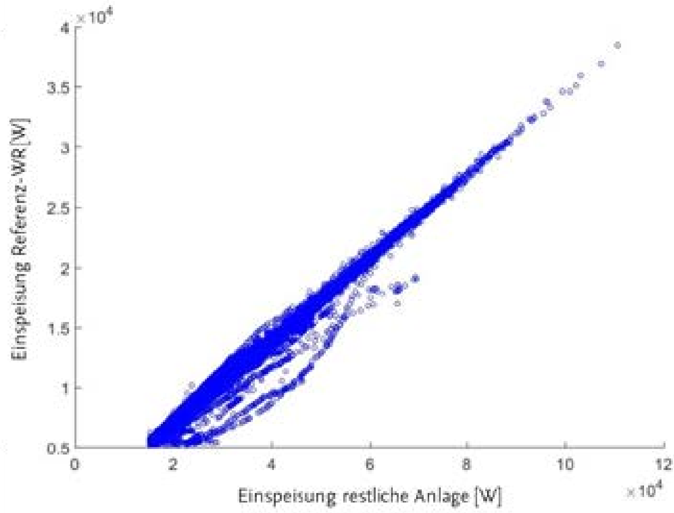
The reasonable use of PV for the provision of control reserve requires not only technical concepts and solutions, but also the reorganisation of the underlying framework of the control power market as well as economic considerations. The manual Frequency Restoration Reserve (mFRR) is the main type of control reserve considered in the project. This will take effect after the automatic Frequency Restoration Reserve (aFRR), which in turn follows the Frequency Containment Reserve (FCR). During the provision of control reserve, the PV system is temporarily operated below its maximum possible feed-in - either to provide positive control reserve or to provide negative control reserve. The power reduction is carried out in relation to the possible feed-in, the estimation of which, in compliance with the required accuracies, represents one of the greatest technical challenges. This procedure is already being used for wind turbines in a currently ongoing pilot phase for the provision of mFRR.

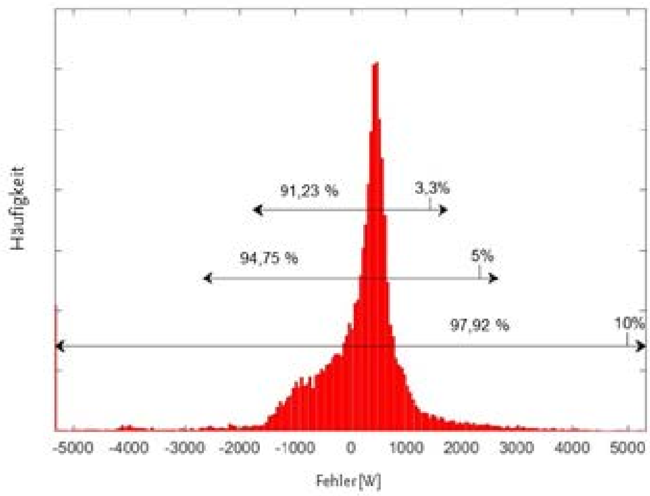
Passive & active verification methods

In principle, verification procedures can be classified into two categories - passive and active. In the case of passive verification procedures, external reference parameters are used to calculate the possible feed-in, e.g. measured data from irradiation sensors or the feed-in power of reference subsystems that have not been reduced in power. With active verification methods, on the other hand, the active power of the PV system is continuously adjusted, e.g. by means of a characteristic curve variation. As part of the research project, a controllable inverter (cover photo) was developed in which this functionality has been integrated. Detailed investigations with this innovative technology were carried out in laboratory and field tests.

The advantage of passive methods lies in the fact that both the possible and the present feed-in in the unregulated operation are available at all times and thus the accuracy can be determined relatively easy. In contrast, in active processes the value of the possible feed-in is only available in decreased operation, so that a direct comparison between possible and present feed-in is not possible. For this reason, investigations to evaluate the accuracy of active processes are far more complex. The implementation itself provides an advantage of active methods, since the inverter used here does not require a model to calculate the possible feed-in, but provides the data internally.

In the PV-Regel research project, both passive and active techniques were evaluated for their functionality, feasibility and fulfilment of technical requirements and accuracies. A suitable framework for these tests is the so-called pre-qualification (PQ) procedure, which each system has to complete successfully in order to participate in the control reserve market.

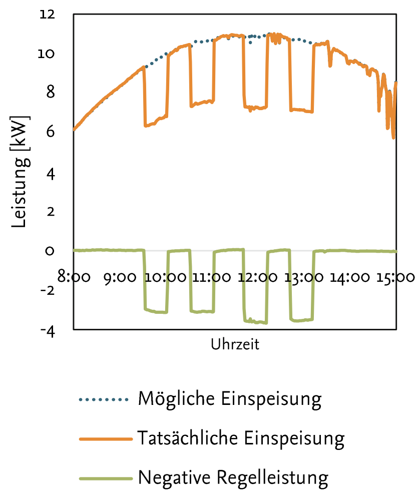




Results of the accuracy tests carried out in the field using two reference inverters

Operation

As part of the pre-qualification, a trial activation of control reserve is demanded. This serves not only the verification of the technical requirements but also the assessment of the pre-qualified power. The following figure shows this request that was carried out with the institute's own PV system (installed capacity: 14.3 kWp). One



Operation run for negative mFRR with the elenia PV system

of two inverters was used as a reference.

The present and possible feed-in of the system as well as the activated control reserve are shown. In this test, a prequalifiable output of 3.5 kW was achieved in the second activation call. The prequalifiable output forms the basis for the accuracy tests.

Evaluation of the accuracy of the reference procedure

The figure at the top shows the results for precision tests on one of the field test facilities with an installed capacity of 204 kWp. Two of the eight inverters are used as reference subsystems. The determined PQ power for the analyses is 53.29 kWp. At the top left, the power of the two reference inverters is compared with the feed-in power of the rest of the plant. A linear correlation can be clearly seen here. The top right-hand corner shows the distribution of the errors. This allows the determination of how many measured values are in certain error intervals, measured by the prequalifiable power. The requirements from the pilot phase for wind power systems are fulfilled by the PV system.

Details on the active verification procedure can be found in the final report of the research project. The results also meet the requirements, showing that the provision of control power with PV systems is possible with both passive and active verification methods.

Further research

The technical suitability of PV systems for the provision of control reserve has been demonstrated using various methods. For market integration, however, the underlying framework still has to be adjusted. Hourly product time slots and the approval of using the possible feed-in as verification method are examples in this context.

From a technical point of view, PV inverters are not only capable of providing mFRR, but can also adjust their power output much more quickly due to the power electronics of the inverters. In this field of research, elenia has already successfully carried out studies on the fast Frequency Containment Reserve and the inertia. The research project Netzregelung 2.0 is based on these concepts.

Project Description

Project Name
PV-Regel

Project Duration
August 2014 – Dezember 2018

Project Partners
SMA Solar Technology AG, GEWI AG

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aufgrund eines Beschlusses des Deutschen Bundestages

Voltage Quality in the Grid

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

A new research project started in the summer of 2019. The project U-Quality deals with voltage quality in the low-voltage grid with increasing number of electric vehicles, photovoltaic systems, battery storage systems and power-to-heat systems.
The voltage quality in the distribution network depends on the producers and consumers connected in the local grid. The current changes in these so-called grid usage cases in the context of the German energy, mobility and heat turnaround thus have a great influence on the voltage quality. The maintenance of voltage quality is one of the central and current tasks for distribution network operators. This is precisely where the U-Quality public research project, funded by the Federal Ministry of Economics and Energy with approx. 2.34 million euros and supervised by Project Management Jülich, comes in. The project partners will conduct research in the field of voltage quality and develop solutions within the course of the project, which will run until mid-2022, in order, among other things, to be able to charge more electric cars in the power grids.

Project consortium

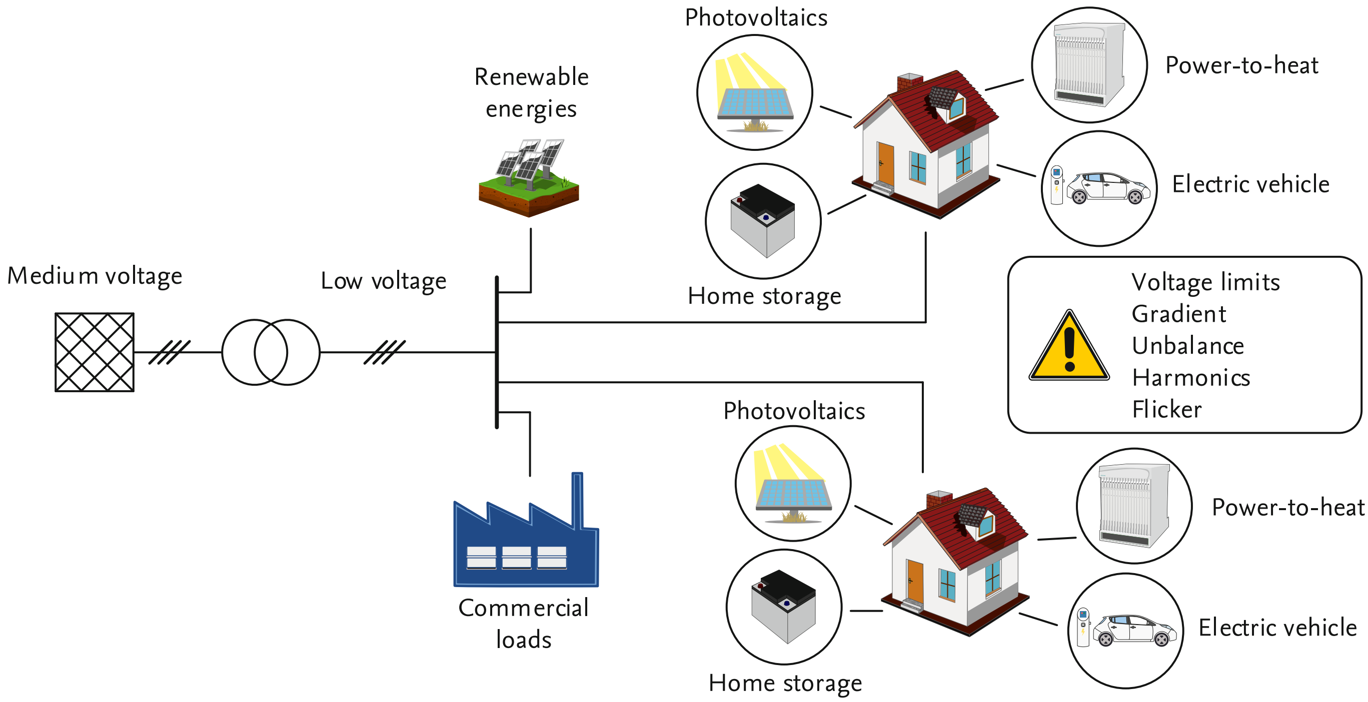
The project consortium consists of four research institutes as well as six distribution grid operators and four industrial partners, who give the institutes the opportunity to test their simulations under real conditions. The participating research institutes are TU Braunschweig, RWTH Aachen, TU Munich and FGH. The distribution network operators and industrial partners are Bayernwerk, Netze BW, Regionetz, Stromnetz Hamburg, Avacon, BS Netz, Maschinenfabrik Reinhausen, Phoenix Contact, SMA and Ruhstrat Power Technology. As consortium leader, the Institute elenia of the Technical University Braunschweig arranged the kick-off meeting (Figure U-Quality consortium at kick-off). The meeting was a successful start for the project and the upcoming cooperation. The participating partners are looking forward to the next years of intensive research and cooperation.

U-Quality consortium at Kick-off

Content of the project

Within the course of the U-Quality project, the influence of the change in grid usage cases on the voltage quality in distribution grids and which components, technologies and processes can contribute to ensuring the same will be investigated (visualized in the schematic representation of the investigations in U-Quality). In addition, the methods and components are adapted and further developed in such a way that they improve the voltage quality not only with regard to static voltage maintenance, but also with regard to unbalance, flicker and harmonics. In the process, recommendations for action for distribution grid operators and manufacturers as well as for the future revision of standards, application rules and test specifications are developed. Furthermore, solutions are being investigated to determine how the effects on voltage quality can be controlled efficiently and cost-effectively.

A three-stage procedure with simulations, laboratory tests and field tests is planned. In order to promote the evaluation of realistic scenarios, an initial measurement campaign will take



Schematic representation of the investigations within the framework of the research project U-Quality

place to record the current situation. The cooperation of innovative partners from industry and network operation guarantees a high degree of practical relevance and rapid implementation of the knowledge gained. Through the cooperation of the project partners in various standardization committees, the project results are directly incorporated into future standards and guidelines.

The participation of top-class industrial partners ensures a high level of practical relevance. The company Ruhstrat will develop a voltage quality regulator prototype, which will be further developed into a marketable product and marketed after the project.

In addition, it is planned to incorporate the knowledge acquired in the project into cooperation and consulting activities with industrial partners and distribution network operators. On the scientific side, the research results will be incorporated into doctoral projects at the three universities. In addition, they will find their way into the corresponding courses, such as lectures, laboratory internships and student theses, and will be presented and discussed at national and international conferences and congresses. Furthermore, the development of related follow-up projects is planned.

In addition, the website www.u-quality.de offers information on the project. This includes, for example, publications produced within the framework of the project.

Working objectives of elenia

Within the framework of the project, elenia is responsible for project coordination and content aspects such as dynamic simulations, economic evaluation and the performance of field tests. The focus of the TU Braunschweig is on the following working points:

1. Carrying out field measurement campaigns at the beginning of the project to record the current situation with regard to voltage quality, and measuring individual components such as PV and battery inverters in the laboratory to determine their influence on voltage quality.
2. Modelling, simulation and evaluation of new grid usage cases with regard to voltage quality characteristics.
3. The implementation of selected voltage quality control methods on available equipment of the existing laboratories and analysis of the feasibility and effectiveness of all methods.
4. The validation of the simulations and laboratory tests from points 2 and 3 in demonstration field tests.

Project Description

Project Name
U-Quality

Project Duration
September 2019 – August 2022

Project Partners
RWTH Aachen – IFHT, FGH e.V.,
TU München – Energieversorgungsnetze,
Ruhstrat Power Technology GmbH

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Sector coupling in households

The contribution of all-electric houses to the successful energy transition (German Energiewende)

At the latest since the worldwide "Fridays for Future" movement, climate protection has been on everyone's lips. In recent weeks, the proposals for climate protection measures on the part of politicians have almost turned upside down. In order not to miss the climate protection targets again in 2030, as is already foreseeable for 2020, a whole bouquet of cross-sector measures has been anchored within the much criticised draft of the Climate Protection Law, including ticket taxation in air travel, tax relief for rail travel, tax depreciation for the energy-related renovation of old buildings, the scrapping premium for oil heating systems, the highly controversial entry-level CO_2 price of EUR 10 per tonne of CO_2 from 2021, the expansion of emissions trading, to name just a few of the more than 60 measures proposed. In all climate protection discussions, the importance of sector coupling, i.e. the linking of the electricity, heat and mobility sectors, plays an extremely important role. In order to limit global warming to 1.5°C, climate-neutral coverage of energy consumption in the three sectors in question in the form of renewable energies is absolutely essential. In addition to the decarbonisation of the energy system also the reduction of dependence on imported fossil fuels and the increase in available flexibility speak in favour of the increasing electrification of all three sectors.

All-electric houses and their impact on electricity grids

Concerning household level, this trend potentially leads to an increasing number of photovoltaic systems, battery storage systems, heat pumps and electric vehicles. These so-called all-electric households use electricity as their main source of energy. At the same time, increasing electrification is creating challenges for low-voltage grids. For some years now, the frequency of grid bottlenecks in both the distribution and transmission grids has been increasing. This causes high costs for grid-stabilizing measures such as feed-in management and redispatch. The solution is to expand the grid at all voltage levels, but this is expensive, takes a long time and encounters major acceptance problems. An alternative is to activate flexibility in the distribution network.

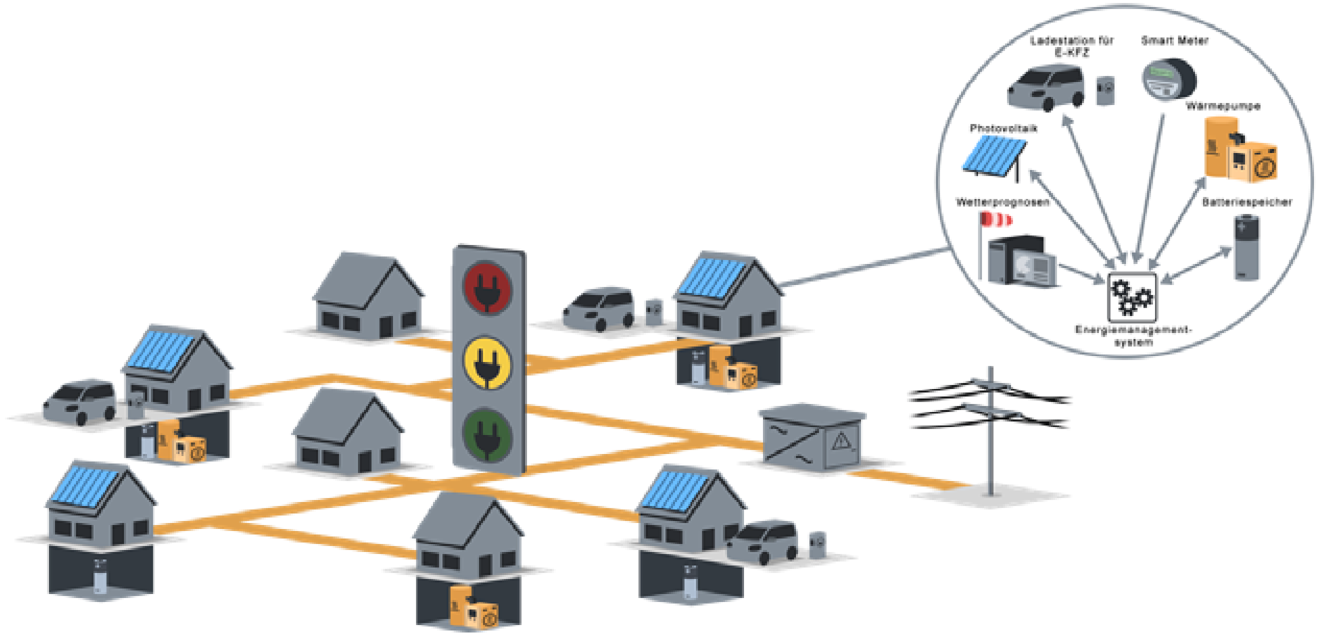
Use flexibility: Smart rather than copper

The aim is to implement the energy system transformation as cost-effectively as possible from an economic point of view by using the existing resources in form of flexible consumers (heat pumps, electric vehicles) and battery storage systems. This enables a local balancing of production and consumption to be achieved with the help of a needs-based activation or deactivation of flexibilities, and cost-intensive grid expansion to be kept to a minimum.

The investigations focus on the current year 2019 as well as the target year 2030. On the basis of evaluated studies regarding predicted technology development paths of photovoltaic systems, battery storage systems, heat pumps and electric vehicles, the penetration of these components can be estimated scenario-specifically (pessimistic, realistic and optimistic development). Thus, it is possible to determine their network effects in different structural classes, ranging from rural areas with high production from renewable energies to urban areas with high loads. Both the stand-alone mode of operation, in which the plant components do not communicate with each other, the self-consumption-optimised mode as well as the grid-serving mode are investigated. The different modes of operation are analysed from both the plant and the grid operator's point of view using the relevant stakeholder-specific evaluation criteria. This involves a comparison of the effectiveness of selected grid-optimising measures. A distinction is made between reactive and active power management (Q(V), P(V)) feed-in management and conventional grid expansion measures. The general procedure is summarised in the figure below.

All-electric house test rig

In addition to the simulations, laboratory tests are carried out in the newly developed all-electric house test rig of the elen-



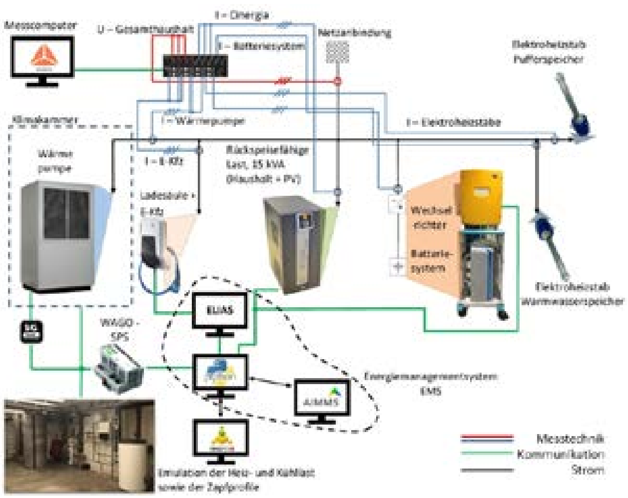
Grid-serving all-electric houses with imminent grid bottlenecks (orange switched grid light)

ia-energy-labs to validate the various operating strategies. In addition to a regenerative load for emulating defined household load or PV generation processes, the components of the test rig include a battery storage unit including inverter for representing a PV battery storage unit, an electric vehicle as an electric consumer including charging station, an air-to-water heat pump as well as the electric heating rods of the heating and drinking hot water storage units, a climate chamber for simulating a defined outside air for the heat pump and the heat sink (heating load and drinking hot water tap profiles) including the interfacing with TRNSYS for the thermal simulation of heating circuits in buildings. The components are controlled by an in-house developed energy management system.

In addition, the focus is also on the system for levies and charges. On the one hand, there is an economic efficiency problem with heat pumps, for example, compared with conventional heating structures, which currently leads to a negligible penetration of heat pumps, especially in existing buildings. The influence of the currently discussed CO_2 pricing on a more CO_2-causing energy source pricing is also being investigated. On the other hand, the current regulatory system for network operators is also examined: currently it favours investments in network expansion instead of avoiding it with the help of intelligence and digitisation. The development of a monetary incentive system for the demand-oriented connection or disconnection of flexible loads and battery storage systems rounds off the relevant research work. This leads to a win-win situation for both plant und network operators.

Thus, the investigations on the effects of cross-sectoral electrification at household level and low-voltage grid level are carried out holistically under technical, economic, ecological and regulatory aspects.

Comparative efficacy of differently operated all-electric houses



All-electric house test rig

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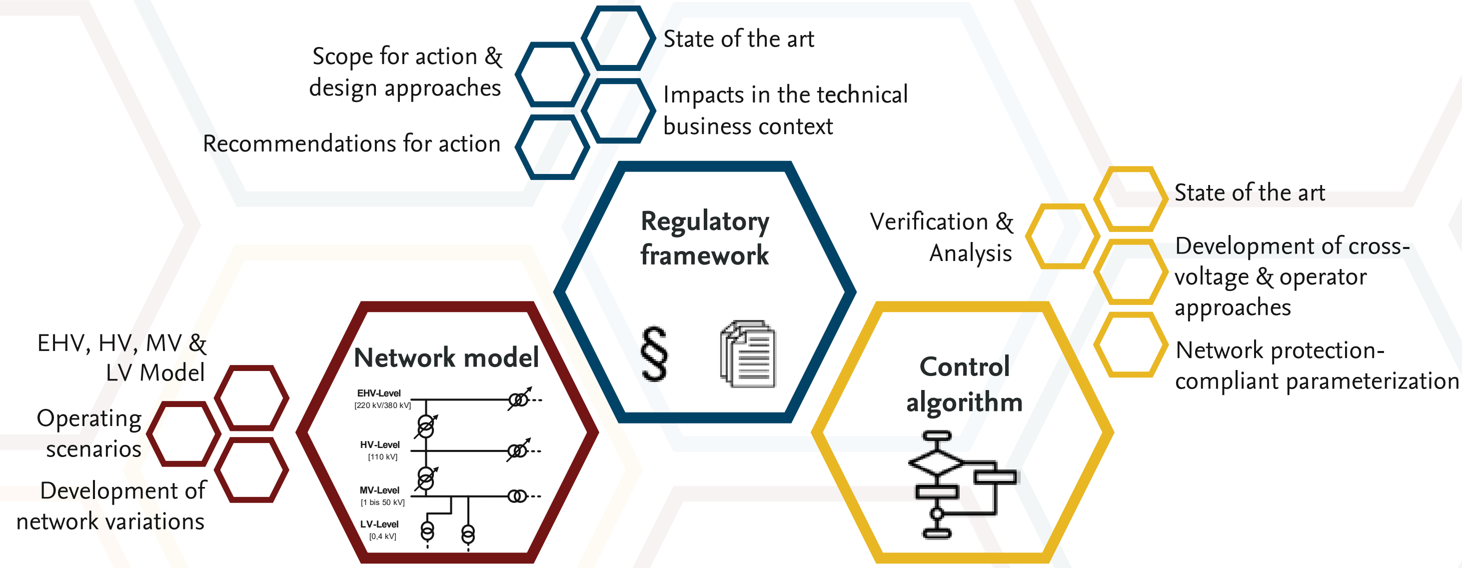


Reactive power management

in distribution and transmission grids using innovative reactive power sources

The transformation process of the energy supply system caused by the *Energiewende* has decisive influence on the existing concepts for maintaining grid and system security. This also applies to conventional methods for maintaining voltage as well as the closely connected reactive power management (RPM) in transmission (TS) and distribution networks (DS). On the one hand, reactive power sources in the form of synchronous generators are successively being turned off as a result of the "Energiewende". On the other hand, the increase of inverter-coupled renewable energy plants (REP) creates reactive power potential in the TS.

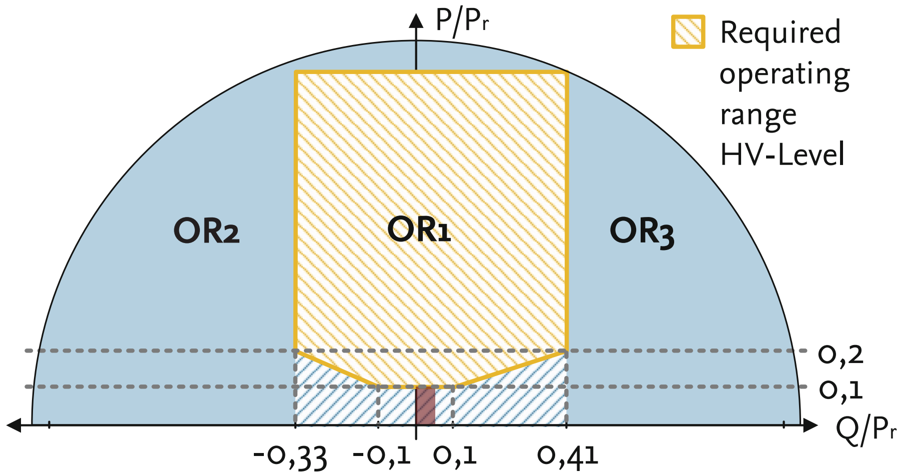
However, the addition of a fluctuating REP also results in greater transmission distances while volumes of operating resources and the reactive power requirements also increase. This is aggravated by the fact that reactive power is a local phenomenon and the transmission over longer distances is not economically feasible. These circumstances lead to fundamental changes in the RPM regarding operation and planning. In the future, the residual reactive power requirement in the transmission network must be covered. To achieve this, reliable and dynamic reactive power sources from the DS present a solution.

Research questions resulting from this have already been partially answered at *elenia* in the *PV Wind Symbiosis* research project. The current follow-up project *Q-Integral* will provide further research results focussing on cross-voltage and cross-operator RPM.

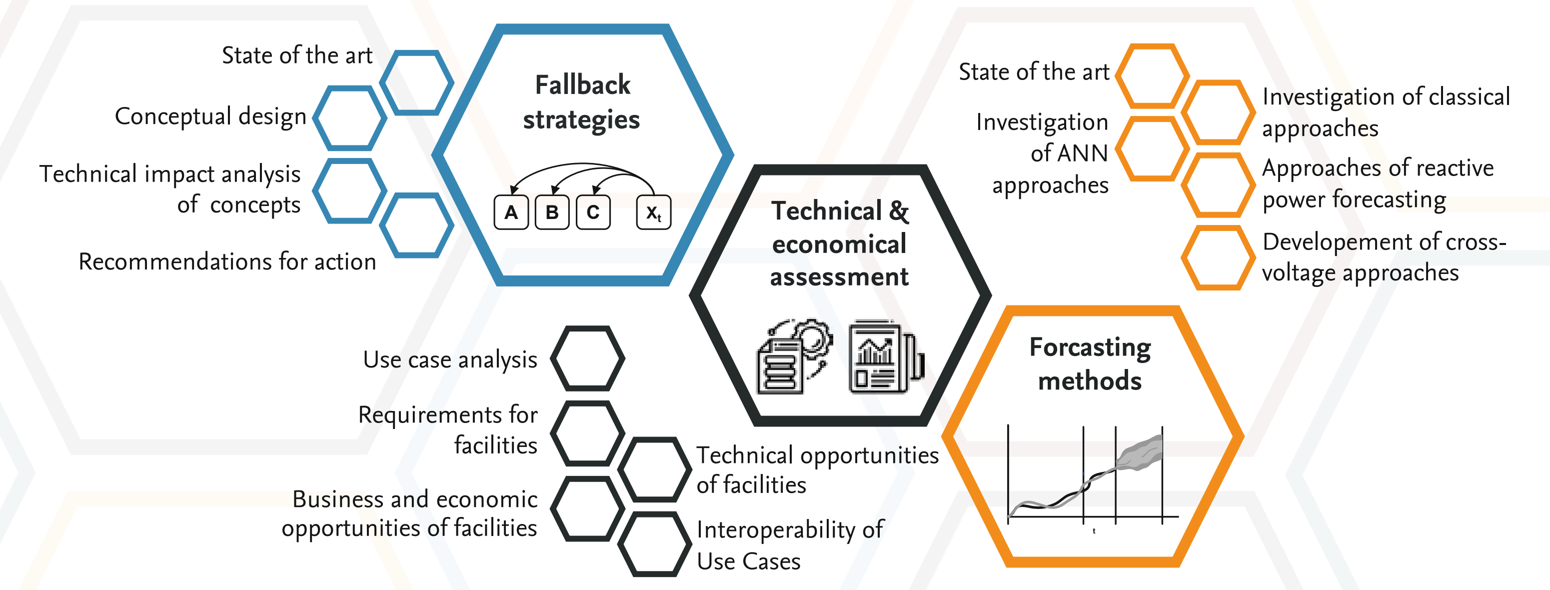
PV Wind Symbiosis

In the *PV Wind Symbiosis* project, various fundamental studies in relation to RPM were carried out. The central task was to determine which photovoltaic power stations (PPS) and wind power plants (WPP) can efficiently be used to feed in reactive power, how this will effect the grid section of a real high-voltage grid (HV grid) and whether the integration of these sources in an RPM is economically competitive compared to conventional solutions.
To this end, active reactive power control algorithms with target functions (e.g. Q = 0 || Ut = Un) were developed at *elenia*. These where tested and evaluated by running simulations with a network model of a real HV grid.

The simulations have shown that REP can already make a decisive contribution to actively meeting reactive power requirements. In principle, inverter-coupled PPS and WEP can provide reactive power in the required operating range and beyond - see OR2 and OR3 figure below. Especially full converter systems are theoretically capable of providing the reactive power quickly, continuously and variably up to the rated power, even in STATCOM operation mode. For the PPS and WPP installed in the HV grid, an adaptation of the software would have been



Operating ranges of renewable energy plants in the high voltage level



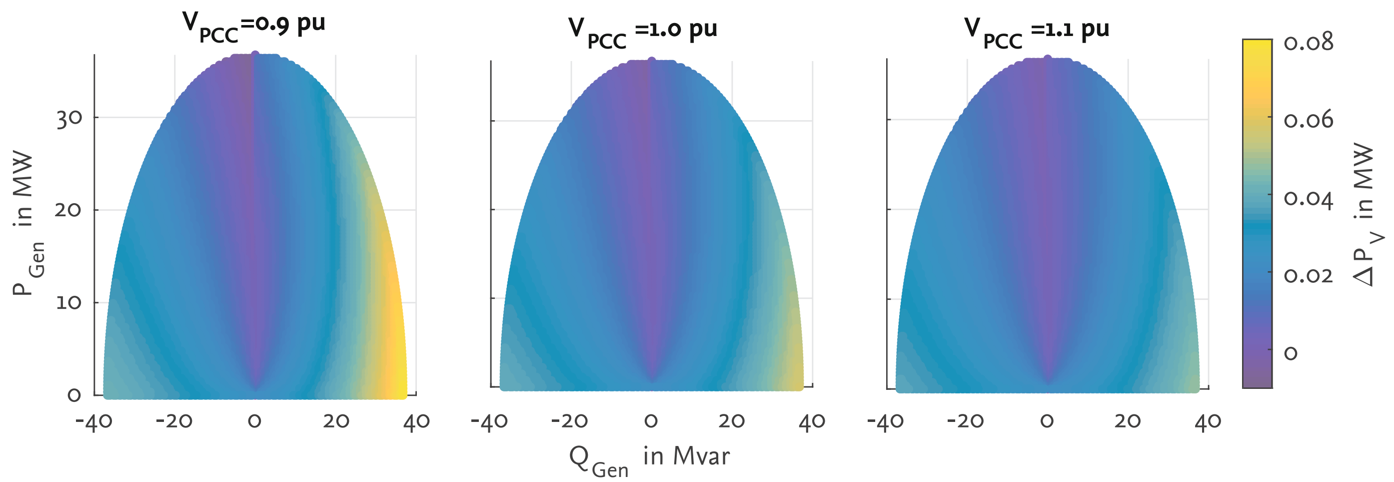
sufficient to obtain the extended operating range. For other systems it may well be necessary to adapt the hardware, which would correspondingly result in higher costs. This has to be negotiated with the respective manufacturers in each individual case.

The evaluation of further simulations has also shown that, as a rule, the theoretically very large operating range cannot be fully used in practice. The reason for this is the reactive power demand in the power plants, which limits the operating range. Nevertheless, the availability of the reactive power supply of REP can be significantly increased by pooling plants according to the currently valid connection rules. Depending on the existing REP with STATCOM function, the availability is additionally increased by the possibility of continuous reactive power supply.

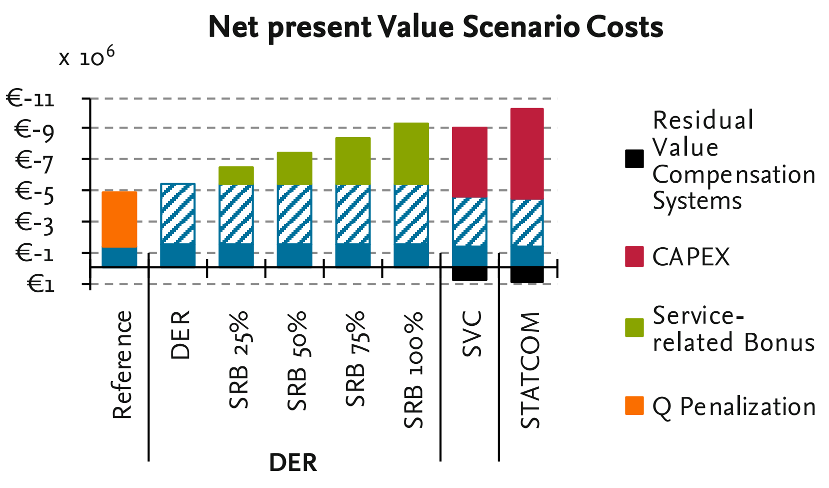
In this context, the project also analysed and evaluated the losses caused by the provision of reactive power in the plants. For this purpose, a detailed simulation model of a pilot park consisting of WPP and PPS was created, and the losses for the entire operating range were determined. The investigations have shown that the losses are significantly dependent on the current working point and the voltage conditions in or at the park - see figure below. A simplified calculation of the losses, for example via fixed loss factors, can lead to erroneous conclusions about operating costs due to inaccuracies. This in turn complicates economic investigations, as losses can vary individually from park to park and exact modelling of the parks is not always possible due to a lack of information.

Based on the analyses of the losses, economic investigations were carried out. For this purpose, the investments and the use of reactive power compensation systems (CS) were compared with already installed REP for the provision of reactive power. These studies have shown that REP is a competitive supplement to the CS and that upgrading the inverters can increase economic efficiency. The following figure on the next page shows the results of the cost calculation within the net present value scenarios. It is evident that the REP benefits from its non-existent or low capital costs (CAPEX). By integrating the REP into the RPM of the network operators´ investment, costs can be reduced. At present, however, the effect is rather neglectable and does not present interesting enough an incentive to network operators. The current incentive regulation (AregV) stipulates that interest is to be paid on CAPEX in particular, while operating costs (OPEX) produce no interest. Since the costs for the provision of the reactive power are allocated to the controllable operating costs in the cost calculation of the AregV, the investment in a compensation system is given preference.

Apart from the lack of an incentive effect for network operators, there is no transparent remuneration system in Germany that promotes incentives for the provision of reactive power by system operators, such as the service-related bonus from the economic feasibility study described above. Fundamental characteris-



Specific losses due to the provision of reactive power of an exemplary renewable energy plant for different voltages



Investment in various reactive power supply options

tics were compiled from analysed studies, which are to be considered when calculating remuneration. This framework was merged with the contents of the minimum requirements of the technical connection rules (TCR) laid down in Germany. This resulted in simplified remuneration model approaches for the provision of reactive power.

The work within the project has shown that REP can be an alternative or complement to the establishment of CS and that its use can bring technical, economic advantages. In addition to balancing reactive power requirements in the balance sheet, the CS fulfil other functions for maintaining system stability, which the network operator must also take into account. The extent to which EEA can fulfil these functions was not investigated within the framework of the project.

Q-Integral

Especially HV grids will be of increased significance in the future RPM. On the one hand, the largest reactive power requirements arise in extra-high voltage grids, and on the other hand, REP can be used particularly efficiently at the HV level to provide reactive power and thus support upstream and downstream grid levels.

The *Q-Integral* project focuses on the interface between DS and TS (see figure below). In cooperation with the network operators *50Hertz* and the three subordinate distribution network operators *E.DIS*, *TEN* and *WEMAG*, a large part of the *50Hertz* network and the subordinate 110 kV networks as well as individual medium-voltage networks are mapped in a network model (see figure on the following page). The network model is used to develop approaches to an RPM that spans network operators and voltage levels. A description of this RPM concept can be found in the figure below.

For this purpose, the RPM developed at *elenia* is adapted to the new requirements and supplemented by further modules such as the reactive power forecast. The aim of subsequent technical and economic investigations is to formulate recommendations regarding operation and planning of the future RPM. With this in mind, the effects of different reactive power control strategies on the grid levels will be investigated and possible efficiency gains and synergy effects of the holistic approach will be highlighted. Through the comprehensive technical and economic analysis of different reactive power sources, conclusions are to be drawn on economic added value. *elenia* receives practical support from the plant operator and project manager *BayWa r.e.* in analysing the economic viability of REP.

If renewable energy sources make a significant contribution to system stability through the provision of reactive power in the future, it must be ensured that availability is guaranteed at all times. Within the project, the *elenia* forecasting procedure for reactive power requirements will be developed and approaches designed to ensure reliable grid operation in the event of communication failure.

In addition to the work packages of *elenia*, *Fraunhofer ISE* is analyzing the effects of increased reactive power supply

Project Description

Project Name
PV-Wind-Symbiose

Project Duration
Oktober 2015 – Juni 2019

Project Partners
Fraunhofer ISE, SMA Solar Technology, ENERCON, MITNETZ STROM

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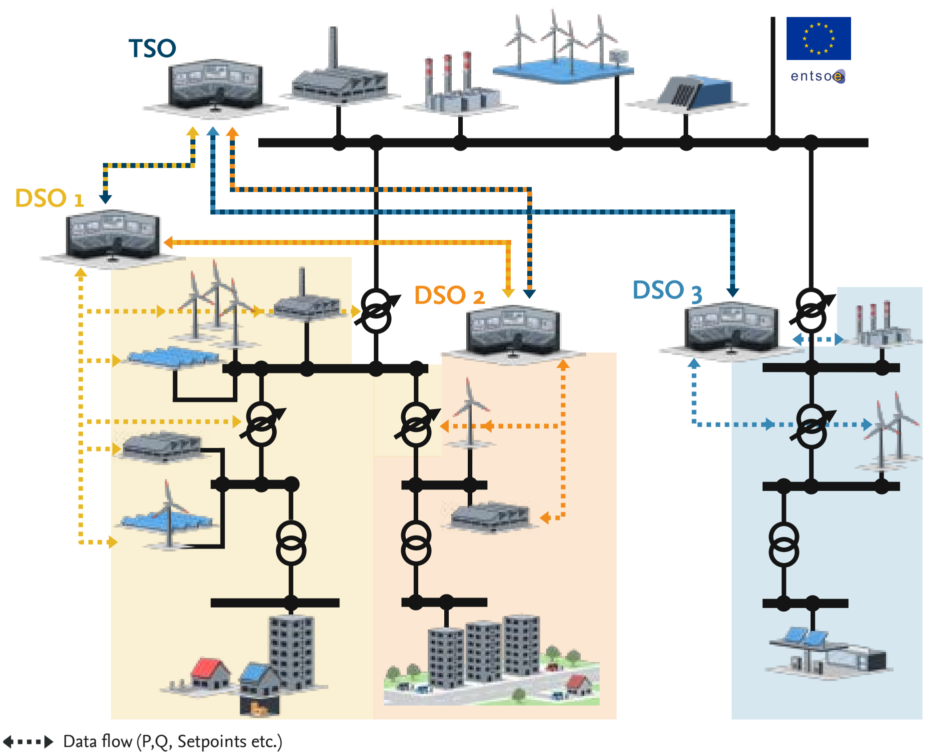
aufgrund eines Beschlusses des Deutschen Bundestages

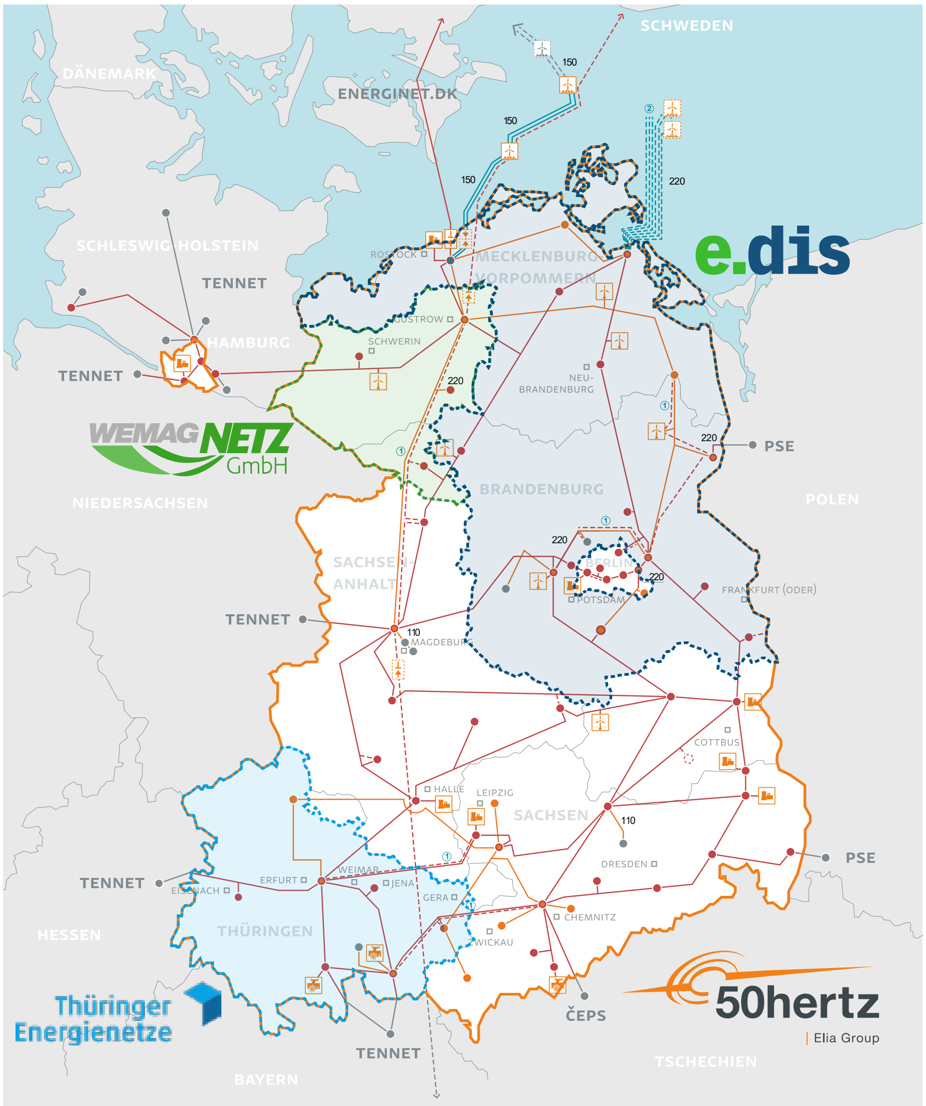


Cross-grid operator and cross-voltage level reactive power management on the protection systems. *Fraunhofer* is supported by *SIEMENS AG* and *SCADA International*. In addition, *Fraunhofer* will investigate the dynamics of various reactive power sources and their effects on network stability.

OTH Regensburg will work on the RPM from a network planning point of view. To this end, it will be analyzed how reactive power requirements can be reduced while still in the network planning process. Together with the *KBR Compensation Plant Construction*, a prototype for the integration of industrial compensation plants into the RPM is to be developed.

The joint network model is currently being developed in cooperation with the funded and associated partners. Subsequently, network and simulation scenarios will be developed on the basis of the published network development plans grounded on the assumptions made by the participating network operators.

Also, the first steps to build an active RPM at *elenia* have been taken. For the further development and adaptation of the control algorithms, the interoperability of the RPM to be designed will be investigated at relevant interfaces of the RPM. This is realized while taking into account the integral effect of the RPM within the network. The underlying modelling process aims at a consistent understanding of the interaction of different points of contact of the RPM. The scope of action for the RPM can be defined from the result.



Grid operator and voltage level-spanning grid model [50Hertz 2017]

Project Description

QINTEGRAL

Project Name

Q-Integral – Aktives BM mit dynamischen Blindleistungsquellen an der Schnittstelle Verteilnetz und Übertragungsnetz

Project Duration

April 2019 – März 2022

Project Partners

Fraunhofer ISE, OTH Regensburg, KBR Kompensationsanlagenbau, 50Hertz, BayWa r.e., E.DIS, SIEMENS, TEN, WEMAG

Gefördert durch:

Bundesministerium für Wirtschaft und Energie

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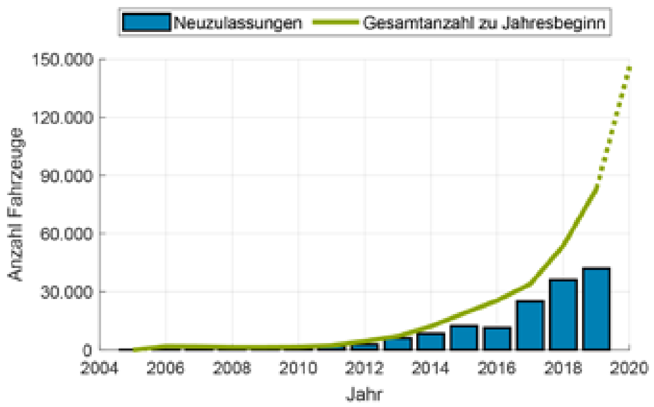
Grid Integration Electric Mobility

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

As early as 2009, the German Federal Government formulated the goals of advancing research, development, market preparation and the market launch of battery-powered vehicles in Germany with the National Development Plan for Electric Mobility. The achievement of the original target of one million electric vehicles was postponed from 2020 to 2022 due to current developments, and depending on the scenario, the number of electric vehicles will increase to 4.2 to 7 million by 2030. Current developments also clearly show an exponential increase in the number of vehicles in Germany.



Growth of all-electric vehicles in Germany (August 2019)

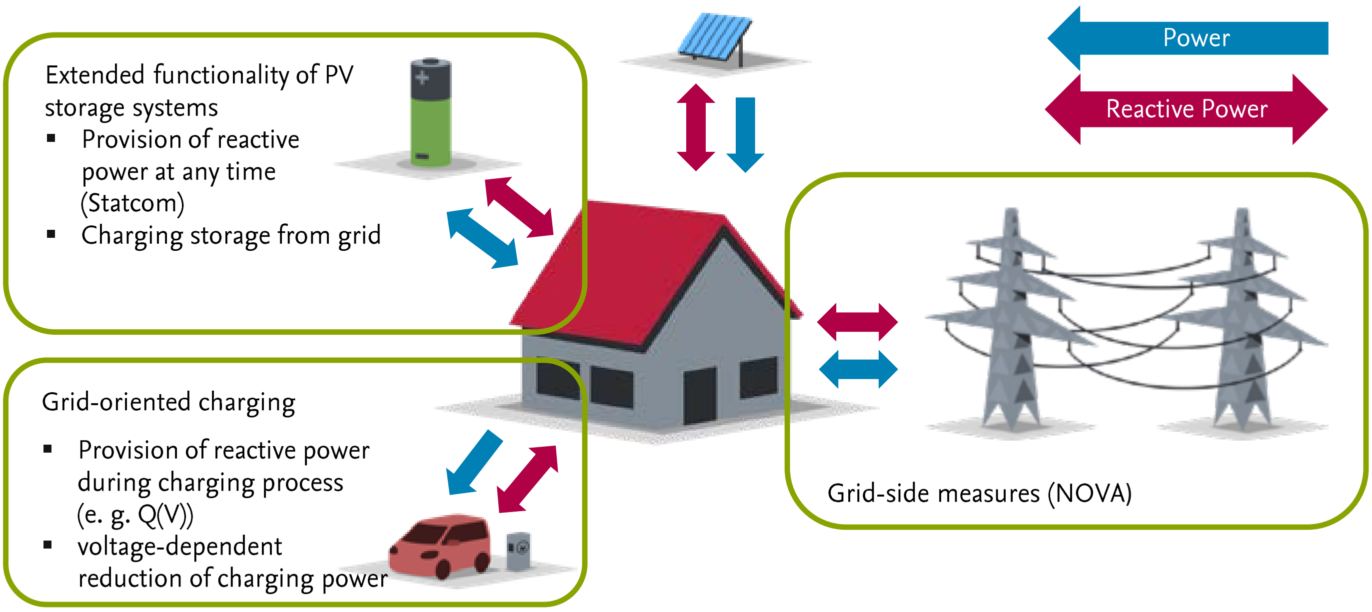
A large proportion of the charging operations will take place at home in the private sector. Suburban residential areas offer good conditions due to their structure and in particular due to their own garages and carports. The maximum charging power in these cases is 11 to 22 kW. Depending on social and demographic factors, electric mobility hotspots with a high penetration of electric vehicles in existing low-voltage grids can arise. However, these grids were not originally designed for these components. A secure grid operation must still be guaranteed. Basically, grids offer a certain capacity for the integration of electric vehicles. Depending on the actual grid structures, certain penetrations of electric vehicles are already possible with typical driving and charging behavior before voltage band injuries or overloading of operating resources occur. The major challenges are days on which high driving performance and relatively simultaneous charging processes can be assumed, such as Sundays with nice weather in spring/summer or Christmas holidays. For this reason, suitable measures are necessary to ensure safe grid operation even in such situations and to comply with the relevant limits. These measures are divided into three different levels with individual functional options: Vehicle, household and grid.

Grid-oriented Charging

With grid-oriented charging, the focus is on the electric vehicle or charging unit and its behavior during the charging process. The normal charging process is characterized by a range with constant charging power and a second range with decreasing charging power from an SOC of 80 %. The grid-oriented charging includes the provision of reactive power and a reduction of charging power. The VDE AR-N 4100 standard already specifies the reactive power supply with a rated power above 12 kVA for inductive charging systems and for DC charging. In particular, the provision of reactive power as required in the Q(V) process as voltage-stabilizing measures ensures an increase in the capacity of low-voltage grids. An additional voltage-dependent reduction in charging power can additionally increase this capacity. To avoid possible discrimination, a minimum charging capacity is defined.

Extended functionality of PV storage systems

The feed-in peak of a PV system and the usual charging period of an electric vehicle are different in time. However, these processes can be coupled with the support of a storage systems. The feed-in peak of the PV system at midday is reduced by the storage and in the evening hours the electric vehicle can (partly) be charged from the storage. This operation reduces



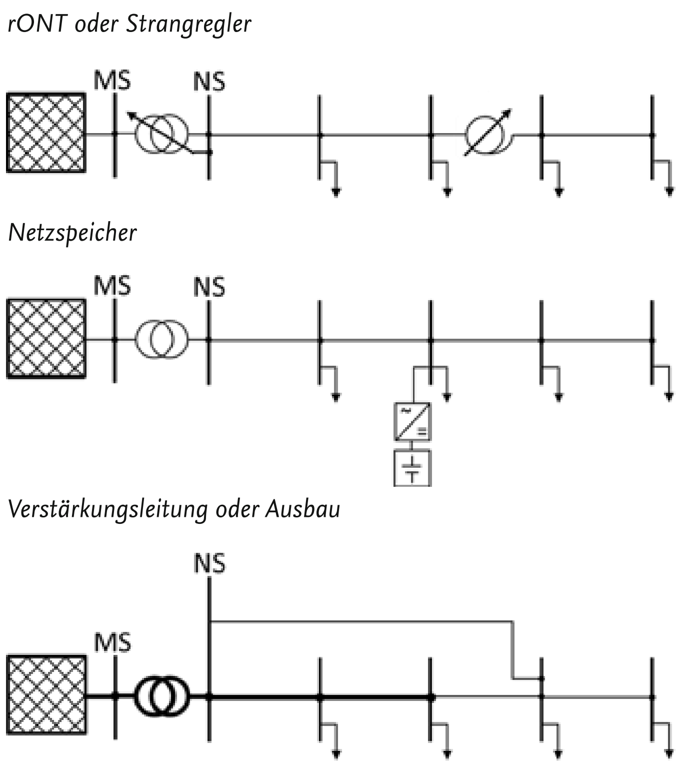
Overview of technical solutions

the load on the grid.

This approach becomes problematic in the winter months with short days or days with bad weather. On these days the storage can only be charged a little or not at all. For these periods an extended functionality is necessary. This includes STATCOM operation, which always makes it possible to provide reactive power and thus even phase shift operation. In addition, charging the storage from the grid is an important approach for the periods described. For economic reasons, this approach has not yet been used, which is why appropriate incentives are necessary. Both functionalities increase the capacity low-voltage grids because both the voltage can be stabilized by reactive power and the grid can be relieved by the energy in the storage.

Grid-side measures

The third approach includes measures in the grid. With the help of transformer components, the usable areas of the voltage band can be increased. These include the adjustable local grid transformer and the line voltage regulators.
The grid storage has identical functions as the preset PV storage. By providing reactive power, it can have a voltage-stabilizing effect and it relieves the grid by providing active power.
The third possible measure is the amplification line or the expansion with the aim of reducing the grid impedance and thus increasing the capacity.



Overview of grid-side measures

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lautlos&einsatzbereit

Development of a guideline for the integrated planning and control of fleet, energy and charging infrastructure to allow for the ecological and economical operation of vehicle fleets under extreme conditions at the Lower Saxony Police Department

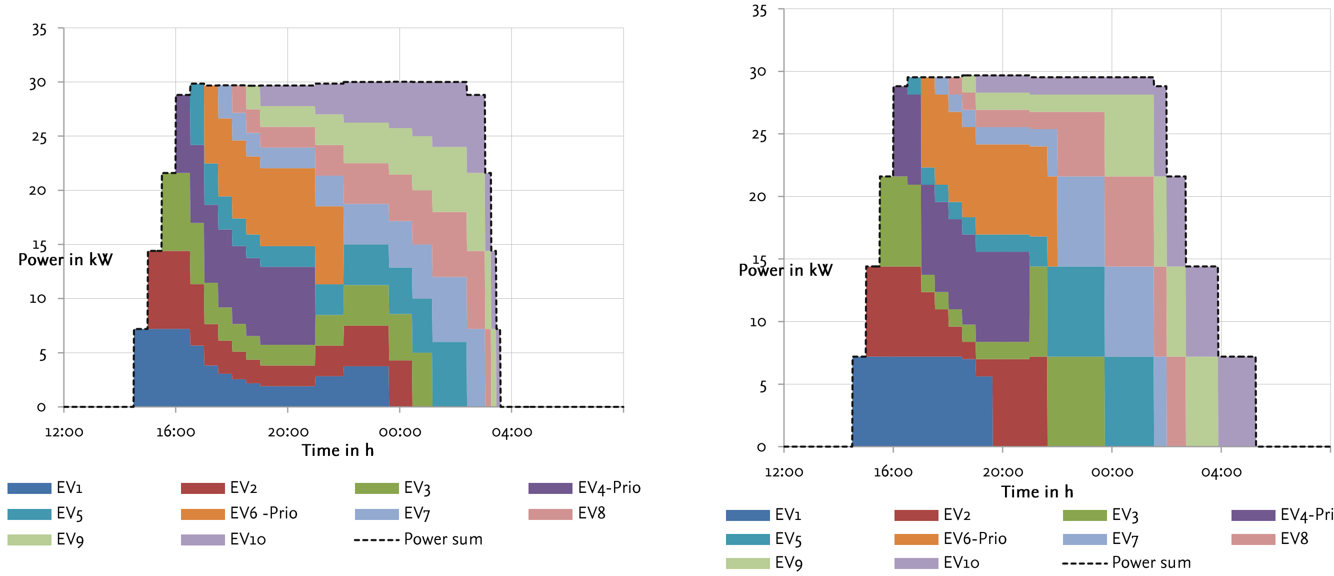
Within the scope of the three-year research project lautlos&einsatzereit, the Lower Saxony police force, together with the Niedersächsische Forschungszentrum für Fahrzeugtechnik (NFF), is developing a guideline for the integrated planning and control of fleet, charging and energy infrastructure. The aim is to increase electromobility even for vehicle fleets that are exposed to extreme conditions, such as police vehicles. Police fleets are characterized by a large number of different vehicle types, a high number of vehicles and a high visibility of their vehicles. Due to the exemplary function of the police in society, a sustainable and environmentally friendly operation of these fleets through the use of new drive technologies is of particular relevance. This is why the police force takes a pioneering role and integrates battery electric (BEV) and plug-in hybrid vehicles (PHEV) into their fleets. The use of BEVs and PHEVs is associated with long charging times, limited ranges and the resulting limited availability of vehicles compared to conventionally powered vehicles. In addition, an energy and charging infrastructure is required to operate the vehicles. With the planned combined use of BEVs and PHEVs in emergency and patrol service, the police are faced with the challenge of ensuring continuous operation with 24/7 availability of the vehicles. This creates a multitude of dependencies between fleet, energy and charging infrastructure and increases the complexity of planning and control many times over.

In the project lautlos&einsatzbereit, 50 BEVs and PHEVs will be put into operation and tested in the Lower Saxony Police Service for the areas of patrol duty, criminal investigation service and for administrative trips. Within the scope of the scientific accompanying research, the mobility and charging requirements of the different fields of application are investigated. Based on this data, an integrated system for fleet planning and control as well as charging management will be developed which meets the special requirements of police operations. The challenge of the new planning and management system is to meet the extreme requirements - especially in the field of emergency and patrol services - such as unscheduled operating times and scope of operations as well as the need for almost 24/7 availability.

The result of the project is a guideline for the integrated planning as well as the ecological and economical operation of vehicle fleets under extreme operating conditions. This can support decision-makers in the planning, procurement and operation of e-vehicle fleets, especially under extreme operating conditions (e.g. other police fleets, but also fire brigades or rescue services).

Within the work package on charging and energy infrastructure, research is being carried out on the planning and control of this infrastructure. The challenge of the developed charging management is the unpredictability of the fleet. The uncertainty regarding the time of deployment of the police means that reliable planning is not possible. A further consideration falls on the limited grid connection of a location. If the site has to be expanded, this is associated with high costs. Since the police forces always have limited resources, this issue can be an obstacle to the purchase of electric vehicles. A sophisticated charging and energy management system also entails costs. Monitoring individual energy flows, forecasting trips and monitoring the state of charge involves additional expenditure and effort, which the locations often cannot afford. Therefore a simple and effective implementation of a charging management system has been developed, which saves costs in the grid connection and which is easy to implement. For such an application, charging algorithms of static charge management were investigated. The following figure shows the charging process of the two algorithms Equal and First Come First Serve (FCFS). The charging algorithms can be compared site-specifically in a simulation with user interface. Thus, for example, it is possible to determine whether it is necessary to upgrade the grid connection.

One level higher than the static charge management is the dynamic charge management, which receives changing real-time



Simulation results of the charging algorithms Equal (left) and First Come First Serve (right) with two priority vehicles of a static charging management (Pronobis, O., Kurrat, M.: Assessment of Static Charging Management Methods, ETG Kongress, Esslingen am Neckar, 8.- 9. Mai 2019)

data. This data includes, for example, the PV feed-in, the building load and the electricity price. With these input parameters, the charging processes can be aligned not only functionally, but also ecologically and economically. The system reaches a more complex level as soon as forecasts of the state of charge and the arrival or departure time are included. Within the research work, two methods, machine learning and Monte Carlo simulation, were analyzed and compared. The amount of input data that produces the best result is currently being investigated.

At the end of the project a lot of data about the loading processes and the trips were recorded. The evaluation of this data is included in the final report. The conclusions and recommendations for action to be drawn from this will be collected in the guideline, which is the result of the project. The questions and remarks of all federal states and other countries (e.g. Luxembourg, Denmark), which were collected in a nationwide workshop at the end of last year, are also included in the guidelines.

Nationwide workshop in November 2018

Project Description

Project Name
lautlos&einsatzbereit

Project Duration
September 2016 – March 2020

Project Partners
Niedersächsisches Ministerium für Inneres und Sport, Landespolizeipräsidium (Konsortialführer)
- Polizeidirektion Braunschweig
- Zentrale Polizeidirektion Niedersachsen
- Niedersächsisches Researchszentrum Fahrzeugtechnik (NFF)
- Institut für Automobilwirtschaft und Industrielle Produktion, TU BS
- Institut für Fahrzeugtechnik, TU BS
- Institut für Werkzeugmaschinen und Fertigungstechnik, TU BS

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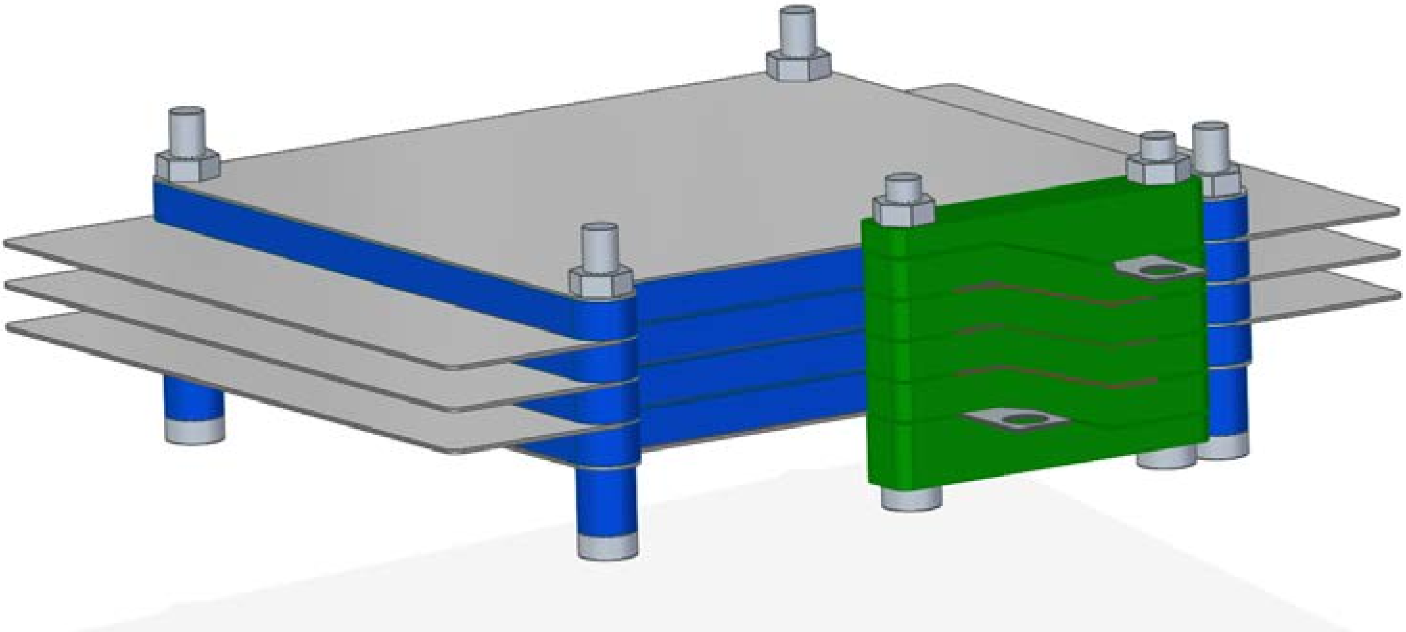
aufgrund eines Beschlusses des Deutschen Bundestages



Second Life Storage Systems

Automotive batteries as stationary storage systems for prosumer households

Within the last decade, the field of application for lithium-ion batteries has increased immensely. Especially in Germany, the so called "Energiewende" requires alternative power trains in the mobility sector, on the one hand. On the other hand, an increasing amount of stationary storage systems in order to mitigate fluctuating energy generation caused by renewable energies is needed. For both applications lithium-ion batteries serve as a promising solution also on the long-term perspective.

Due to the increasing popularity of battery-electric mobility, there will be an increasing amount of lithium ion battery systems at their end of first life in the future. Consequently, costs for lithium-ion battery systems are likely to decrease while stationary storage systems become more profitable. Automotive batteries have a guaranteed state of health (SoH) of at least 80 % at their end of first life, which is by far not the “final end of life” of a battery system. Additionally, their load profile in the first life application exceeds the load profile of a stationary storage system. With these facts in mind, it stands to the reason that automotive batteries are applicable as stationary storage systems in a so-called second life. In order to do so, both the battery system’s safety and economic viability need to be guaranteed.

In terms to answer questions regarding the technical viability, characterisation methods well approved on battery cell level are transferred and adapted to battery stacks. With a focus on capacity tests and inner resistance tests, the current state of health of a battery is determined. Consequently, the dominating ageing mechanism is identified and, regarding all the findings together, an operation strategy with the objective of a long remaining useful life is derived. Speaking of operation strategy, both a battery management system and an energy management system mentioned become relevant. While the latter determines the required dimension in terms of power and energy, the battery management system tracks data of the current operating point. These are, amongst others, current, voltage and temperature. Based on the current measured by the battery management system, information concerning the available power is passed on to the energy management system. Using this information, the energy management system recalculates the operation strategy.

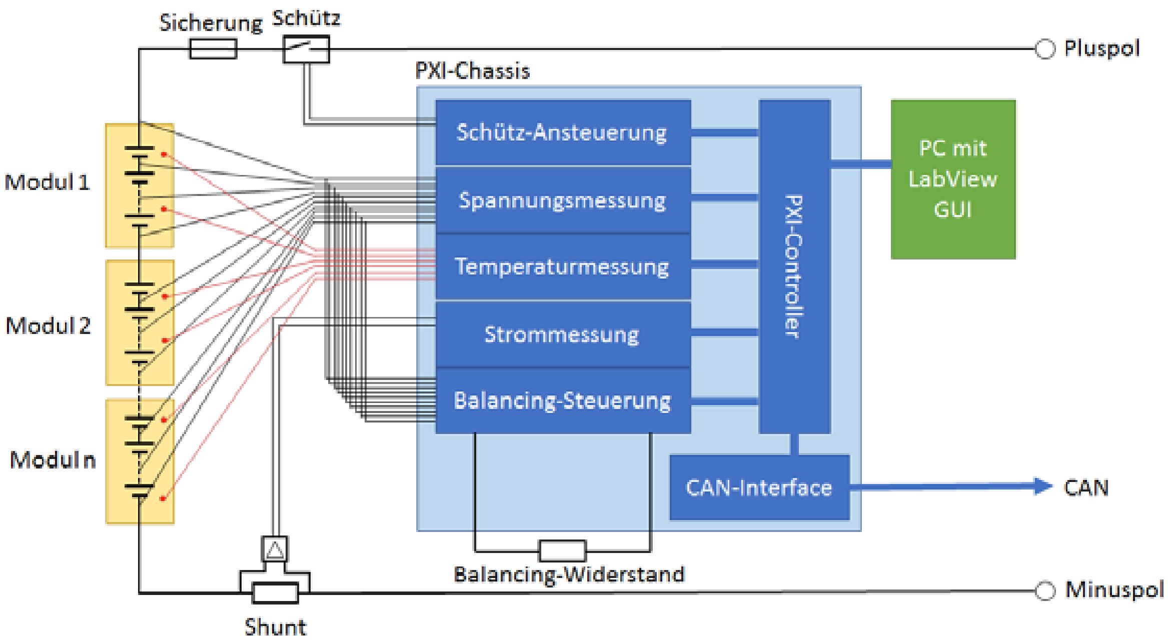
Configuration of the 2nd-Life storage system

In order to configure the stationary storage system, a household with an annual energy demand of 4 MWh is taken as a basis. Accordingly, the storage system is dimensioned such that a power of 20 kW and an energy content of 12,5 kWh can be provided. Furthermore, the cut-off voltage is limited to 300 V in order to both spare the peripheral power electronic and to enable an efficient operation.

Storage System	Target Value	Actual Value	Stack Configuration	
$E_{storage}$	15 kWh	16,8 kWh	E_N	1086 Wh
$U_{storage}$	320 V	370 V	U_N	14,8 V
$C_{storage}$	40,5 Ah	54 Ah	C_N	75 Ah
Config.	100s3p		C_{use}	54 Ah

Configuration of a 2nd-Use Storage System

As 1st-Use HV-batteries serve modules with a nominal voltage of 14,8 V and a nominal capacity of 75 Ah each. Assuming that at least 80 % of the initial capacity is still available, combined with a battery saving operation strategy (for example by limiting the cut-off and end-of-charge voltage), the useful capacity



The BMS as a monitoring and control instrument

is set to 70 % of the initial capacity. Putting all together, the 2nd-use energy storage system is configured to 25 modules in a row. The according nominal data are shown in the table.

Characterisation of battery modules

Previous research has concentrated on investigations on cell level, while only little effort has been devoted to examining stacks and systems. Regarding these, differences between stacks with homogenously and heterogeneously aged cells need to be considered. Therefore it is unclear, whether examining on cell level is necessary to determine a battery stack's condition or if it is sufficient to examine the stack only. Moreover, the battery's ageing progress highly correlates to the former load profile. For this reason it is either necessary to know about the battery's history or to find characteristic parameters which indicate the future aging behaviour.

With these objectives in mind, testing procedures for characterising lithium-ion cells serve as basis in order to adapt these to measurements on stack level as well: capacity tests and inner resistance tests as well as the electro-chemical impedance spectroscopy. Concerning the latter, it is no proven testing procedure for battery stacks thus far and is therefore another objective of our research.

Monitoring by a battery management system

For the monitoring and controlling of the storage system, a universal battery management system (BMS) is developed. It must offer the possibility to program it freely and to adapt it to variable cell configurations. Therefore, the implementation is realised by using a PXI system and LabVIEW.

This BMS enables controlling modules as well as individual cells and delivers data regarding the state of charge, for example, via a stored database. In addition, module or cell parameters can be adjusted as well as the cell chemistry. Integrated temperature sensors allow a temperature monitoring. Moreover, the BMS has access to the main electric contactor to prevent current flow in the event of an imminent fault.

Project Description

Project Name
NetProsum2030

Project Duration
September 2017 – August 2020

Project Partners
Institut für Elektrische Maschinen, Antriebe und Bahnen (IMAB), IAV GmbH, SMA Solar Technology AG

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Optimized Battery Formation

Speed-up and energetic optimization of cell formation

The formation and maturation of batteries are one of the most important process steps during the production of lithium-ion batteries. During the first charge cycles the passivation layer (Solid Electrolyte Interphase, SEI) is formed between the electrolyte and the anode. The SEI has a big influence on the performance and aging of the battery. Subsequent to the formation batteries are matured for many days in order to stabilize the electrolyte and the properties of the cell. There is an increased safety risk within this period because explosive gases are produced inside the battery cell. The formation as well as the maturation are time-consuming and energy-inefficient process steps. Furthermore a lot of expensive storage place have to be provided. The lead time varies from days to weeks depending on the material and process parameters. The required energy accounts for a high amount of the energy costs during the battery cell production. In spite of the high relevance within the battery cell production, the know-how of the formation and the influence from process parameters regarding the battery quality is limited.

The project OptiZellForm aims at an accelerated and energy-efficient formation procedure. Thereby the interactions between formation, maturation and cell quality are focused. In addition the safety of the formation shall be increased based on the acquired knowledge.

Reference formation procedure

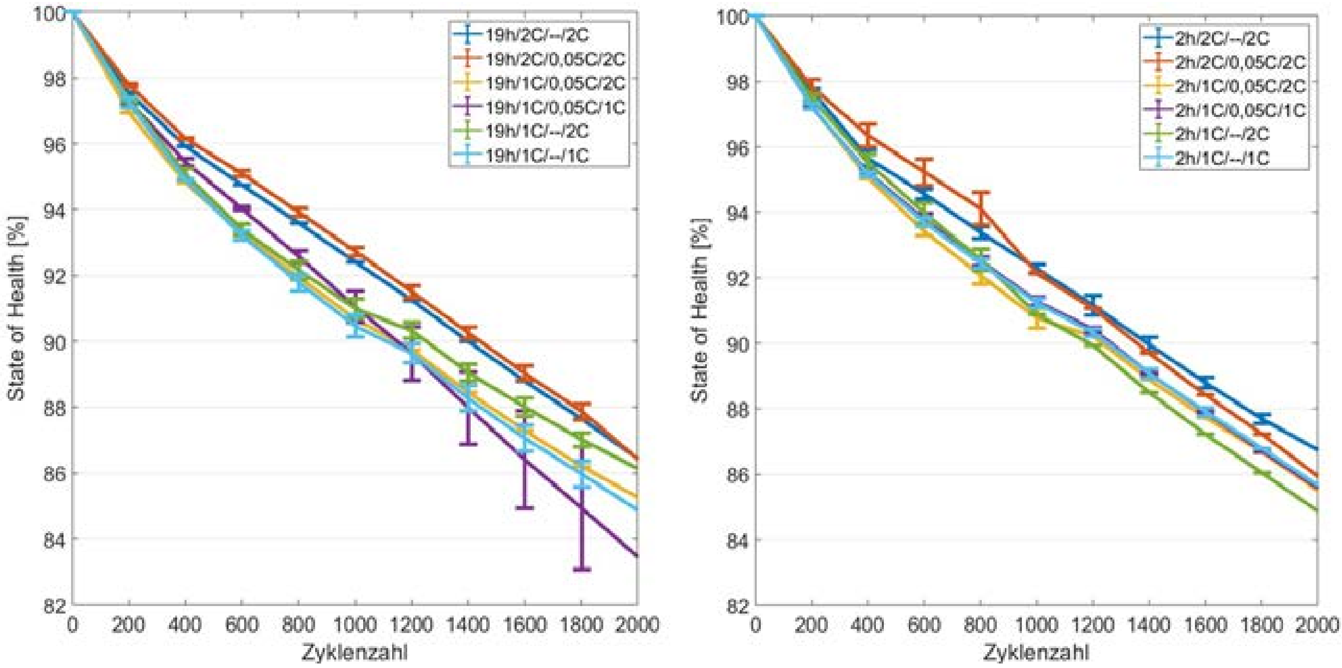
A reference formation procedure have been defined in order to investigate electro-chemical influencing parameters. This reference procedure is based on the different standard procedures of the Project Partnerss. Preliminary investigations have shown good results by doing just a single charge and discharge cycle within the formation of the 5 Ah pouch cells. These cells were built at the Münster Electrochemical Energy Technology (MEET). The quality and properties of the cells are comparable to cells which are formated with several charge and discharge cycles. By saving additional cycles the production time and the energy consumption is significantly reduced. Before charging the battery for the first time, the cell is wetted with electrolyte for a defined timespan. This wetting is necessary in order to fill out all the pores inside the electrodes. After the defined wetting time the cell is charged for the first time with a constant current (CC) until the cell voltage reaches 4.2 V. Then the cell is charged with constant voltage (CV) until the current drops below 0.05 C. Finally the cell is discharged until 3 V.

Parameter study

A parameter study have been conducted with the aim of determining the influence of sensitive parameters. The four parameters: wetting time, charge current, CV-charging and discharge current were varied. For every parameter two different variants were investigated. The wetting time was set to 2 h and 19 h while the charge and discharge current was set to 1 C and 2 C. The CV-charging was either implemented or excluded. In total twelve different formation procedures were designed and

Step	Steptype	Mode	Limit
#0	Wetting	-	t = X1 h
#1	Charge	X2 C (CC)	U = 4,2 V
#2	Charge	U = 4,2 V (CV)	I < 0,05 C
#3	Discharge	X3 C (CC)	U = 3,0 V

Reference formation procedure



Cycling of batteries with different formation procedures

cycled (see figure). It is conspicuous that there is no significant difference between a wetting time of 19 h and 2 h, concluding that the electrolyte is already wetted very well after 2 h. Furthermore the time-consuming CV-charging step during the formation does not have an impact on the aging behaviour. In contrast to that, the formation procedures with the high charge current of 2 C (red and blue curve) show a slightly better cycling stability compared to the formation procedures with just 1 C charge current. So charging with high currents of 2 C does not have any negative impact on the cell quality although the procedure is much faster.

Within an extension of the parameter study charge currents of 3 C have been tested but the cells were not able to reach the maximum voltage of 4.2 V because of lithium-plating related to the high current. So these cells have not been cycled. The lithium-plating was diagnosed by post-mortem studies. Lithium-plating is highly dangerous and can lead to safety problems. Some cells of the 2 C formation also showed slight lithium-plating but this did not affect the cycle stability. Nevertheless a formation procedure should not lead to lithium-plating, so an optimized charge protocol is necessary.

Design of optimized charge profiles

A simulation model have been developed in order to design optimized charge profiles. The model is parameterized by special 3-electrode-cells with a reference electrode between the anode and the cathode. The output of the model are optimized charge current profiles which hold the anode voltage above 0 V to avoid lithium-plating. The profile starts at high charge currents of 3 C. The current is continuously decreasing with higher state of charge. New pouch cells have been produced and formated with the simulated current profile. A post-mortem study proved that no lithium-plating occurred. Furthermore the formation time is reduced in comparison to the fastest 2 C formation and the discharge capacity is increased by 5 %. In the further project time the cells are cycled in order to check the cycle stability and to derive conclusions regarding the SEI.

Project description

Project Name
OptiZellForm

Project Duration
July 2016 – January 2020

Project Partners
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PEM (RWTH Aachen)

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Knowledge-based battery cell production

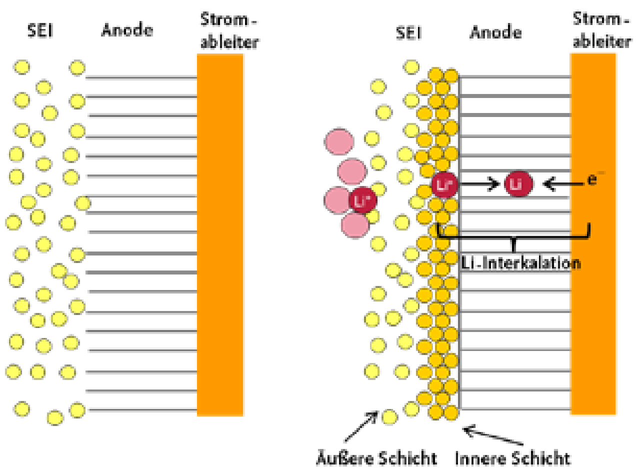
Data mining as a basis for cyber-physical systems in Li-ion battery production

With the project DaLion4.0 the direct continuation followed of the lighthouse project DaLion of Battery LabFactory Braunschweig. With the successful project completion of DaLion at the end of 2018 further exciting questions arose, which are to be researched in the second funding phase. Competitive battery cell production continues to be a priority in the focus of the project DaLion4.0, because they are essential for the success of the electromobility and Germany as a business location. The battery cell production is a complex production system characterized by specialized production processes, associated periphery and complex technical building services equipment (TGA) for the guarantee of defined environmental conditions as well as various interacting influencing parameters. The produced battery cells have to satisfy target values in the production (cost, time, environment) as well as target criteria in the product properties. For example, these include defined energy and power densities, lifetime and safety. Due to the complexity of the production system and the the different levels of maturity of the used technologies, the interactive relationships from process parameters and the resulting product properties currently are only partly known. This gap is to be closed by the project.

A key process for the targeted adjustment of battery cell characteristics is the formation. Along the entire production chain, this process step is at the same time most time- and cost-intensive. The research topic at elenia is the investigation of the formation process to build up a detailed understanding of the process and thus achieve an optimization of this production step. The long-term goal is to create a model-based concept for the identification of cell-specific, optimal formation procedures to develop and implement a solution that react on new cell types (high-energy and high-performance cells) and cell chemistries. To avoid the interactions of the variations in the formation procedures on the cell performance without evaluating a time-consuming cyclisation, quality tests which are already developed at the institute are used (see fig. on the right)

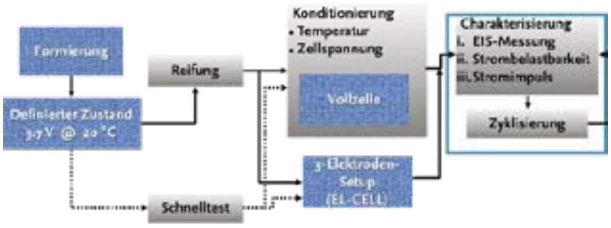
Formation as bottleneck in production

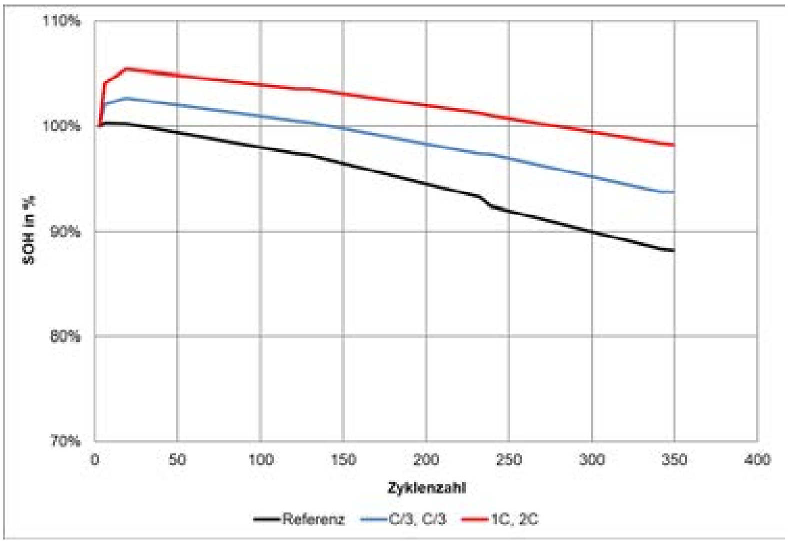
The formation describes the initial loading and unloading of the cells and is the final process step in the battery cell production. Due to the surface layers which are formed during the initial first cycles, important cell properties such as the nominal capacity and the long-term behaviour of the cell (cycle stability and safety) are defined. The lower figure shows the formation of the so-called Solid Electrolyte Interphase (SEI), which is build up on the anode surface from decomposition products of the electrolyte under irreversible consumption of lithium. The SEI is essential for reliable battery operation. On the one hand, it prevents further decomposition reactions of the electrolyte, since no electrons migrate through the SEI. In addition, the electrode is protected against further negative influences (e.g. exfoliation) which cause premature ageing. On the other hand, the SEI continues to grow in the following cycles, whereby lithium ions are irreversibly consumed from the cathode active material and the conductive salt. This results in a loss of capacity and an increased internal resistance of the electrolyte. Thus, the SEI represents an additional barrier when



SEI-Bildung während der Formierung

Zyklus	Prozessschritt	Modus	C-Rate	Variation
1	Laden Entladen	CC-CV CC	C/10	C/3, 1C
2	Laden Entladen	CC-CV CC	C/2	C/3, 2C
3	Laden/ Entladen	CC-CV CC-CV	C/10	C/10
4	Entladeimpuls		1C, 1s	
5	Reifelagerung (8 Tage)		-	
6	Entladeimpuls		1 C, 1 s	





- Table which gives an overview of the different charging and discharging currents in the formation variations (top left).
- Long-term performance of the formation variations (right).
- Comparison of the conventional evaluation of the cells via cyclization and self discharge test and the evaluation by a quality test which is developed at the institute (bottom left).

lithium ions intercalate in the active material of the anode.

A short-term goal is to develop a formation procedure for the reference cells (NMC 622 I graphite) that is as time- and energy-saving as possible and have at the same time a comparable cell quality like the produced cells from DaLion (NMC 111 I graphite). For this purpose, both full cells and EL-Cells (3-electrode setup) are considered. Since not all influencing factors can be addressed simultaneously, the initial focus is on different charging and discharging currents. The number of cycles and the environmental conditions such as pressure and temperature will be considered in the further part of the project. The reference formation is the standard procedure of the BLB. The procedure consists of two forming cycles and a characterization of the cells based on a capacity test, an internal resistance test and a determination of self-discharge by means of 8-day maturation. The table in the figure above shows the variations in the formation as well as the reference procedure. The graph shows the state of health (SoH) @C/10 of the battery cells with different formation procedure over the number of cycles. Already after 350 cycles, the comparatively better performance of the cells with higher C-rates in formation is noticed. The cells with the 1 C ,2 C formation show a SOH of approx. 98 %, whereas the reference cells only have an SOH of approx. 88 %. At the same time, the process time is reduced by a factor of 7. The increase of the nominal capacity and thus the SOH of the faster formed cells after the first 20 cycles is noticeable, which corresponds to a conditioning of the cells. To verify these trend, the cells will age another 500 cycles.

Charging the cells at high C rates can lead to lithium plating, which poses a major safety risk. In order to exclude the deposition of metallic lithium, post-mortem investigations are planned for methodical investigations of the SEI structure and composition by Raman spectroscopy and scanning electron microscopy. The results were finally presented at the end of this year as part of a project meeting as well as at the BLB conference (International Battery Production Conference, IBPC).

In order to achieve the goal of reducing the entire time of the production step, the maturation is considered in addition to the forming process. For this purpose, the maturation is examined for its applicability as a self-discharge test and a rapid test is implemented as a possible surrogate (see figure above).

Project Description

Project Name
DaLion 4.0

Project Duration
Januar 2019 – Dezember 2021

Project Partners
TU-BS
(iPAT, IWF CH/KD, ifs, InES, IÖNC, elenia)
FMP, Cooperion, ISRA, Manz, Bredex, GPS
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aufgrund eines Beschlusses des Deutschen Bundestages

Quality analysis in the production of lithium-ion batteries

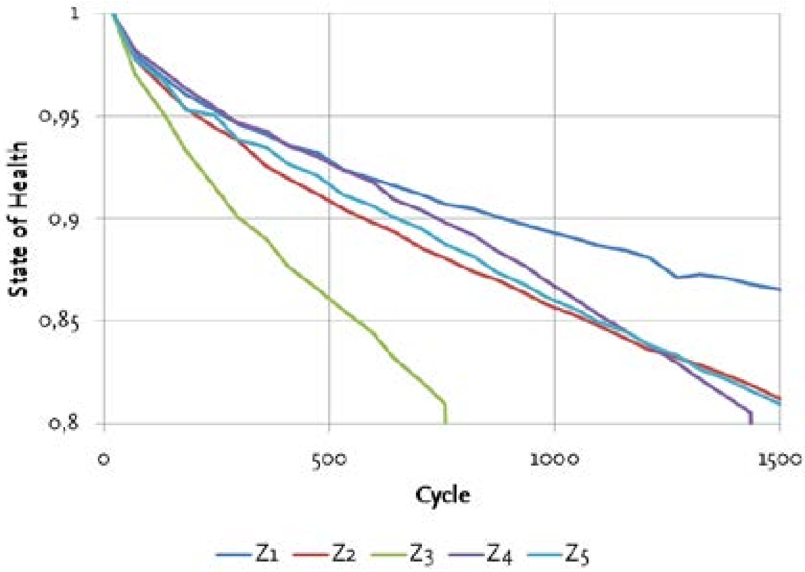
Evaluation of the cell quality based on key figures derived from the formation process

Lithium-ion batteries are of great importance for electromobility and for the stationary storage of electricity generated from renewable energies. It is still uncertain which battery technology will dominate in the long term but at the moment batteries based on lithium-ion material systems are undisputed market leaders. Lithium-ion batteries owe this position to the many positive properties they have compared to other battery technologies. These include in particular a high energy density (90 - 250 Wh/kg) and a long service life (1,000 - 5,000 full cycles), as well as a high cycle efficiency (>98 %) and a low self-discharging rate (<3 %/month). These properties determine the performance of the individual cells in the respective application and make a decisive contribution to meeting the requirements in the respective field of application.

But there are also barriers to the market penetration. The high investment costs in particular have a negative impact. Costs have fallen significantly in recent years (2008: >1000 €/kWh, 2019: 150-250 €/kWh). Nevertheless, the battery still makes up a large part of the value chain of an electric car. Due to the high costs and the influence of the cell properties on the fulfilment of the requirements, the knowledge of the quality of the individual cells is of decisive importance. On the one hand, the knowledge of the quality enables to make predictions about the cell behavior during its lifetime. On the other hand, battery module construction requires the quality of the cells in order to classify and assemble them according to their quality. Cells of the same quality should be connected to a battery module to ensure that the cells behave as equally as possible.

Challenges

The expected cell properties are predetermined by the selected materials. However, the design of the individual process steps in the production also influences the characteristics of the cells. Since the setting parameters of each process step are subject to a certain variation and other factors (e.g. environmental conditions, production employees) influence the intermediate products, there is also a variation in the cell properties and thus a fluctuation in quality. In the previous figure the State of Health (SOH) is shown for five cells which were produced in the Battery LabFactory Braunschweig (BLB).



Comparison of SOH profiles of five identical cells

It can be seen that the green cell (Z3) shows the course with the largest gradient already at the beginning of cycling. The situation is different with the purple cell (Z4), which shows similar behavior to Z1 (dark blue) up to 600 cycles. After that, the ageing progresses more intensively, so that Z4 reaches the end of its life before Z2 (red) and Z5 (light blue), whose ageing behavior is constant in the midfield.

General framework

The aim of current investigations of the elenia battery technology research group is therefore to identify parameters at the beginning of the life cycle that will enable an early and reliable assessment of quality.

In practice, an end-of-line test is usually performed after production to characterize the cells. Depending on the quality demands and the used measuring methods, this can be designed in different extents and lasts from a few hours to a few days. Since this is an additional process step that takes a lot of time and is therefore associated with high costs, the aim of these investigations is to determine the quality of the cells on the basis of the measurement data recorded during formation.

The formation and the maturation storage are the final process steps in cell production. During the formation, the cells are charged and discharged for the first time. Due to chemical reactions between components of the electrolyte and the graphite electrode the Solid Electrolyte Interphase (SEI) grows on the anode surface during initial charging. After formation, the cells are stored at a defined temperature. This process step is called maturation storage. Cells of poor quality show an increased self-discharging rate in this step.

As part of the DaLion project (Data Mining in the Production of Lithium-Ion Battery Cells, previous project to DaLion 4.0), more than 150 cells with a theoretical capacity of 9 Ah manufactured at BLB were formed using the same procedure and were afterwards cycled. While 78 cells were produced as reference in 7 batches, the remaining cells differ by variations in the process steps of calendering, laser cutting and Z-folding. This provides a large database for investigating the noticeable differences in quality during formation.

An overview of the forming and maturation procedures used can be found in the adjacent table. In addition to the two for-

Test step	C-Rate	Explanation
Charge/ Discharge	C/10	First formation cycle
Charge/ Discharge	C/2	Second formation cycle
Charge/ Discharge	C/10	Capacity test
Charge/ Discharge	1 C	Setting SOC 50 %
Discharge pulse	1 C for 1 s	Internal resistance
Maturation		8 days
Discharge pulse	1 C for 1 s	Internal resistance

Forming and maturing procedure

mation cycles and the maturation period, the procedure also includes a capacity test and two discharge pulses used to determine the internal resistance. During formation and maturation, the cells were kept continuously in a temperature test chamber at a constant temperature of 20 °C. All cycles were performed in the voltage range 2.9 V - 4.2 V.

Outlook

The measured data from formation and maturation are currently being investigated with regard to their significance for the cell quality by deriving key figures and using various evaluation methods. In the key figures, the Coulomb efficiency and the hysteresis voltage of the individual cycles give an indication of loss processes within the cells. For example, cells with low efficiencies and high hysteresis voltages are generally of lower quality than cells with high efficiencies and lower hysteresis voltages. The energetic efficiency in connection with the internal resistance also enables an assessment of the cells with regard to their energetic efficiency and the associated heat development of the cells. Nevertheless, the key figures, which can be determined directly from the measurement data, give only an initial indication of the quality of the cells and serve above all to identify outliers.

Therefore, differential voltage and capacity analysis is currently being tested as a more promising approach. With these evaluation methods, the gradients of the voltage and capacitance curves of cycles with low current intensities (C/10 or lower) are set in relation to each other. Characteristic courses are obtained whose local minima or maxima allow to drawn conclusions about areas in which phase equilibria are present and areas in which phase transitions take place. These methods are used for the analysis of processes in full cells when no reference electrode is available.

Project Description

Project Name
DaLion 4.0

Project Duration
Januar 2019 – Dezember 2021

Project Partners
TU-BS (iPAT, IWF CH/KD, ifs, InES, IÖNC, elenia), FMP, Cooperion, ISRA, Manz, Bredex, GPS + div. assoz. Partner

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aufgrund eines Beschlusses des Deutschen Bundestages

Smart Modular Switchgear II

Construction and testing of DC-grids and DC-Switchgears for voltages up to 3 kV

Introduction

Besides the DC-transmission various applications of the DC-technology are currently developing. Worth particular mentioned are: server farms, industrial grids, transmission grids and building grids. The research project Smart Modular Switchgear II (SMS-II) includes the topics protection technology, switchgears and dynamic grid behavior. A demonstration grid with different voltage levels is set up for the examinations. This allows the reproduction of various grid topologies. The described setup is used to test the decoloped protection system and the switchgears. Furthermore, the reaction of the grid dynamics on the switching behavior and error detection is identified. The demonstration grid is to be understood as bidirectional transfer function between the protection algorithm and the switchgear.

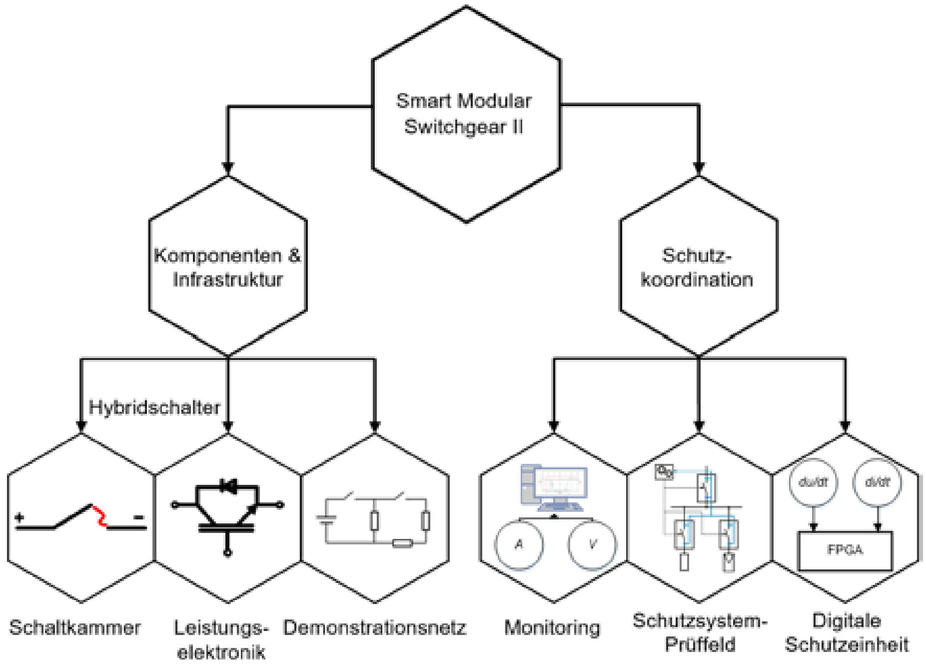
Classification into the research of the institute

The project SMS-II builds on the previous project SMS-I. In the course of SMS-I the basis for an automated error detection was laid. The used voltage was 24 V. The project ended with the adjustment of the protection system to a voltage of 380 V. The aim of the follow up project SMS-II is to adjust the obtained findings on the protection system from 380 V to 1000 V and 3000 V. Moreover, this project links the protection technology to two other core competences of the elenia, i.e. the switchgear technology and energy transmission grids. In the whole project group other institutes and companies analyze the electromagnetic compatibility (EMC), the power electronics and the overvoltage protection.

In the following the focal points of the project, i.e. protection technology, demonstration grid and switchgear technology will be discussed.

Protection System

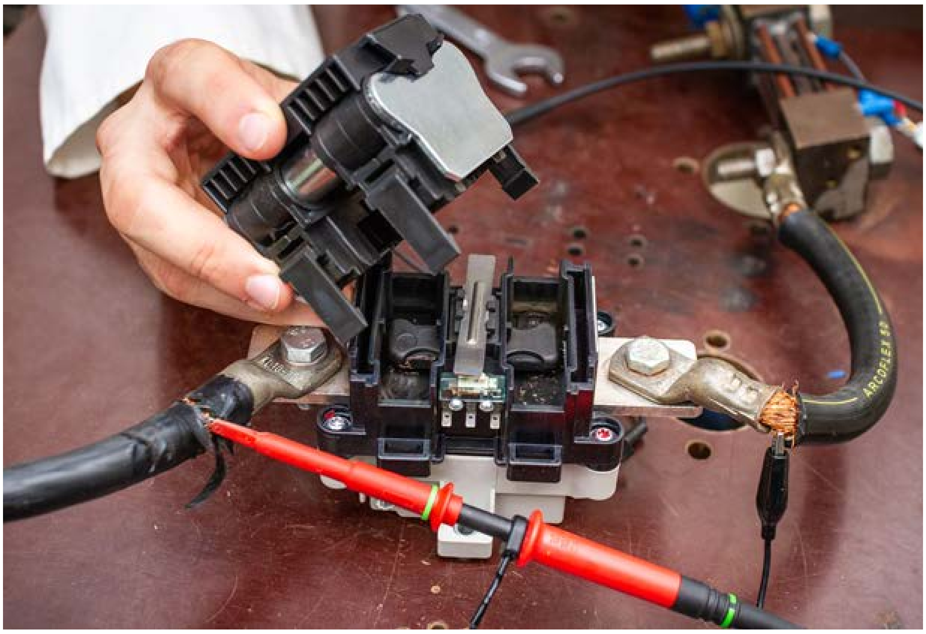
In the previous project SMS-I a modular protection concept for the localization, classification and selective switch-off of errors in DC-grids with a nominal voltage up to 380V was developed. The concept is based on a permanent monitoring of the system state, using current and voltage sensors, which are installed on each switchgear present in the grid. The data collected by the sensors is directly passed to a central protection unit, where a FPGA is used to calculate derived quantities, which are necessary for the



Project overview SMS II

execution of the protection algorithm.

In the project SMS-II the protection concept will be further developed, so that it can be used in 1 kV grids and later on also in 3 kV grids. In addition to the optimization of the used LabVIEW-algorithm, this also includes extensions to the program code, which allow for an allocation of the system monitoring to multiple protection units and thus, if necessary, for the monitoring of larger grids or grids with a wider spatial distribution. In the first year of the project an experimental set up, based on 24 V is realized to simplify this process. Different grid topologies can here be generated quickly and easily by variating the configuration at a terminal strip. In addition MOSFETs are used as switchgears, because they allow for an accurate time analysis of the relevant processes due to their fast switching times.



Switch-off investigations of DC switchgears

Demonstration grid

One of the goals of the project SMS-II is to reproduce the above mentioned DC grid structures with help of the demonstration grid. All planning tasks for this have been completed in the first year of the project. Currently, the demonstration grid for voltages up to 1 kV is in the stage of development. The 3D drawings are completed and soon the order of the material will be placed. The data of the demonstration grid is given in the table below.

The grid components are permanently installed on the test apparatus. The grid structure can be adjusted by variable plug connectors. The size of the grid can be extended with little effort in the future. The demonstration grid can be connected with another grid via a cross coupling. A special feature of the grid is the electronic load, which can be freely parameterized with software and therefore be used as both load and source.

Characteristics of the demonstrator grid

Parameter	Value
Voltage levels	380 V, 1000 V, 3000 V
Power	40 kW
Network topology	variable
Switchgear topology	hybrid
Load flow	bidirectional
Load	Ohmic, inductive, capacitive, electronic
Connection to other network unit	Possible

At the end of the year the construction of the test apparatus was completed. In the new year the electrical commissioning starts. There are many interesting tasks for students, who look for a student assistant job or a Bachelor/Master thesis with a high experimental share.

Switchgears

Building on the results of previous examinations in the project SMS-II hybrid switching devices are used. The protection unit needs for the secure interruption of the current path switchgears, which have a quick and almost constant switch-off-time. In this year a hybrid switching device has already been tested for voltages up to 1000 V. The volume resistance, the actuator delay and the Shutdown behavior were measured. The requirement of the protection unit for short tripping times is particularly challenging. Intended are times that are far less than 10 ms, the measured times however are close to 10 ms. In the next year optimizations and further measurements will be made.

In the future a hybrid switching device for the voltage level of 3 kV will be developed. For this all components still have to be designed. To identify the requirements the results of the examination of the 1 kV grid are used. Many known as well as many yet unknown problems have to be solved in order to develop the described hybrid switching device. Students are welcome to work on these problems in the course of a student project.

Summary

Each component of the project, i.e. protection technology, demonstration grid and switchgears was looked at separately in the first year. In the following year the individual components will be progressively put together. Many interesting results are expected to see, which derive from the interactions of the different components.

Project Description

Project Name
Smart Modular Switchgear-II (SMS II)

Project Duration
Januar 2019 – Dezember 2022

Project Partners
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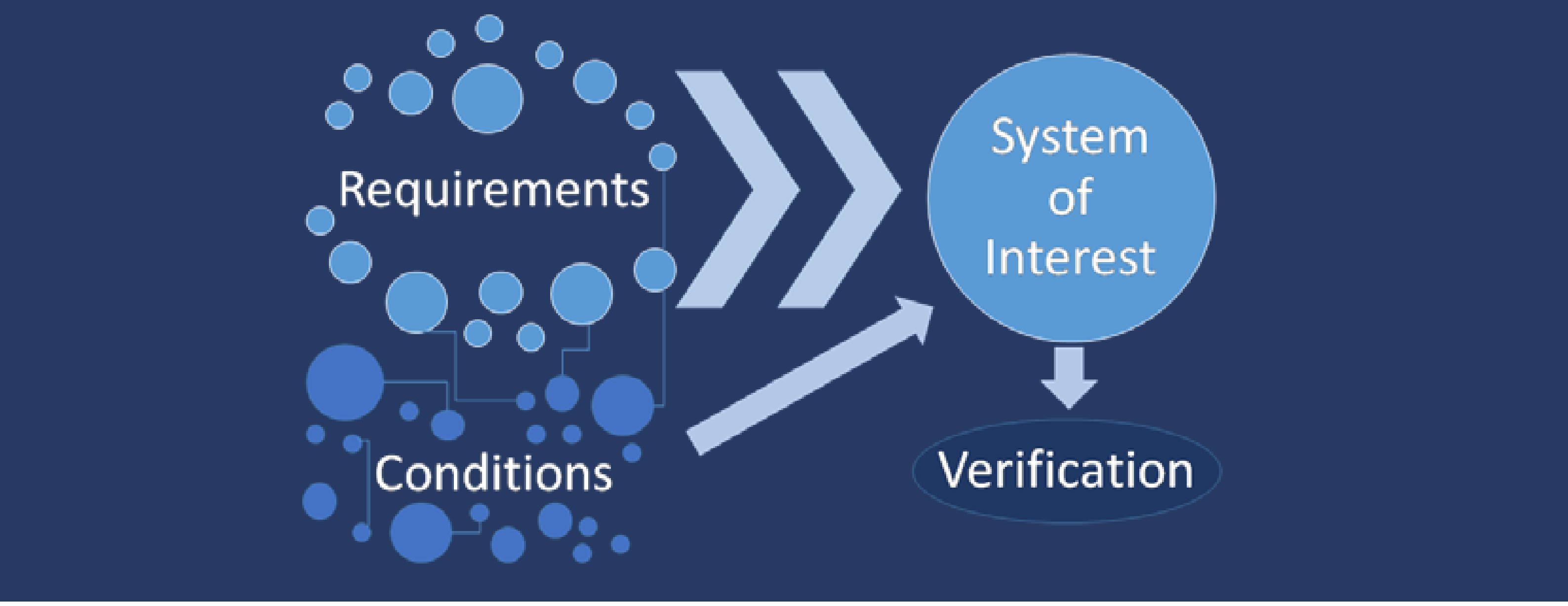


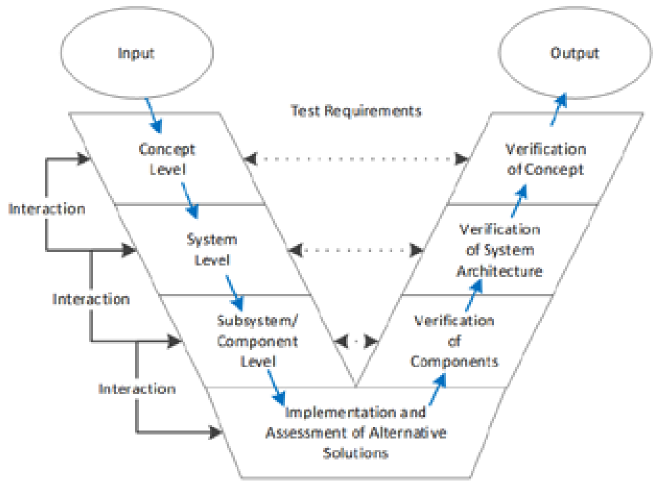
Systems Engineering

Development of HVDC Grid Connection Concepts Based on Systems Engineering

More and more offshore wind farms are being built far away from the coast. There are larger areas available and the wind blows both stronger and more constant compared to coastal regions. In the German North Sea in particular, the Wadden Sea nature reserve poses additional challenges. In order to transmit large quantities of energy over long distances, high-voltage direct current (HVDC) transmission is often used instead of high-voltage alternating current (HVAC) transmission. In addition to economic aspects, the HVDC technology also makes it possible to control the AC grid of the wind farm with the help of so-called Voltage Source Converter (VSC). IH-VDC is not only utilized for the connection of offshore wind farms, but also to connect different countries or asynchronous grids. The Line Commutated Converter (LCC) can also be used here. There are already initial projects in which the auxiliary power of oil and gas platforms are to be covered by an HVDC connection.

Although the inverters are very expensive, the HVDC technology offers many advantages. For this reason, many HVDC connections have been put into operation in recent years. HVDC connections not only stabilize the high-voltage networks, but also the entire electrical network and thus improve supply reliability, e.g. in microgrids. The methodology of Systems Engineering (SE) enables the systematic development of power transmission systems. This methodology is described in more detail in the following section "Definition of Systems Engineering". In order to increase reliability and reduce costs in the long term, systems engineering studies concepts at different levels of detail (see p. 50).

In order to develop innovative network topologies, it is important to identify and define all the requirements for such a system at an early stage. The review of the technical requirements are then checked with simulations.

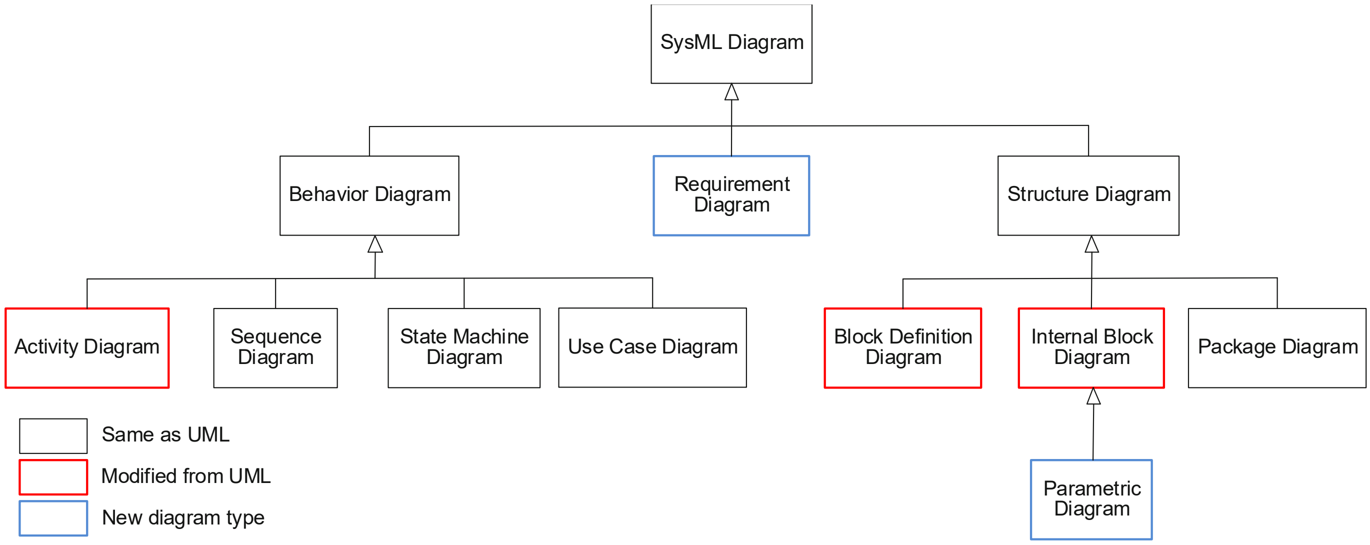


V-Model of Systems Engineering

Definition of Systems Engineering

SE is an approach to the holistic development and definition of complex systems. The goal is to meet the requirements of all stakeholders involved. In addition, the interdisciplinary cooperation of different specialist groups in all phases of a system life cycle is of high relevance. Increased complexity of systems and continuous changes increase the risk of developing new systems. Reducing this risk is one of the main tasks of SE. A recursive and iterative approach with a constant comparison of the requirements with the status in the development process plays an important role.

The origins of SE, as described above, date from the beginning to the middle of the 20th century. The increasing automation of technical systems, especially in the military sector, led to an increase in the system complexity and the risk of development errors. An interdisciplinary joint development process became more and more important. The subsequent digitalisation and networking, which continues to this day, further increased the complexity and thus strengthened the significance of system



SysML Diagram Taxonomy

thinking as described in SE for the development of new systems and the further development of existing systems. This importance is also reflected in the fact that SE is now practiced in many different application areas in different ways. In addition to the traditionally important aerospace and defence industries, SE is also used in areas such as consumer electronics, the automotive sector, information technology, the public sector and the energy sector.

Possible uses of SysML

SysML is a language mainly used in Model based Systems Engineering (MBSE). Like other languages, SysML has grammatical rules and vocabulary. SysML is a part of the unified modeling language (UML) and helps system engineers to communicate about a system design. UML also forms the basis for some diagram types. Others, such as the requirements diagram, are new types that are only associated with SysML. The figure above is based on the Object Management Group (OMG) SysML standard and gives an overview of the different diagram types.

Systems Engineering Processes

Within each phase of a Systems Lifecycle Model (SLM), different processes and activities can be performed and applied to move from defined inputs to defined outputs of the phase. The international standard ISO/IEC/IEEE 15288:2015 divides 30 possible processes into 4 categories:

- Technical Processes
- Technical Management Processes
- Compliance Processes
- Organizational, Project Supporting Processes

The 14 technical processes in the standard serve the definition and analysis of requirements and, based on this, the development of systems, products and services.

In the later phases of the life cycle, they serve the technical implementation of the production, the assurance of technically correct performance through to support in the disposal or decommissioning of the system. Each process is defined by specific inputs, activities and outputs. In addition, certain framework conditions (controls) must be taken into account when processes are carried out and prerequisites apply that must be fulfilled for the implementation of processes (enablers).

Inputs can, for example, be data and materials, i.e. outputs, of a preceding process. Inputs can also come from external sources. Examples include information on requirements, measurement data, test reports, materials needed to create the output, or parts of services.

Outputs can also be inputs to a subsequent process. However, outputs can either go directly into another process or go through a process several times. Controls represent the framework for process execution. This can, for example, be legally defined by laws and contracts.

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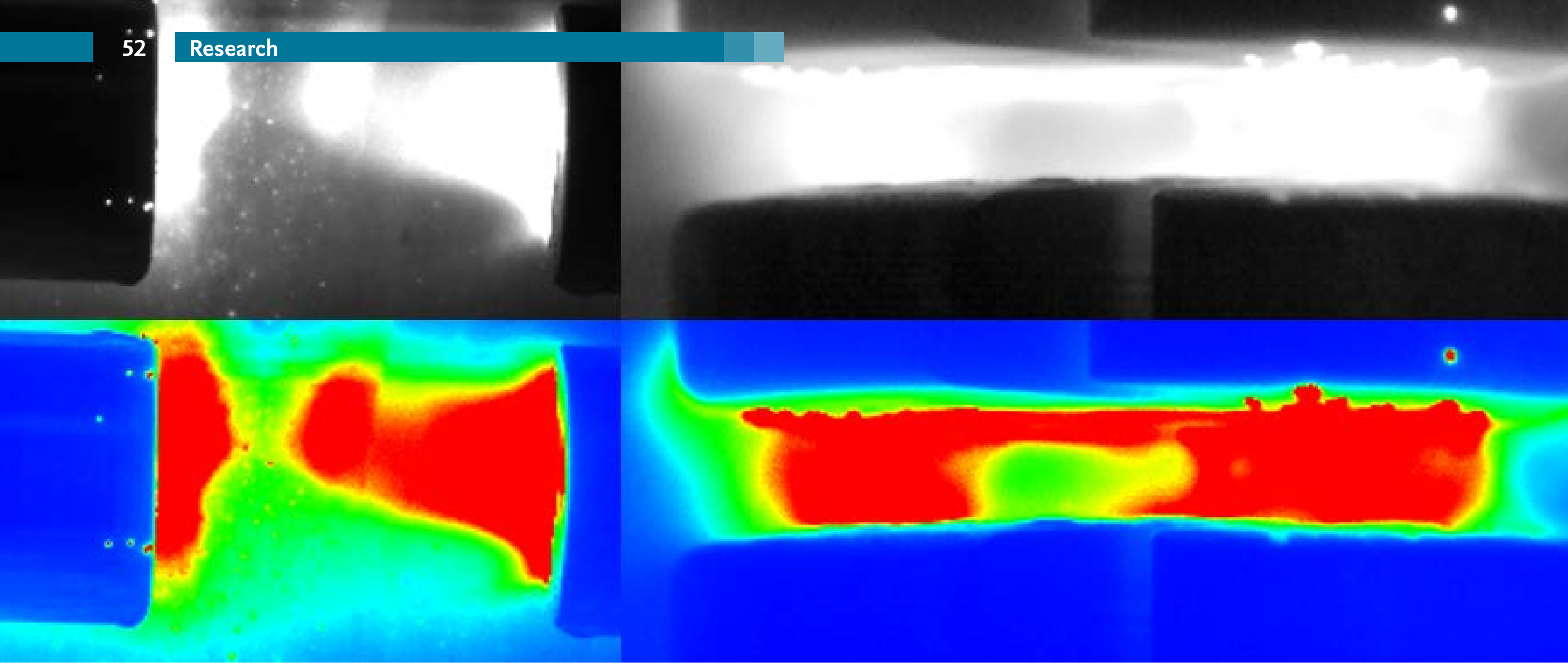


Movement of vacuum arcs

Determination of local current density in vacuum circuit breakers with high-speed camera and Hall sensors

The energy turnaround is changing the switching tasks in the medium and high-voltage distribution networks. Decentralised generators, capacitive and inductive supply of power, storage and loads must be automatically switched on and off in the future. The increase in required switching capacity, automation and thus switching frequency require an increased use of circuit-breakers. The vacuum switching principle is excellently suited for these new tasks. The development goals are therefore aimed at improving the switching performance with a long service life and compact design, also with a view to the replacement efforts of SF6 switches in the high-voltage level due to the high greenhouse gas potential of SF6. This makes the switching behaviour in vacuum for higher voltages and thus for larger switching distances the current object of investigation.

Switchgear must be able to switch on circuits, conduct operating and residual currents and switch off. Preignition arcing occurs during switch-on, especially with capacitive loads that contribute to contact erosion. When switching off, a conductive metal vapour plasma is created between the contact pieces during contact opening, which conducts the current to the next current zero crossing. In the current zero-crossing, the plasma loses its conductivity and the metal vapour density decreases due to diffusion and deposition. The recurring voltage between the now separated circuits should not lead to a new ionization of the remaining metal vapour plasma in the open switching path. This successfully completes the switch-off process and creates a galvanic isolation.

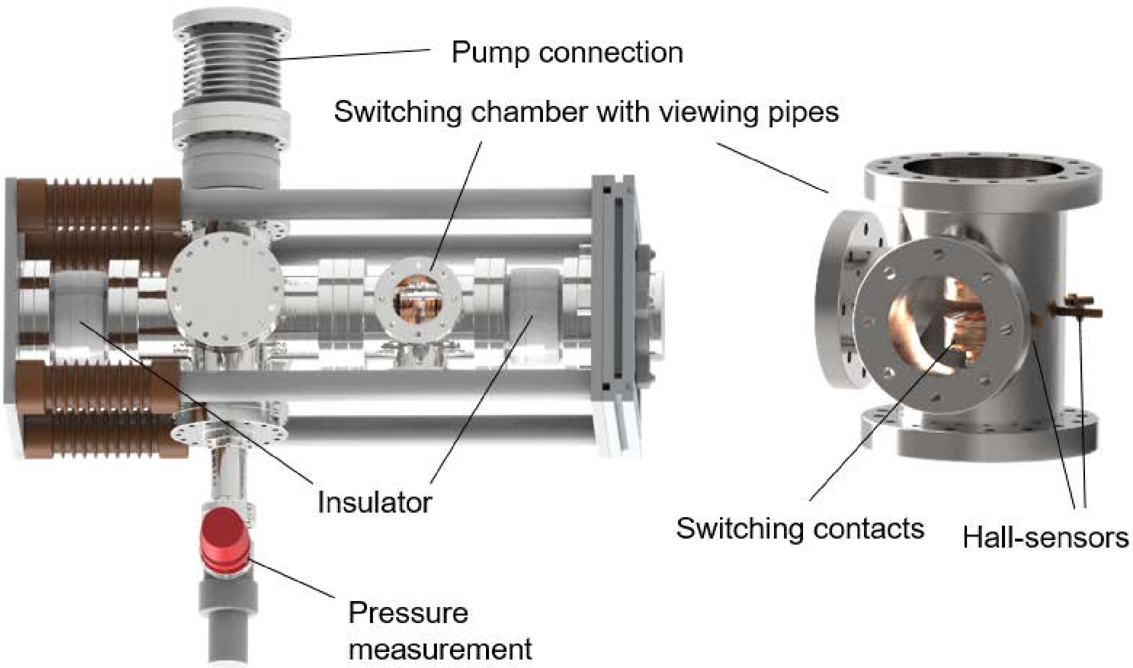
Optical radiation measurements on metal vapor plasmas in vacuum

High-voltage vacuum test vessels made of stainless steel with sight glasses and ceramic insulators enable the observation of the metal vapour plasma and the focal spots on the contact pieces during the switching process. The recipient has to be evacuated to a pressure of less than 10-4 Pa. However, the test vessel differs from a commercial vacuum switching chamber with a condenser screen. This gives the metal vapour plasma a larger volume in the test vessel. In addition, the condensation screen must be removed so that the switching distance can be seen from the outside.

Through the sight glasses, modern high-speed camera systems record the processes with a refresh rate of up to 0.5 Mfps (million frames per second). The high frame rates are necessary because the ions from the metal vapor plasma move at speeds of several km/s (or mm/µs). The contracted arc itself moves at several 100 m/s across the contact surface. In addition, the arc position changes spontaneously within some 10 µs, i.e. the current flow commutates to a new point on the contact surface. The observation of the light arc running movements or the jumps across the contact surface (Ø ≈ 100 mm) requires a corresponding pixel resolution. According to our own experience, the minimum requirements for the sensors are a resolution of 500 x 120 pixels in the high-speed range in order to guarantee a resolution of 0.4 mm per pixel. With regard to arc observation during contact opening and a stroke (contact gap) of 10 mm, a height-re resolution is desirable. The simultaneous detection of the intensively radiating focal spots and the weakly radiating but conductive areas of the metal vapor plasma requires a high pixel depth of the sensors.

Research project

The main goal is to determine the current distribution in the contact gap as well as the current density distributions in the plasma column from the magnetic flux density profiles in cooperation with the TU Darmstadt and the optical radiation intensity profiles. This means the coupling and further development of magnetic and optical measurement methods. The simultaneous measurement of magnetic field and optical radiation thus makes it possible to clarify the question of where exactly the current flows, in the core or on the envelope of the plasma column. From the radiation measurements, state-



Construction of a test switch for combined optical and magnetic measurement

ments about charge carrier densities and electron mobility in the outer shell are possible, since the radiation propagates diffusely within the plasma column as in a nebula (optically dense plasma). However, the magnetic field results from the total current flow. By comparison with the distributed magnetic field measurement, the current density distribution in the plasma column can be deduced. This requires the creation of a joint experimental setup, the respective further development of the measurement methods and the adaptation of the evaluation methods in order to enable the combination of both methods. Only then can the desired information on the metal vapour generation, the migration movements of the base points also be determined in real, commercial vacuum switching chambers and the coupling of the plasma column (arc base points).

State of research

At present, the modified switching chamber for the application of magnetic and optical measuring methods is under construction. The construction can be seen in the figure. The design offers a feasible compromise between the possibility of observation and removal of the Hall sensors for magnetic field measurement. First comparison measurements and associated simulation will be started in the following year.

Project Description

Project Name
Magneto-Optische Lichbogenanalyse

Project Duration
Januar 2019 – Dezember 2021

Project Partners
TU Darmstadt
Institut für Elektrische Energiesysteme

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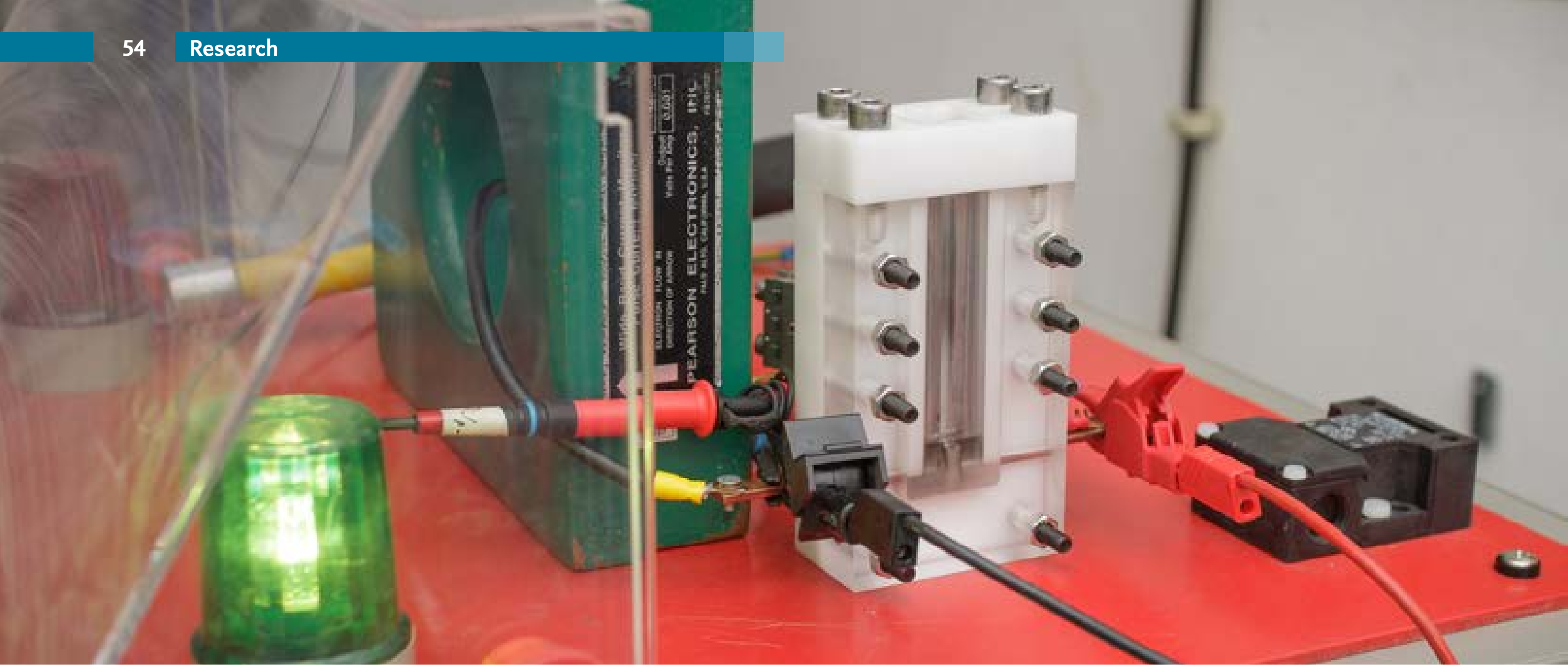
DFG Deutsche Forschungsgemeinschaft



Lightning Protection Devices

Investigation of the behaviour of spark gaps under surge current load using imaging methods

Lightning protection devices, type 1 arresters, are required in the distribution networks to ensure fail-safe operation. With these devices, any lightning current that occurs is diverted directly to the earth connection so that the subsequent electrical systems are protected. The surge current generator at laboratory in the elenia is used for the purpose of investigating the conductance during a surge current. The tests are standardized according to international standards. An 8/20 μs surge current form is used.
Spark gaps are used as type 1 arresters.

Schematische Grundprozesse während des Ableitvorgangs

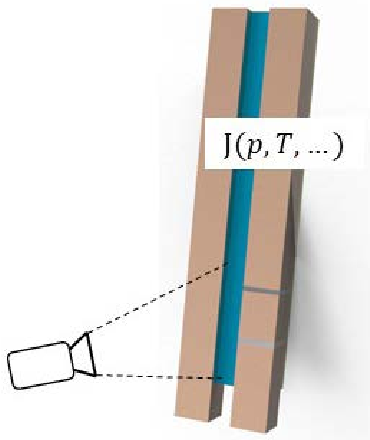
Between the two contacts an arc plasma is ignited, which forms the low-impedance path to earth potential. During this process the following functions are provided:
First, a path with a high conductivity is provided so that the surge current flows almost completely to earth, ensuring the protective function for the back-end area. In the subsequent area, the conductivity of the switching path must be reduced by many orders of magnitude in order to effectively suppress a follow current. The follow current is driven by the connected low-voltage grid, which interacts with the short-circuit in the spark gap.

The difficulty lies in covering these opposing requirements. The behaviour of the spark gap depends on the plasma properties (pressure, electrical conductivity and temperature) and the geometry of the plasma chamber. These parameters are used to improve the protective function and the development process.

Experimental model

At the institute we have developed various model spark gaps especially for the investigations of the plasma propagation behaviour. For the high speed camera based investigation of the current density special electrode configuration was used. Figure 2 shows the model spark gap.

The plasma is ignited in the lower area between the electrodes. Through a connection at the upper end of the plasma chamber, a pressure equalization with the environment takes place. The cathode electrode (in the figure on the right) is divided into three segments, each of is connected to a current shunt. This allows us to measure the current for individual areas.



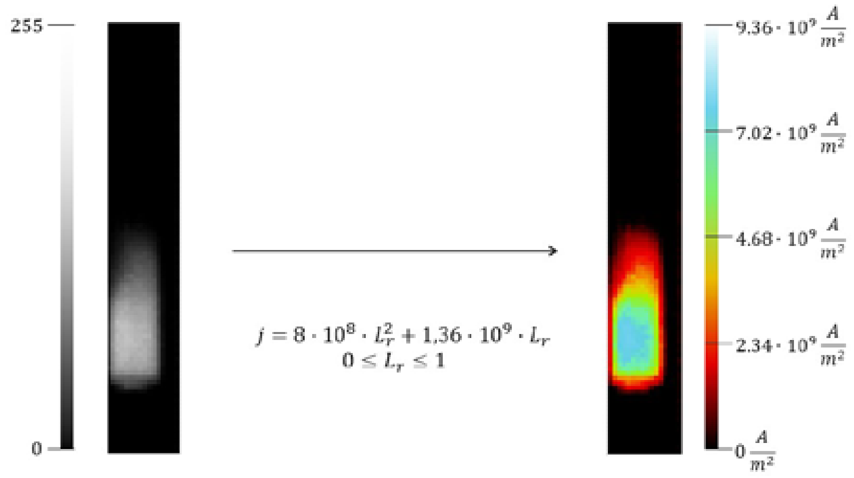
Model spark gap with track arrangement and separated electrode

The current density depends on the electrical conductivity, the plasma pressure and the temperature of the plasma. The aim of the investigations is to create a simplified model for the current density during the derivation process.

Modelling

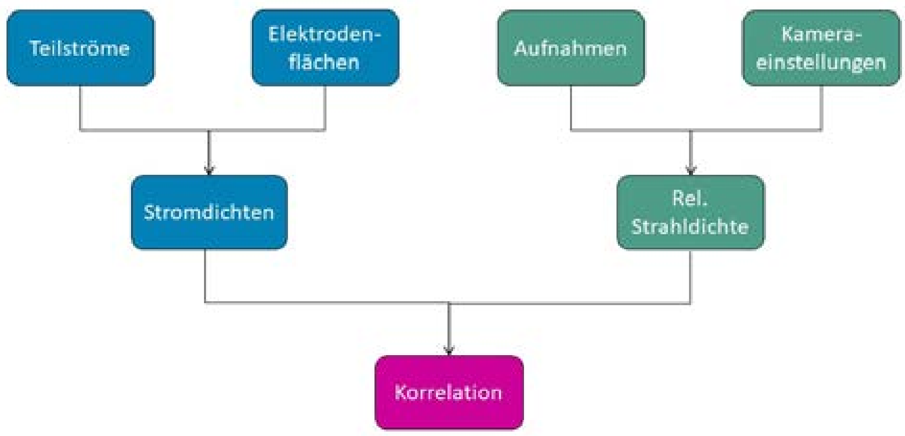
The modelling can be seen in Figure 3. With the construction of the model spark gap using the partial cathodes, it is possible to measure partial currents. Current densities can be determined by knowing the plasma-electrode surface and assuming that the plasma homogeneously fills the inter-electrode space. The right-hand side of Figure 3 shows the combination of the taken images with the camera settings (integration time, aperture, neutral density filter). This results in the radiance, which is normalized to the maximum achievable intensity of the camera. As a result, these two quantities, the current density and the relative radiance, are correlated by an empirical model.

Results



Application of the quadratic function for the determination of local current densities

The result of the experimentally generated model is shown in Figure 4. On the left side you can see a picture of the high speed camera. This allows a quantization of the plasma brightness with 8 bits (values from 0 - 255). The amplitude of the surge current is 20 kA. The recorded intensity is correlated during the exposure time with the temporal average value of the current density. The correlation, which is due to a quadratic regression of the measurement data, is shown in the middle. The validity range of the model for surge currents is between 10 and 20 kA. In order to obtain a current density distribution from the intensity distribution on the left, the developed model is used. Each individual pixel is converted into a current density with the transfer function. The result is the image on the right. The scale shows a possible current density distribution in the range between 0 A/m^2 and 10^10 A/m^2 . It can be seen, that most of current flows through the lower part of the electrode. This kind of model is often sufficient to obtain a rough estimate for the description of the plasma state.



Schematic overview of the correlation of electrical and radiation physical properties

In further contributions the boundaries of the method has to be investigated to give a statement of the applicability under different circumstances. Furthermore, an integration into an automated measurement data evaluation is useful to make the applicability more efficient.

Source

Kopp, T., Peters, E., Kurrat, M.: *Estimation of Current Density Using High-Speed-Camera Recordings in a Model Spark Gap during Surge Currents*, Plasma Physics and Technology, Symposium on Physics of Switching Arc, September 2019

Project Description

Project Name
Lichtbogentechnologie

Project Duration
Juli 2018 - Juni 2021

Project Partners
Phoenix Contact

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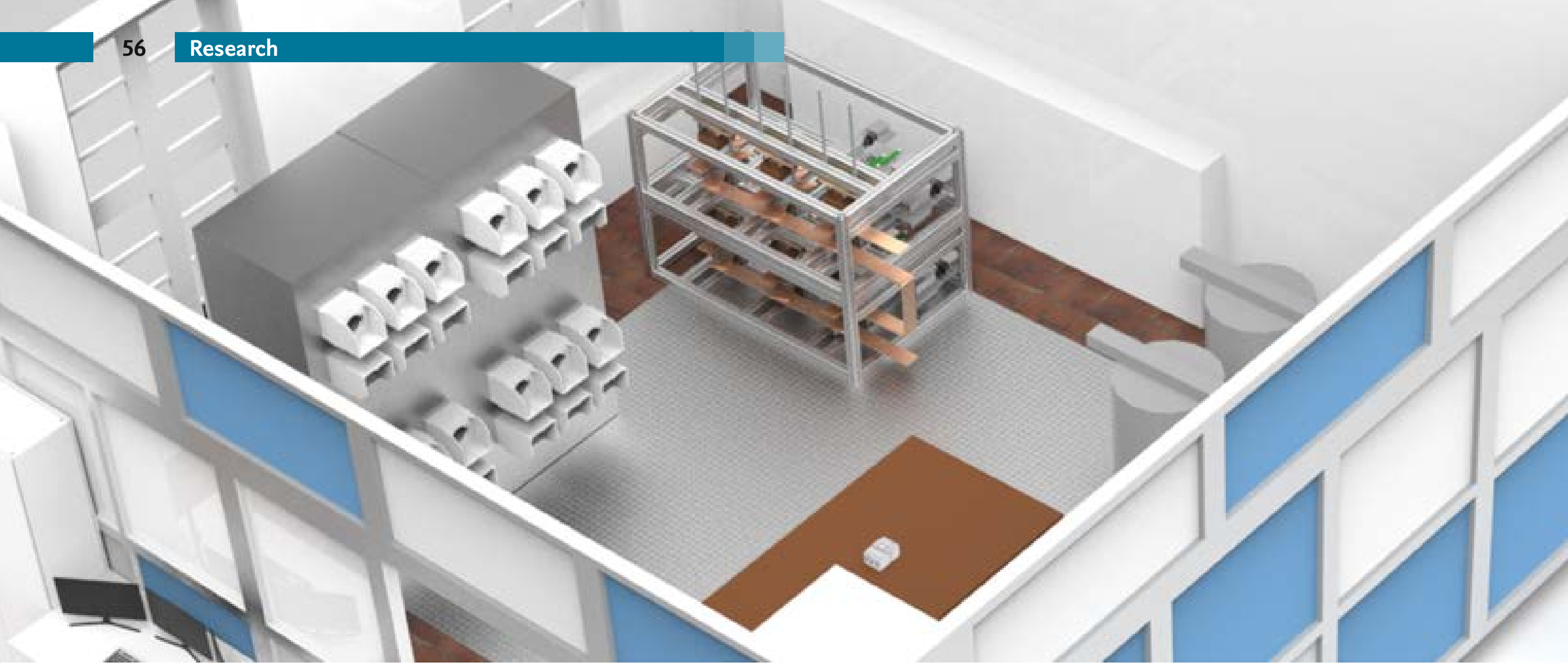


Universal Power Switch

New construction of a high-performance direct current test bay in the course of the UPS funding project

The proportion of direct current networks is increasing more and more. Areas of application include wiring systems in electric vehicles, ships and aircraft. Also due to the energy transition, a further increase can be expected due to renewable energies such as photovoltaic systems, stationary and mobile battery storage, as well as the grid connection of offshore wind farms. In order to control the load flows in these grid structures safely, suitable circuit breakers are indispensable. The combination of state-of-the-art power semiconductors and mechanical protective switchgears in a hybrid switchgear is a promising future-oriented solution for the development of suitable, cost-effective circuit breakers. Hybrid circuit breakers combine the advantages of mechanical switchgears and power semiconductors in a single device and can be used for DC and AC applications. In a joint project between industry and science, such an optimized circuit breaker is being developed in UPS.

The new high-performance DC test bay

In the course of this project, a new test laboratory for AC and DC high-current testing is being built at elenia. The design of the test field started at the beginning of the project. Different possibilities for the generation of a test DC voltage had been considered. These were further developed and then discussed with the manufacturers: ABB, Ampegon and Astrol.

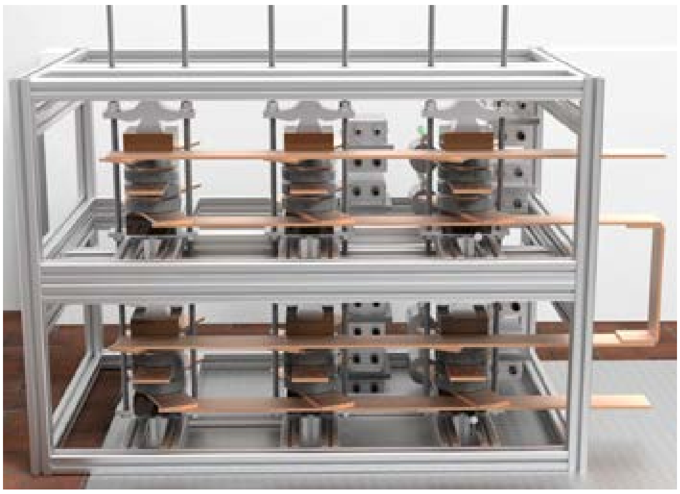
The current plans provide for a maximum test voltage of 12 kV DC and a maximum test current of 30 kA. Due to the high performance required, the grid connection is planned in close cooperation with the responsible offices of the Technical University of Braunschweig and the local grid operator BS|NETZ.

Power technology

The heart of the new laboratory is a controlled B12 rectifier. No phase control of the rectifier is required for the necessary test parameters. The basic behaviour of the B12 bridge was verified in SPICE simulations. The rectifier is supplied by two transformers installed in the basement of the institute. The output voltage of the two transformers, which is shifted by 30°, results in a particularly low residual ripple of the DC voltage. The own test field including rectifier, measuring and testing technology is erected in the high-voltage hall of the institute. The construction projects within the scope of the UPS project are planned with the building management of the Technical University of Braunschweig.

Protective technology

During the experiments in the laboratory, transient processes may occur that can be coupled into control systems. In order to rule out possible interference, safety-relevant control circuits are implemented in contactor technology. Compared to electronic solutions, this is less susceptible to interference due to significantly higher control voltage levels and is therefore more reliable for this safety-relevant area of application. The protective technology takes over the control and protection of the primary technology, which ensures that faulty switching can be reliably avoided by corresponding mutual interlocks. In



Structure of the B12 rectifier in the test bay addition, the protection of persons is ensured by appropriate door switches, which must automatically and instantly disconnect the power section of the test facility from the power supply when actuated. A programmable logic controller is used to control the secondary technology. Since it will be located far outside the test chamber, the device will not be influenced or disturbed by transient processes.

Measuring and control technology

The test sequence is specified with a sequencer from Amotronics. The sequencer has 8 digital inputs, 16 digital outputs and 8 analog outputs, it is fully real-time capable and can control the outputs with an accuracy of up to 50 ns. For reasons of noise immunity, all control signals are transmitted to the individual switches via fiber optic cables. The Amotronics sequencer was put into operation by a research assistant within the TU laboratories. The software was tested for its suitability and the device was integrated into the TU network. The Se-quenzer meets the specified requirements and can be used for the upcoming tests.
The installation and calibration of the new measurement technology will be carried out in close cooperation with PTB.

Grid connection

Since it is impossible to obtain the power required to operate the test field from the university's 6 kV grid, the planning envisages a direct connection to the 20 kV city grid via a newly installed switchgear in the elenia premises. The evaluation of the suitability of the network structure was carried out in close consultation with the network operator BS|NETZ. Simulation campaigns in PSCAD have been carried out for this purpose. This made it possible to determine the voltage drop in the 20 kV level with transient power consumption by the test field. Different network points, load cases and connection scenarios were considered. The simulation results were made available to BS|NETZ for planning the connection. Scenarios with voltage drops of less than 10% at maximum power consumption have been required by BS|NETZ. BS|NETZ has considered network perturbations as well as thermal and magnetic loads on equipment in its network infrastructure. For this purpose, corresponding network calculations were done out both by BS|NETZ and by the TU. The calculations independently come to the conclusion that it is possible to provide high surge test currents from the medium voltage network of the BS|NETZ under certain circuit conditions within the scope of permissible network perturbations. The thermal and magnetic loads that occur with premature aging of the affected equipment are estimated to be low. If, however, the equipment is affected after all, solutions for a sustainable use of equipment and the associated reliable network operation of the BS|NETZ must be found.

The connection contract for the 20kV supply is available for signature in the presidium of the TU Braunschweig, so that planning security for the execution of the construction project could be established. The supply via a 20kV line is now no longer an obstacle. According to BS|Netz, the work could begin soon and will only take a few months, depending on the order situation.

Project Description

Project Name

Universal Power Switch

Project Duration

Juli 2016 – Juni 2020

Project Partners

E-T-A,
Rockwell Automation,
PTB,
TU Braunschweig

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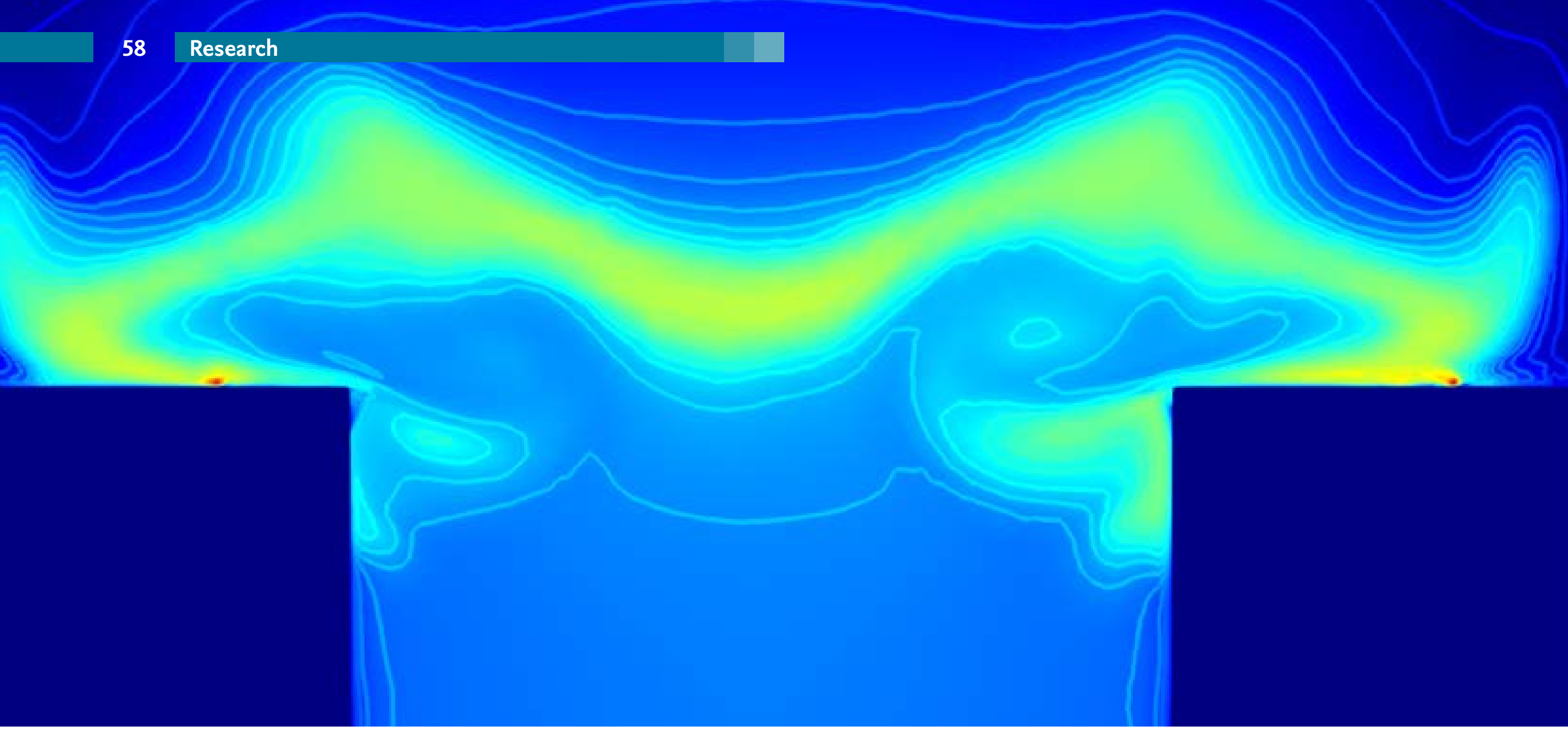


Research field plasmas

Computational models for thermal plasmas

Introduction

Computational models are essential for understanding and investigating the basic physical processes in plasmas. In general, computational models can be divided into black box models, qualitative physical models and more general physical models. The general physical models are well suited for the spatially and time-resolved analysis of the behaviour of a plasma.

The general physical models can be divided into a single particle description and a description of the plasma as a liquid. Computational models describing the plasma as a fluid are used as a suitable approach for the plasmas considered in our investigation. The plasma is described as a single liquid in which the particles in the plasma have the same temperature. In order to understand the behaviour of plasmas in time and space, several physical domains can be included and coupled together in the computational models.

Plasmamodel

Starting from the Liouville theorem, the evolution of the distribution of species in a plasma is described by the generalized Boltzmann equation. This is a single particle description, which has a dependence of seven variables.

By building the moments of the Boltzmann equation, the equations of magnetohydrodynamics (MHD) can be obtained. The plasma is considered as a liquid.

The magnetohydrodynamic (MHD) equations include the equations for the description of the electric and magnetic fields and the description of the plasma as a fluid. This set of equations is solved in a coupled form.

The description of the plasma by means of MHD is based on conservation equations, which represent the conservation of mass, momentum and energy. The influences by the electric and magnetic fields are represented by the Maxwell equations. The set of equations is coupled. A weak coupling occurs via the electric flow field, the electric field strength and the magnetic flux density.

Radiation

The plasma is an extremely exciting natural phenomenon, as its visible luminous appearance also informs about its state. For a description in the computational model, further descriptive equations are added to the MHD equations. The radiation in the plasma is an important transport mechanism. The processes of emission, absorption and scattering by the plasma must be considered. In general this leads to the general radiation transport equation.

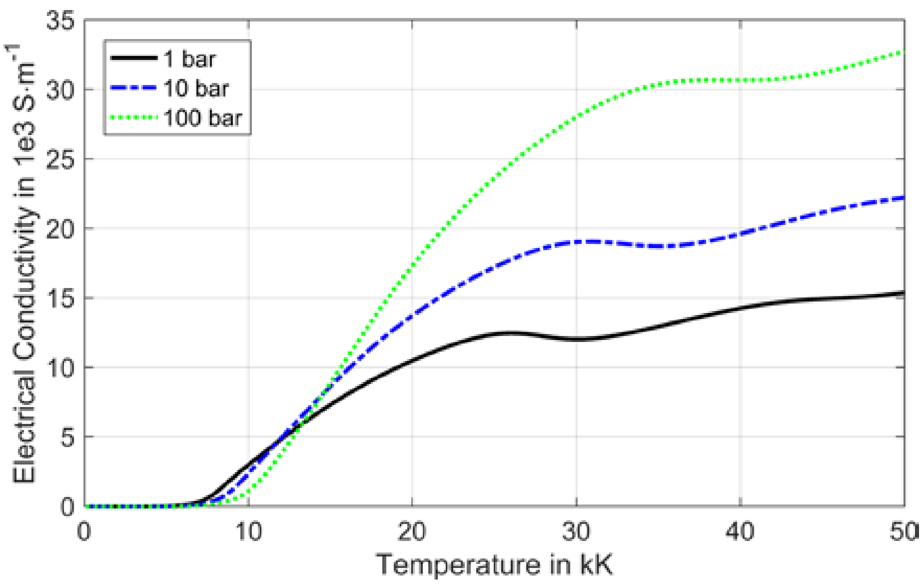
For a suitable numerical solution of the radiative transfer equation, established radiation models are used. The net emission coefficient or the PN approximation should be mentioned. For the radiation models the absorption coefficients of the plasma are used as input data. Depending on the numerical performance and the accuracy of the results, both models are used.

In the overall model, additional equations are considered for the radiation, which are solved together with the MHD model

Plasma properties

The computational model is completed by the physical properties of the plasma. These properties are temperature and pressure dependent quantities in the MHD equations. The properties can be divided into the thermodynamic properties and transport properties. The thermodynamic properties include enthalpy, specific heat capacity and density. The electrical conductivity, the thermal conductivity and the dynamic viscosity belong to the transport properties.

The properties are calculated in advance and stored for the physical properties in the MHD equations. For the calculation of the properties, two approaches have to be mentioned which are used. The calculation of the thermodynamic properties is typically carried out using the approach of minimizing the free enthalpy



Calculated electrical conductivity

according to Gibbs. The calculation of the transport properties is based on the Chapman-Enskog theory. Taking into account the gas mixture, temperature and pressure, the properties of the plasma are obtained. Figure 1 shows a schematic diagram of the calculation of plasma properties.

The properties are calculated for a wide temperature range of up to 50.000 K and a wide pressure range of up to 100 bar. Figure 2 shows an example of the calculated electrical conductivity in dependence of the temperature for three different pressures.

Plasma-Electrode interaction

An additional component in the modelling process is the interaction of the plasma with the environment. Basically this includes the electrodes. The properties of the electrodes, which are the heat capacity, electrical conductivity and thermal conductivity, are highly nonlinear and strongly depending on temperature. These properties are essential for the heat conduction processes in the electrodes and can be described using Fourier's law of heat conduction.

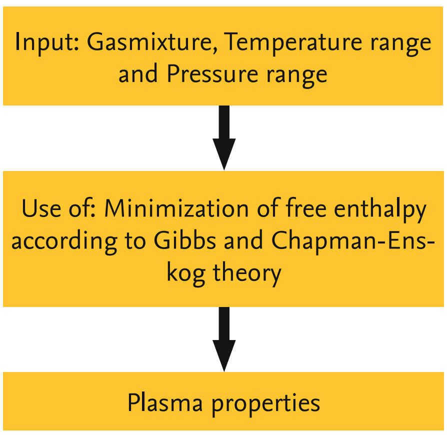


Fig. 1 Calculation of Plasma Properties

Solution of the computational model

The theoretical model is obtained from the individual descriptive equations and the properties for the plasma and the solid states. Taking into account suitable simplifications and assumptions, a solvable mathematical model is obtained from the theoretical model. In this case the mathematical model consists of a set of coupled differential equations which have to be solved in the computational domain. The solution of the descriptive equations is done by suitable numerical methods. The steps of the development of the computational model are shown in Figure 3.

For the numerical solution of the differential equations, the computational domain is divided into individual discrete elements. In the calculation domain the differential equations are discretized and a linear system of equations is generated.

Suitable numerical methods for the discretization include the finite element method or the finite volume method. Taking into account the boundary conditions, a linear system of equations is obtained from the set of differential equations. Using further iterative methods, the linear system of equations is then solved.

For the solution of the plasma equations either pressure-based or density-based methods are used. The pressure-based methods are used for incompressible fluids. The SIMPLE method, also known as Semi-Implicit Method for Pressure Linked Equations should be emphasized here. An iterative solution of the pressure and momentum equations is performed. The density-based methods are used for compressible fluids. Typically, the pressure is determined from the equations of state. In close cooperation with the Institute for Theoretical Physics a computational model has been developed. Further investigations deals with the improvement of the computational model.

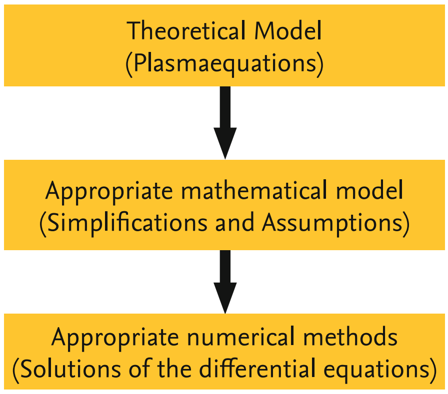


Fig. 3 Steps of the developement of the computational model

Project Description

Project Name
Research field plasmas

Project Duration
Januar 2018 - Dezember 2021

Project Partners
Phoenix-Contact

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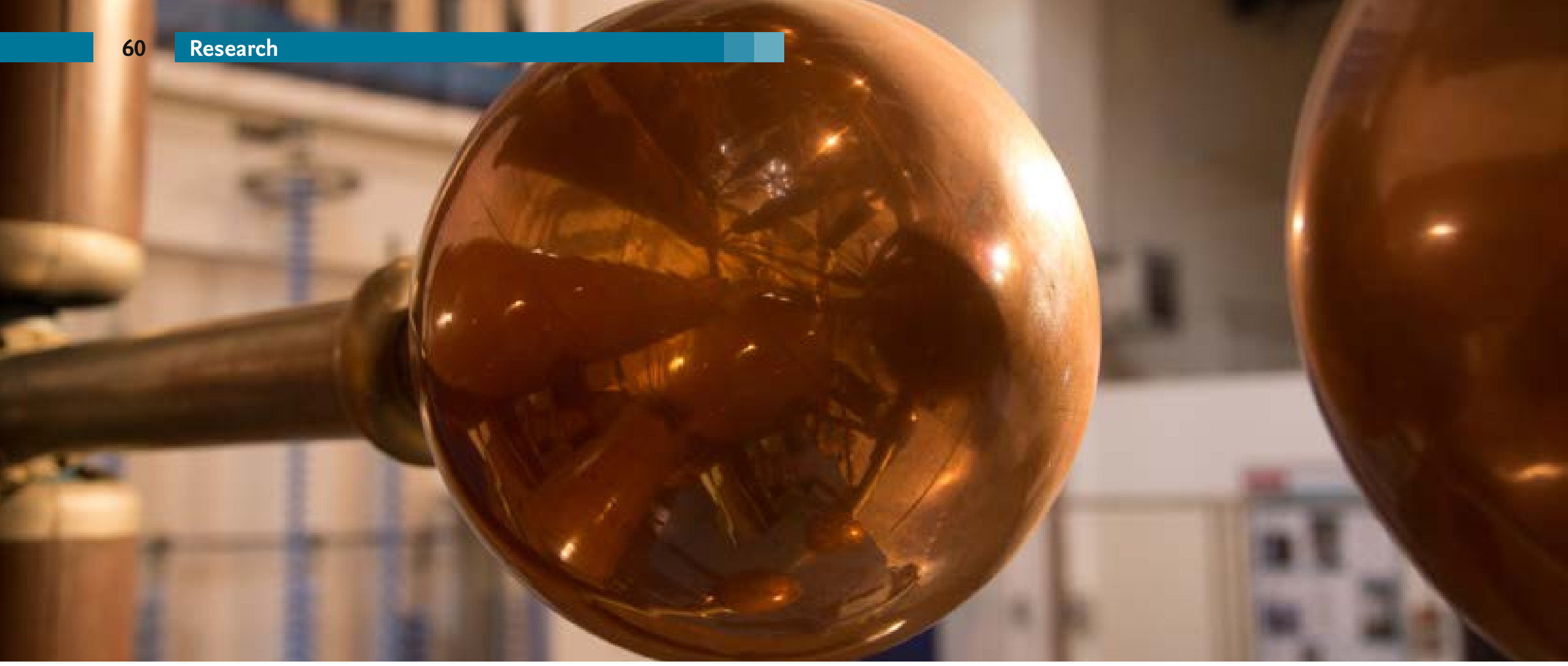


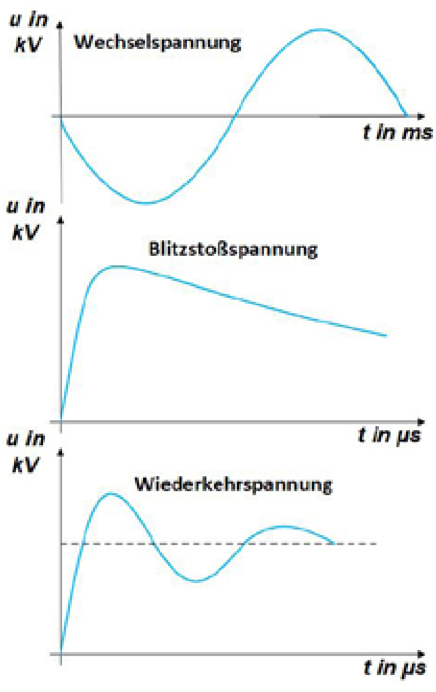
Dielectric strength

From alternating voltage to lightning impulse voltage to transient recovery voltage

This year, three voltage forms (middle figure) were of particular interest in elenia's high-voltage lab. This was again the alternating voltage in cryogenic nitrogen gas, as in the previous year, which was considered at high gas densities. The motivation for this is to support the design of the insulation system for superconductor applications, which can consist of liquid and/or gaseous nitrogen depending on the operating mode and condition. In addition, it also went into the reverse density range, into the high vacuum. There, investigations were carried out with lightning impulse voltages in the vacuum vessel. In order to characterize the dielectric strength, especially in vacuum switches, a test setup with transient recovery voltage was realized.

AC voltage in cryogenic nitrogen gas

A test arrangement in the cryogenic atmosphere confirmed that Paschen's law can be applied at temperatures around 80 K in cold nitrogen gas, insofar when it is related to the gas density. Based on this, further gas breakdown mechanisms and the provision of charge carriers, valid for room temperature, were investigated for their applicability in the cold gas. The Townsend and Streamer mechanisms were considered more closely as relevant processes of gas breakdown. The breakdown voltages of uniform and weakly non-uniform field arrangements were determined and the macroscopic electric field strength in the gas volume simulated. Based on this, the ionization coefficient could be derived and thus charge carrier densities could be evaluated. These carrier densities then make it possible to calculate whether a sufficient space charge is generated to lead to a field amplification of the order of magnitude of the macroscopic electric field. The calculation shows that the Townsend mechanism in cold gas at electrode gaps of 1-3 mm is the effective breakdown process at AC voltage. This consideration was also carried out under lightning impulse stress. There a transition area could be found where at 1 mm the Townsend mechanism still applies, but at 3 mm already the streamer mechanism is dominant.

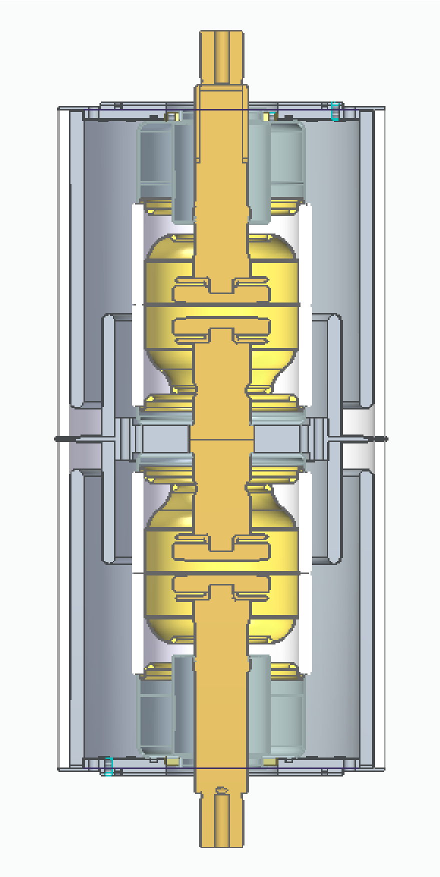


The three types of voltage

Lightning impulse voltages in vacuum

In addition to the high-voltage investigations in the field of alternating voltages, lightning impulse voltage investigations will be carried out more frequently this year. The motivation for this lies in the German Energiewende. In addition to the much-discussed renewable energies and the intelligent power grid, the requirements placed on components in the power grid are also changing. For example, the use of renewable energies requires considerably more switching cycles in the grid and a correspondingly higher load on the components. At the same time, environmentally friendly switching methods are being considered. With its outstanding properties, the vacuum circuit-breaker is an outstanding solution for applications in the medium-voltage network. Approaches to also use this as an alternative to the sulphur hexafluoride switch in the high-voltage grid are currently being investigated at elenia. In the high-voltage lab (right), experiments are being carried out on the dielectric behavior of double vacuum interruptions. Many areas of this topic were already investigated in the 1980s and 1990s, so the dielectric strength of double chambers is largely known. The influence of components on flying po-

tentials was also addressed in some papers and investigated in combination with control condensers. A research gap exists in approaches for the capacitive control of these flying potentials. The elenia has found a new solution for this and is investigating it in detail in several final papers in our high-voltage lab.
In a first master thesis, an additional external shielding arrangement was developed which surrounds the double cham-



Vacuum switch with a double-break

ber (Figure 3). Vacuum condensers are used to control the flying potentials, i.e. the center potential and the potentials of the steam shields of the double arrangement. Since the resulting capacitance is in the 50 pF range and thus relatively low, a shielding was developed at the same time which reduces the external interference. This means that all flying potentials can be reliably adjusted when subjected to lightning impulse voltages.
In a second master thesis, the developed shielding arrangement was installed in a vacuum receiver and the dielectric strength of the system was determined using the classical up- and down method. In order to ensure that the resulting X-ray emissions are harmless, lightning impulse voltages are used in this work. Furthermore, a cooperation with PTB Braunschweig exists at this point, which with its expertise makes it possible to record and evaluate the X-ray emissions during the lightning impulse voltage application in the μs area.

There is a publication on this topic within the framework of ISDEIV 2018 in Greifswald and another one is planned for the upcoming ISDEIV in Padova / Italy.

Transient recovery voltage in vacuum
Since the beginning of the year, a new form of voltage has complemented the high-voltage technology research area at elenia. The transient recovery voltage (TRV) is a typical form of voltage that is generated when a circuit-breaker opens. The characteristic shape is characterized by a fast oscillating curve (several kHz) and a high amplitude of up to 150 kV (in the medium-voltage network). In a master thesis, a high voltage circuit was designed and characterized by no-load and short-circuit tests. This work was used to prepare the way for the construction of a high voltage circuit for the generation of the TRV.

The opening process of a circuit-breaker in the grid is often triggered by a grid fault. In the event of a fault, the circuit-breaker is only stressed by a high short-circuit current and subsequent return voltage. A synthetic test circuit is used at elenia to investigate the switching characteristics of vacuum switches in the high-voltage level. The test circuit consists of a high-current circuit which has been an integral part of the synthetic power test field for several years. The high current circuit generates a short-circuit current of up to 63 kA. The construction of a high voltage circuit started this year. It will enable a transient recovery voltage of up to 150 kV at frequencies of 5 to 10 kHz.

In addition to dielectric strength tests using lightning impulse voltages, it will also be possible to use the TRV in the future. For this purpose, the TRV is used on a double-break switching chamber in a vacuum. The double-break switch is also used as a single-break switching path. Here, a high contact distance of up to 30 mm is realized to investigate the breakdown mechanism and the re-strengthening for long arcs, thus ensuring the dielectric strength of the vacuum switch for the high voltage levels.

With the investigations presented using the three voltage forms, elenia's High Voltage Technology research department is up to date in the field of research.

High voltage lab with vacuum vessel

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Timo Meyer
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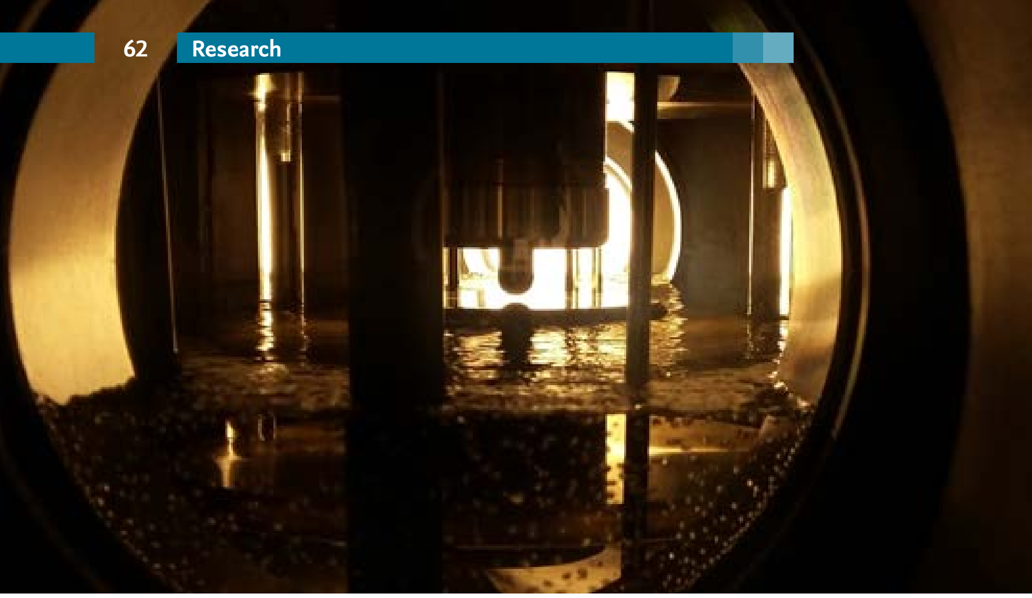


Nicholas Hill - A Cold Dissertation

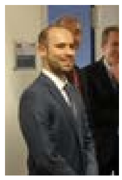
with the title „Evaluation of breakdown voltages in cold nitrogen gas“

In the following the short version of the work can be found in an adapted version.

With an increasing number of high temperature superconductor applications the knowledge of the electrical strength of liquid nitrogen, a cooling and insulating medium, becomes more and more important. In order to avoid having to examine each component of a superconductor system separately within the framework of insulation coordination, it is useful to develop a method with which the electrical strength can be estimated. This work provides a methodology to support such a design.
As a starting point for the calculation, known breakdown models can be used, such as the disguised gas breakdown. Considering that there is always a heat input in superconductor systems, either due to operation or in case of failure, a mixture of liquid and gaseous phase can be formed. Many investigations have already shown the strong influence of a gas phase in liquid nitrogen on the insulation. Therefore, in order to investigate the breakdown mechanism in liquid nitrogen, the process in cold gas must be understood beforehand. In this paper, this is done using self-determined breakdown voltages in cryogenic nitrogen gas. Simple models for the theory of the gas breakdown are preferred to a complex and comprehensive model in order to enable a better engineering application. First, relevant theories on discharges in gas are described. This includes the calculation of ionization coefficients, the number of electrons and via approximations also the influencing variables such as areas or volume effects as well as the volt-time area. Since the models are applied to the measured breakdown voltages, a description of the state and properties of the nitrogen gas investigated during the experiments follows. Then it is described how the alternating and lightning impulse voltages are generated and determined. The discussion of the determined breakdown voltages is followed by a detailed analysis of possible processes of charge carrier preparation, which are required for the initiation of the breakdown. This includes the ionization in the volume by cosmic and background radiation, photoemission and field emission. Subsequently, the actual process leading to the breakdown of the insulation path is considered. The discharge according to Townsend and Streamer are regarded as relevant models. The modelling and discussion is supported by electrostatic field simulations to determine the electric field strengths and thus avalanche formation along the field lines. Finally, follow-up questions and further investigations give a preview for the future research.

Cryostat (left) with storage tank for liquid nitrogen (right)

Profile



At elenia: since 04/2013

Activities at elenia:

- Electrical strength of liquid and gaseous nitrogen, partial discharge diagnostics at elevated temperatures in low-voltage devices
- Head of workgroup (as of 10/2019) and responsible for high-voltage lab
- Face of the Electromobility programme (tu-braunschweig.de/eitp/studium/emob, since May 2014)

Tobias Marseille - Vacuum switches

Short version

Vacuum circuit-breakers (VCB) for the medium-voltage level represent a crucial component in the power supply as switching devices. During the switch-off process of possible short-circuit currents in the grid of up to 63 kA (RMS), a considerable stress is caused by the switching plasma, which the VCB can safely control due to its special design of the switching contact pieces. A commonly used type is the Transverse Magnetic Field (TMF) Switching Contact Pieces. When high currents (> 10 kA) are switched off, the switching plasma causes the melting of anode surface areas. These are called anode spots and take on diameters of a few millimetres. They cool down to the current zero crossing, whereby the temperature level to zero current plays an important role in the re-solidification of the switching path. The temperature level of the anode surface at the zero crossing point of the current is a measure of the current-breaking capacity of the switching contacts and must not exceed a certain limit temperature, as otherwise a low-pressure breakdown after Townsend is possible. In this work, the cooling anode spots at the zero crossing point of the current in conventional TMF switch contacts (copper/chromium 75/25 (wt. %)) are analysed for the first time using a calibrated thermographic measuring method. For this purpose, a novel method for thermographic surface temperature measurement is developed, which is used for the analysis of the cooling anode spots for current zero crossing during switch-off processes with different current intensities of 20 kA (RMS), 25 kA (RMS) and 31.5 kA (RMS). It allows a detailed insight into the cooling processes of the anode spots.

When the vacuum arc dies out up to 3 ms before zero current, the cooling anode spots can be clearly identified on the switching contact piece surface. The positions of the cooling anode spots correlate with the travel behaviour of the vacuum arc, which is recorded simultaneously with a high-speed camera. The center of gravity of the spots depends on the current intensity and moves with increasing value from the inner surface area to the outer edge of the switching contact piece. At the start, temperatures of > 2200 K are recorded in the cooling processes of the anode spots. These temperatures drop to a level of 1350 K and a level duration of up to 3 ms. This is due to the latent heat released during the solidification of the contact piece material at the eutectic point. After complete solidification, the areas cool further to room temperature. A temperature of approx. 1400 K is determined for the zero-current transition, which is lower than the limit temperature of 1700 K and therefore has no influence on the reconsolidation of the switching path. The thermographic surface temperature measurement requires knowledge of the emissivity of copper/chrome 75/25, which is measured in an additional experimental setup. For this purpose the switching contact piece material is melted with an induction coil and its thermal radiation is measured at the same time. This setup allows the measurement of the emissivity of any metal at different temperatures. The emissivity of copper/chrome 75/25 is measured for the temperature range between solid (1350 K) and liquid (1903 K) in wavelength ranges from 1.5 µm - 1.7 µm. This results in an emissivity curve from 0.237 ± 0.026 to 0.125 ± 0.016. The method for surface temperature measurement in connection with emissivity measurement can be applied to various switchgear devices with visible contact piece surfaces and contact materials, so that this work represents a general basis for the thermal investigations of switch contact piece surfaces.

Profile

At elenia: 11/2013 to 06/2018

Activities at elenia:

- Member of the PMO
- Surface temperature measurement of vacuum switching contacts in cooperation with ABB

Now working for:

TenneT Offshore, Production engineer for HVDC systems

Ole Binder - HGÜ

by Ole Binder entitled „Development of a test procedure for loss determination on HVDC multilevel converter modules“

In the present thesis, the switching and loss behavior of submodules (TM) are researched experimentally. For this purpose, the operation of a modular multilevel converter (MMC) for high-voltage direct current (HVDC) transmis-sion is reproduced using scenarios.

Essential components of a TM are high-voltage capacitors and IGBT modules. In addition to the presentation of these basic TM components, the structure and operating principle of an MMC are explained. Together with the description of the control of converter operation and the current paths of a submodule the foundation is thus laid to derive suitable test arrangements. The struc-ture of the newly installed test bench, the low-inductive design of the newly developed submodules and the meas-uring system specially assembled for the investigations are documented. Intro-ducing a limiter circuit allows semicon-ductor forward voltages to be accurately measured and semiconductor junction temperatures to be monitored. The loss is determined by the evaluation of measured electrical signals. For a quick and easy analysis of the dynamic TM-switching behavior a standardized eval-uation procedure is introduced.

With a simplified converter model, MMC valve currents are simulated for different MMC operating states. These calculated current curves are the basis to define the operational test scenarios, which are reproduced in the pilot plant experimentally. The development of the test sequences by specifying set points is explained and illustrated by means of measured signal curves. The TM under test is continuously operated in the respective scenario for a certain period of time. Insight into the switching processes and the thermal stress of the TM under test is given. The amount of loss caused by switching operations and conduction states of IGBTs and diodes and the submodule capacitor is shown. The accuracy of TM loss determina-tion during continuous scenario operation using the introduced evaluation meth-od-ology is analyzed.

Finally, the measuring system and the relevant measuring chains are examined in detail. Measures are derived to achieve high accuracy in electrical measurements and loss determination. The measuring system is calibrated to meas-ure DC, AC, step and impulse voltages, and the achieved measurement uncertainties are listed. On the basis of the calibration results, the achievable uncer-tainty is calculated with which switching and conduction losses can be deter-mined with the used measuring system.

At the conclusion of this work, a test environment and a reference measure-ment system are available to analyze and optimize the switching and loss behavior of MMC submodules.

Profile

At elenia:

from 11/2010 to 04/2016

Activities at elenia:

- Co-founder of elenia Project Management Office (PMO)
- Head of the research focus group "Components of Energy Supply"
- International research project EMRP ENG07 "Metrology for High Voltage Direct Current (HVDC)".
- Committee work (CIGRE Working Group B4.52 "HVDC Grid Feasibility Study")

Now working for:

EnBW AG as Manager Electrical Engineering in the field of offshore wind energy

Uwe Westerhoff - Battery technology

Classification of lithium-ion battery cells by means of parameter-based methods

In the wake of the energy and mobility transition, innovative energy storage systems are a key technology for achieving the climate protection goals of the Paris Agreement of 2015. The rapidly increasing demand for energy storage devices for mobile and stationary applications means that the number of battery cell, module and system manufacturers and their production capacities is growing rapidly. The short cell development and production ramp-up times contribute to the increasing importance of integrated quality assurance from the electrode to the system. An important component of integrated quality assurance is the classification of battery cells in the incoming goods department of a module and system manufacturer.

The present work is dedicated to this challenge with a metrological analysis of the quality characteristics of Li-ion battery cells on the basis of electrical and electrochemical measuring methods in order to be able to classify battery cells in an incoming goods inspection. For this purpose, 250 pouch cells are metrologically examined in a two-stage quality test procedure and their properties are summarized by a multitude of key figures in a key figure system.

The first test corresponds to a short time-saving incoming goods inspection (Short Quality Test) using electrochemical impedance spectroscopy. Each cell is then characterized with a comprehensive test routine consisting of capacitance, open-circuit voltage, C-rate and internal resistance measurements as well as electrochemical impedance spectroscopy at different charge states. The results are further processed with the evaluation methods of differential voltage analysis, the distribution function of relaxation times and the equivalent circuit diagram method. This combination of characteristic-based methods corresponds to the Long Quality Test. The key figure system from the results of this test routine provides a good selectivity of the quality characteristics in order to sort and classify the cells. Finally, the quality of the short incoming goods inspection was evaluated with this key figure system. With this short test, cells with distinctive quality characteristics can be identified and classified.

Profile

At elenia:

from 06/2012 to 12/2018

Activities at elenia:

- Construction and operation of battery cell test stands for forming, maturing and cyclisation of Li-Ion batteries at elenia and BLB
- Development and implementation of protective measures for the testing of Li-Ion batteries
- Head of the research focus group "Electromobility"

Now working for:

Volkswagen AG in battery cell production

Jan Mummel - Electric Mobility

Decision support in the planning of infrastructures for electric vehicle fleets

At around 22 %, the transport sector is one of the main causes of greenhouse gas emissions in Germany [UMW18c]. By electrifying the powertrain, an energy supply with a high proportion of renewable energy sources can significantly reduce greenhouse gas emissions during vehicle use. The establishment of electric vehicles is thus an important component of the mobility turnaround.

In order to permanently establish electric vehicles as an alternative to conventional vehicles, the development costs of vehicles must be reduced to the level of current vehicles. In addition, economic operation of the vehicles is necessary. In the commercial sector in particular, public charging infrastructure (LI) cannot be used for the most part without the user incurring additional time and costs. Therefore, the construction of the necessary infrastructure must be taken into account for the operation of commercial electric vehicles. The sole consideration of the energy costs of driving consumption is not sufficient here. The infrastructure of electric vehicle fleets includes the LI and the energy supply. The energy supply can come from the energy supply network and, if possible, from local decentralised renewable energies (DEA).

The dissertation shows that already now a sustainable integration of the infrastructure for electric vehicles in the commercial application can succeed by a founded planning. The special feature here is that the integration of the infrastructure considers a holistic approach taking into account the technical, ecological and economic requirements.

The first step is to examine electromobility in the context of mobility and energy system transformation. Building on this, this dissertation develops a model that supports fleet managers in planning the required infrastructure for a commercial fleet. Scenarios for the LI with different charging power for controlled and uncontrolled charging processes are created and simulated. In addition, the economic effects of different grid connection services are ana-lysed taking into account the power price and the ecological and economic effects of the integration of local DEA are investigated. On the basis of these, decision support is provided for the fleet managers with regard to previously defined target criteria such as sustainable operation of the fleet without restricting mobility behaviour.

Using the exemplary example of an electric vehicle fleet of an energy supply company, it can be shown that with a higher charging capacity of 22 kW with intelligent LI and the integration of a local DEA (photovoltaic system) in operation, an improvement can be achieved in terms of ecological and economic considerations without influencing the mobility behaviour compared to a conventional fleet.

Profile

At elenia:

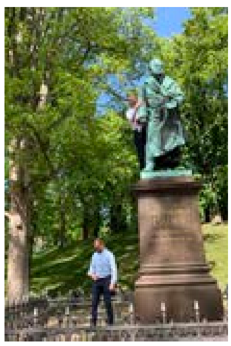
from 01/2013 to 12/2018

Activities at elenia:

- Head of the research focus group "Electromobility" - 06/2016-12/2018
- Niedersächsisches Researchszentrum Fahrzeugtechnik (NFF) - Scientific Managing Director - 01/2017-01/2018
- NFF - Coordination Research Vision "Sustainable Mobility" - 10/2013-10/2014

Now working for:

PE-Systems GmbH as Managing Partner



Ole Marggraf - Voltage Control

Design and evaluation of autonomous voltage control concepts for distribution grids

Driven primarily by the “German Energiewende”, new approaches to static voltage control in the distribution grids, such as the voltage regulated distribution transformer (VRDT) and the voltage-dependent reactive power control (Q(V)), have been devel-oped in recent years. Together with already existing concepts, such as the line volt-age regulator (LVR) and the on-load tap changer (OLTC) in high voltage /medium voltage transformers, as well as technologies transferred from higher voltage levels, such as STATCOM, they form a wealth of possibilities for static voltage control. These include the measured current voltage at the grid connection point as the con-trolled variable. In contrast to the effectiveness of the control methods, the interaction of the various autonomously operating voltage regulators in particular has hardly been considered so far.

The present work is dedicated to the interaction of the autonomous voltage control-lers in the distribution network in the form of simulations, laboratory tests and a field test in a real low-voltage grid. Interactions between voltage controllers of the same as well as different types are considered. To prepare the investigations, dynamic simula-tion models for the on-load tap changer in high voltage /medium voltage transform-ers, a voltage regulated distribution transformer and a line voltage controller were created and validated on the basis of laboratory measurements. An already existing and validated inverter model could also be used from preliminary work. For the la-boratory tests, a hardware-in-the-loop simulation of a voltage regulated distribution transformer was set up and validated.

The investigations on possible voltage-controller-interactions focus on Q(V) control, since it is only through a reactive power transport, caused by voltage control that mu-tual controller interactions in the distribution network are made possible. The results of the simulations, laboratory tests and field trials, show that interactions can occur theoretically and practically, but should never be interpreted as instabilities. However, such interactions, which were undesirable from the grid's point of view, could only be caused for remote or faulty controller parameters and installed capacities of the gen-eration plants above the grid's capacity. They can therefore be neglected for the practical design of autonomous voltage control concepts for distribution networks. Furthermore, no limiting boundary conditions for the use of autonomous voltage regulators could be found.

This is followed by a simulation-based comparison of the effectiveness - in the form of an increase in the hosting capacity with regard to further decentralized generation - and efficiency - in the form of reactive energy and losses - of the investigated volt-age control concepts using the concrete example of the field test network "NETZlabor Sonderbuch". The results are supplemented by an economic evaluation based on market research and a survey of distribution network operators.

Profile

At elenia:

from 01/2013 to 05/2019

Activities at elenia:

- Coordination and execution of the FNN study Static Voltage Control as well as the research project "U-Control" on Static Voltage Control
- Planning and construction of a research photovoltaic plant at elenia
- Member of the "Smart Grids" work group since March 2017

Now working as:

Project Developer HS-Primärtechnik for 110-kV-substations at Avacon Netz GmbH

Stephan Diekmann - Energy management

Technical-economic analysis of electrical building energy management in apartment buildings

The Energiewende and the associated extensive restructuring of the energy system is one of the largest engineering projects of our time. The ambitious goals of climate protection and a renewable energy supply can only be achieved by the participation of all economic sectors.

In this context, too little scientific consideration of the high proportion of apartment buildings in the household sector is addressed in this research. Legal, regulatory and organizational barriers are identified as key factors in the previous reluc-tance of the housing industry, residents and other stakeholders. Among other things, these are based on the variety of actors and the lack of personal identity between potential operators and users of decentralized energy systems.

This thesis shows the technical and economic potential of electrical energy management in apartment buildings and thus provides incentives to enable the holistic success of the Energiewende. The new concept of scalable multi-level energy management is presented. It combines the approaches of tenant electricity (Mieterstrom) and the simultaneous multiple use of photovoltaic storage systems. Residents and other stakeholders will benefit from the efficient participation in the Energiewende and the overcoming of the rising electrification of the household sector, driven by megatrends such as digitization and electromobility, will be favored.

Furthermore, a demonstrator building will be presented, which was involved in the research work. Among other things, it is conceived and realized as a laboratory environment for future practical investigations of the developed approaches.

This thesis examines the described concept by means of a computer simulation regarding the influencing factors for technical and economic targets. The simulation results confirm the assumed potential both for residents and plant operators as well as across buildings. On the basis of various simulation scenarios, the advantages of a dynamic multiple use of technical systems over several households compared to a static allocation of system shares becomes particularly clear. The insights gained and recommendations for action foster the participation of apart-ment buildings in the Energiewende and thus make an important contribution to achieve the goals.

Profile

At elenia:

from 02/2013 to 12/2018

Activities at elenia:

- Electric mobility (FleetsGoGreen, MOBIL4e), Electric building energy management for apartment buildings (BASIS)
- Young member referee of the VDE Bezirksverein Braunschweig e.V. - 02/2013 to 12/2018
- IT coordinator and system administrator

Now working for:

Hidden Industries GmbH, Braunschweig as Managing Partner

Daniel Unger - Solarstromspeicher

Economic integration of multiple-use solar energy storage systems

The constant availability of electrical energy is of great economic importance. More flexibility is needed for a future energy system with increasing generation from renewable energies. Solar energy storage systems can make a contribution to the required flexibility. 560 households have been simulated, which differ in the annual energy consumption, the photovoltaic system size and the storage size. The combinations are selected in such a way that the sum corresponds to the average distribution in 2015. As a result, an average storage capacity of 4.8 kWh is developed.

There are two modes of operation that allow solar energy storages to offer their available capacity on the energy market. In the sequential mode of operation, only one user uses the solar power storage system in each time step. This can be the household with the own consumption optimization or the supplier with the use on the energy market. The solar power storages are always handed over empty to the next user. Thus, an average of 22 % of the storage capacity is available for multiple marketing each year. In the second operating mode, the simultaneous operation of solar power storags, an average of 55 % of the storage capacity can be used for multiple marketing per year. The increase compared to sequential operation is possible because all users use the solar storage at the same time. In general, availability is higher in the winter months than in the summer months.

The use of solar energy storages on the energy market influences the remaining generation structure. A fundamental model of the energy market will be developed for the investigation of the effects, which is based on a mixed integer optimization. The simulation of scenarios takes place in a time grid of 15 minutes for a winter week with high load and low feed-in from renewable energies and a summer week with correspondingly low demand and high feed-in. The input data include the power plant park in Europe and the transmission capacity of the cross-border interconnectors. The use of multiple solar power storage in 2015 will have little impact on the energy market. The reason for this is the low installed number of storages.

In the year 2030 a higher available number of solar power storages leads to a higher influence on the energy market. In general, multiple-use solar power storage systems represent a further flexibility option. In few hours, the flexibility options complement each other, so that the use of solar energy storages leads to an increased use of pumped storage power plants. In some scenarios, however, the use of solar energy storage systems also reduces the use of pumped storage power plants. The energy generated by gas-fired power plants is reduced with an increasing number of multiple-used solar power storages. A higher storage capacity leads to higher full load hours of coal-fired power plants or foreign, cheaper generation technologies. Only with a rising CO_2 price does generation from gas-fired power plants increase.

Profile

At elenia:

from 06/2012 to 06/2018

Activities at elenia:

- Multiple use of solar energy battery storage,
  Reactive power supply of decentralized generation plants
- AGL 02/2017 to 06/2018

Now working for:

Hidden Games as Managing Partner

Publications

Alija, M., Kurrat, M.:
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Drees, R.:
Fast Charging Formation, IBPC 2019 - International Battery Production Conference, Braunschweig, 4.- 6. November 2019

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Partial Discharge Testing for Low Voltage Switchgear at High Temperatures, 66th IEEE Holm Conference, Milwaukee, 15.-18. September 2019

Hill, N., Blaz, M., Haake, F., Hilbert, M., Kurrat, M.:
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Hoffmann, L., Ryll, K., Kurrat, M.:
Key figure-based evaluation and process quality relationships of the formation result of lithium-ion batteries, International Battery Production Conference, Braunschweig, 4.- 6. November 2019

Hoffmann, L., Grathwol, J., Haselrieder, W., Leithoff, R., Jansen, T., Dilger, K., Dröder, K., Kwade, A., Kurrat, M.:
Capacity distribution of large format lithium-ion battery pouch cells in context with pilot production processes, Kraftwerk Batterie, Aachen, 2.- 4. April 2019

Hoffmann, L., Westerhoff, U.:
Formierung und Reifung von Lithium-Ionen Zellen – Beschleunigung und energetische Optimierung, Batterieforum Deutschland, Berlin, 23.-25. Januar 2019

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Pfeiffer Vacuum HiPace® 300 Turbovacuumpump with TC400-Drive electronics ideal for UHV applications

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Estimation of Current Density Using High-Speed-Camera Recordings in a Model Spark Gap during Surge Currents, Plasma Physics and Technology, Symposium on Physics of Switching Arc, Tschechien, 9.-13. September 2019, S. 60-64. ISBN 2336-2626

Köppe, H., Schuster, M., Grab, R., Engel, B.:
Reactive Power Provision with Distributed Energy Resources: Limitations, Potentials and Losses,
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Kühn, B., Weber, B., Gentsch, D., Kurrat, M.:
Influence of varying gaps between TMF contacts on constricted high current vacuum arcs, Plasma physics and technology, Symposium on Physics of Switching Arc, Czech Republic, Brno, 9.-13. September 2019, S. 103-106. ISBN 2336-2626

Kühn, B., Gentsch, D., Weber, B., Hilbert, M., Kurrat, M.:
Recent Developments Of Field Grading For High Voltage Vacuum Circuit Breakers, The 21st International Symposium on High Voltage Engineering, International Symposium on High Voltage Engineering, Budapest, Hungary, Springer, 26.-30. August 2019

Nuschke, M., Winter, B., Strauß-Mincu, D., Engel, B.:
Power System Stability Analysis for System-split Situations with Increasing Shares of Inverter based Generation,
NEIS 2019, Conference on Sustainable Energy Supply and Energy Storage Systems – NEIS 2019, Hamburg, Germany,
Berlin: VDE-Verlag, 19.-20. September 2019

Peters, E., Claaßen, L., Kurrat, M.:
Beschreibung einer Methode zur Bildanalyse von Schaltlichtbögen in Niederspannungsschaltgeräten ,
Albert-Keil-Contactseminar, Karlsruhe, 9.-11. Oktober 2019

Pronobis, O., Kurrat, M.:
Assessment of Static Charging Management Methods, ETG Kongress, Esslingen am Neckar, 8.- 9. Mai 2019

Ries, J., Reinhold, C., Herr, H., Engel, B.: Modular Control System for Testing of Electrical Power Systems and Energy Management Systems in elenia-energy-labs, ETG-Fb. 158: Internationaler ETG-Kongress 2019 - Das Gesamtsystem Im Fokus der Energiewende, Internationaler ETG-Kongress 2019, Esslingen am Neckar, Berlin: VDE Verlag, 8.- 9. Mai 2019, S. 159-164. ISBN 978-3-8007-4505-0

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Aktuelle Methoden zur Bestimmung von Oberflächentemperaturen an VakuumschaltContacten,
VDE Fachbericht 75 Contactverhalten und Schalten, 25. Fachtagung Albert-Keil-Contactseminar, Karlsruhe, Berlin: VDE VERLAG GMBH, 9.-11. Oktober 2019, S. 135-143. ISBN 978-3-8007-5084-9

Wussow, J., Modica, G., Engel, B.:
Integration of Electric Vehicles in Extreme Suburban Grids with the Support of Extended Functionality of PV Storage Systems, E-Mobility Integration Symposium, Dublin, 14. Oktober 2019

Wussow, J., Modica, G., Engel, B.: Grid-Oriented Charging of Electric Vehicles as Approach for Increasing Penetration in Residential Areas, ETG Kongress, Esslingen am Neckar, 8.- 9. Mai 2019

Mechanical connection between asynchronous and synchronous machine (metal bellows couplings and torque sensor)

Labs & Workshops

3

Laboratories of the elenia

elenia's diverse fields of research are equally reflected in its state-of-the-art laboratories. Applied implementation capabilities round off our research. Whether it is the elenia energy labs, battery test laboratory, performance test field or high-voltage hall - each laboratory offers a considerable benefit to our research and service projects. In 2019, the laboratories were again expanded and further developed, e.g. in the form of new test setups or individual components. Our mechanical and electrical workshops also make an important contribution to the proper operation of our experimental setups and/or laboratories.

Energy Management Lab

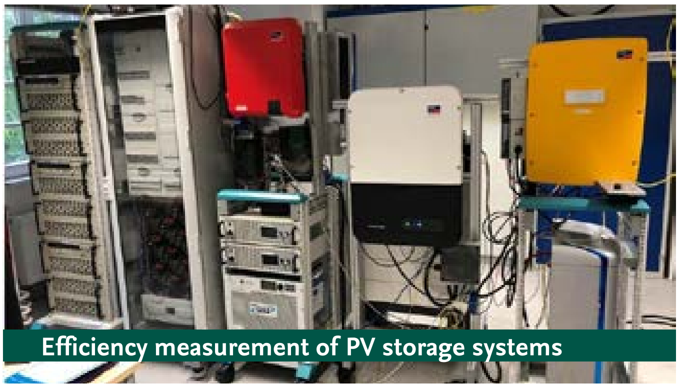
Sector coupling through efficient energy management and intelligent measurement systems

The Energy Management Laboratory provides a space to study innovative energy management concepts for household and prosumer electricity-only demonstrators. The research focuses on prosumer behaviour in the context of electric mobility, the coupling of the heat and electricity sectors, load and storage management as well as newly developed metering and measurement concepts. For this purpose, numerous devices can be used, such as various AC loads, DC sources, a charging infrastructure and a heat pump test stand consisting of an air-to-water heat pump, a temperature controlled chamber and a heating circuit. To measure the currents and voltages that occur, multi-channel measuring systems from the company DEWESoft are used. The power and data links between the energy management laboratory and the grid dynamics laboratory also provide the option of cross-laboratory measurements. This enables the investigation of new research questions and projects in the field 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 ModSys-eelabs control environment developed at elenia. With this control environment, the user can realistically simulate a residential building that meets his requirements in just a few steps according to the modular construction concept. Since the laboratory was opened at the end of 2018, a prosumer demonstrator has already been set up in the NetProsum2030 project and studies have been carried out on various mobility concepts in the EnEff Campus: blueMAP project. In the future, the research projects flexess and MELANI will be carried out in the energy management laboratory. In the project flexess the targeted use of flexibilities of technical equipment in the areas of household, GHD, commercial trade and electromobility fleets will be 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 metering concepts for the multiple use of PV home storage systems are being developed. In addition to research activities, teaching activities will also benefit in the form of numerous student projects that can be carried out in the labs and the additional laboratory student-projects offered in parallel to lectures. Furthermore, the wide-ranging equipment of the energy management laboratory enables the execution of efficiency measurements of PV storage systems according to the efficiency guideline and thus expands the service portfolio of the department.

DEWESoft Sirius DAQ Measuring System

Overview - Lab equipment


Efficiency measurement of PV storage systems

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

Simulation of a PV system

- Inverter: „SUNNY TRIPOWER STP 20000TL-30“
- 2 DC-Sources: „Elektro Automatik EA PSI 91000-30“ (10 kW each)

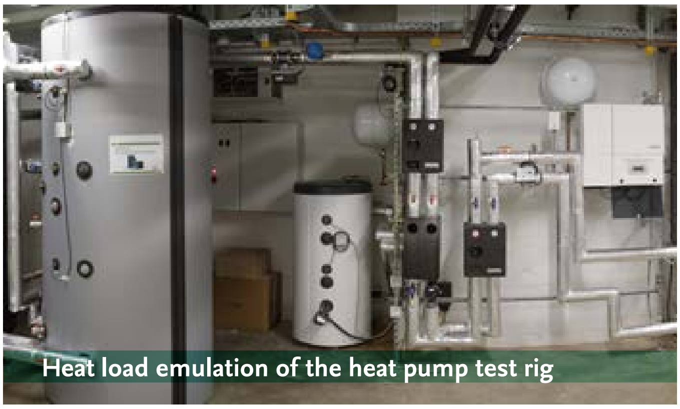
Replication of Consumers

- 3 AC-Load: „Höcherl & Hackl ZSACR“ (9,8 kW each)


Charging station at Mühlenpfordthaus

Charging infrastructure of elenia at Mühlenpfordthaus

- » Two Mennekes AC-Wallboxes with charging power up to 22 kW
- » Multicharger (CCS Typ 2- and CHAdeMO-Connector) for DC charging up to 22 kW
- Physical coupling of the charging infrastructure with the energy management laboratories possible
- The elias charging management system developed in the Fleets-Go-Green project is used for IT integration.
- Research in the field of generation-oriented charging and grid-oriented charging


Heat load emulation of the heat pump test rig

- Hardware-in-the-Loop heat load emulation in combination with the TRNSYS building software for emulating the heating and cooling load of buildings
- Temperature-controlled chamber with temperature range from -5°C to 35°C, optional humidity control
- Trinkwarmwasseremulation durch Vorgabe von Zapfprofilen
- Durch die Einbettung in ein institutseigenes Energiemanagementsystem sind Untersuchungen unterschiedlicher Betriebsweisen von Luft-Wasser-Wärmepumpen möglich, hierzu zählen die temperaturgeführte, eigenverbrauchsoptimierte und netzdienliche Betriebsweise

Overview - Services

Measurement of storage efficiency

Testing of control methods and communication protocols

Combined experiments with 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

Measurements at defined, constant temperature and air humidity

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Grid Dynamics Lab

Grid stability in times of inverter-dominated grids - *Milliseconds matter*

The grid dynamics laboratory is the place in which, current research topics on the integration of renewable energy generation systems into the low-voltage grid are examined. The focus is on highly dynamic, transient Processes. A dedicated team consisting of scientists, assistants and the institute's own workshop works closely together. A laboratory and its team introduces itself:

About the laboratory - Central questions

The main goal of the investigations in the grid dynamics laboratory is to develop new strategys for the transition in the energy policy. While the stability of conventional energy supply systems are primarily based on large power plants in higher mains voltage levels, the structure of the power generation is currently changing. This means, that the number of decentralised inverter-based power generation systems is increasing rapidly, especially in the lower mains voltage levels. Renewable energy generation systems are connected via inverter to the grid and therefore differ from conventional thermal power plants, which generate power via large synchronous generators. The Requirements for modern generation plants with respect to their behaviour in a highly volatile, dynamic grid are manifold and due to their power electronic characteristics, the communication structures and their regulation form a complex topic.

By investigating different scenarios in the laboratory environment, which depict the future power supply infrastructure, it is possible to locate opportunities as well as challenges of a new grid structure with a high amount of renewable energies and electromobility. The fundamental changes in the power supply infrastructures require a continuous re-evaluation of the grid stability taking the interaction between the conventional and novel energy supply systems and regulations for securing the grid stability intp account. In the grid dynamics laboratory the infrastructure for these investigations is available:

The grid dynamics laboratory provides the appropriate infrastructure for this purpose: flexible energy sources, grid constructions, electrical loads, generation plants, freely parameterizable converters and Power-Hardware-In-The-Loop real-time simulators allow for a wide variety of scenarios, especially critical situations: Many scenarios that are not seen too often in a real energy supply infrastructure can be tested and driven through without consequences.

The laboratory environment therefore focuses in particular on experiments and scenarios that deal with particular load situations of grid components and the grid supporting properties and functions of decentralised generation plants.

The grid dynamics laboratory as a service provider for research and industry In addition to our everyday research activities, we also regularly process orders for external partners - from startups to larger industrial customers. For our clients, the main focus is on issues relating to the safe operation of equipment, software and/or hardware components within a representative low-voltage environment.

Typical tasks for external partners include:

- The device response characterization, 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 first assessment of the conformity of prototypes with (newly developed/existing) grid connection guidelines

News from the laboratory - Coupled machine set

The central challenge for our energy supply system in the next few years will be the stable transition to a CO_2-neutral energy supply system. From a technology standpoint this means the transition from a grid primarily defined by synchronous

PION AG charging station in the 7-hour 44 kW continuous load test

generators of fossil power plants towards a grid defined by converter-based regenerative plants. In many respects, this changes the fundamental behaviour of the energy supply infrastructure. This motivates extensive tests of this transition in the lab. For this purpose the grid dynamic laboratory offers a coupled machine set, for investigations in grid-parallel operation of inverters and synchronous machine under laboratory conditions.

The machine set is currently being installed in the laboratory and the first test runs are being carried out. The specially developed control for the protection of personnel and hardware, the control of the machine as well as the coordination of various components involved in the operation ensure safe laboratory operation for all future tests.

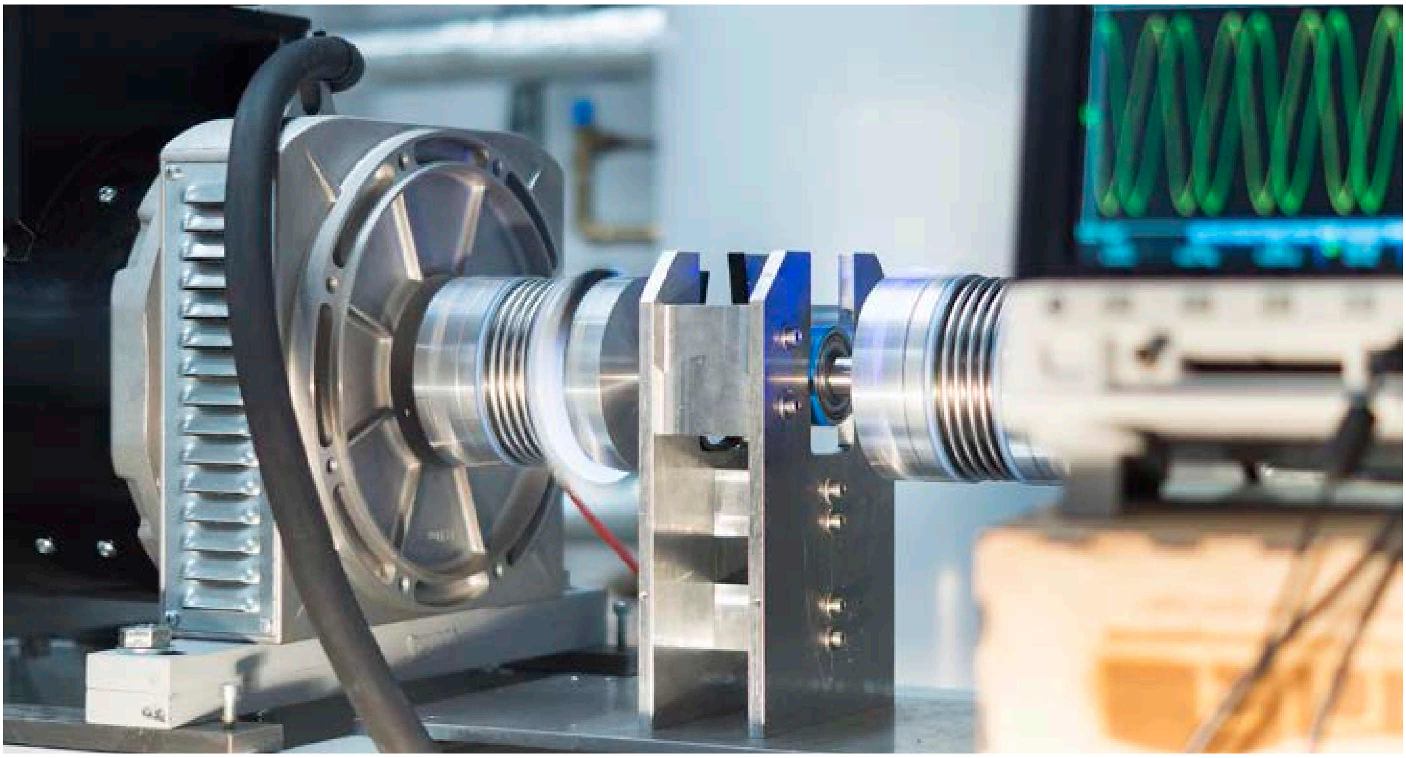
The current focus of the experiment is the reaction of grid components to fast leaps in the grid phase and grid amplitude, mostly caused by errors. In these states, machines tend to oscillate, but are able to stabilize the grid by delivering short-term high overcurrents. Inverters can act more flexibly, but are strongly limited in overcurrent.
Can these systems complement each other in the transition? How can the grid be operated in a stable fashion with different degrees of penetration of inverters and machines? How should inverter controls be designed for this? The grid dynamics laboratory invites you to investigate these questions.

News from the laboratory - OPAL Real-Time-Simulator

The tests carried out in our laboratory offer a decisive advantage for our research: scenarios or behaviours designed in abstract and necessarily simplified simulations can be verified under more realistic conditions. These experiments are often more meaningful, control systems can prove their correct behaviour for the first time in the real world. However, before implementing controls in hardware, it is a good idea to test their functionality in more flexible embedding scenarios. In order to map grid errors and controller behavior in the millisecond range, the laboratory requires an integrated measurement and control layer that works reliably and without delay in these areas.

Powerful OPAL real-time simulator

For this purpose, a powerful real-time simulator was added to the laboratory. The real-time simulator makes it possible to enable hybrid application cases from simulation and hardware in real time. This has several advantages: simulations can be transferred step by step to the laboratory. Part of the test setup



Coupled machine set in test mode after alignment and calibration of the shaft flange is taken over by laboratory equipment, the rest takes place in the simulator. Devices and simulation models work together in parallel and in real time. Causes for deviations between simulation and laboratory tests can thus be better isolated and found in small increments. In contrast to conventional lab equipment, a simulator enables the flexible mapping of elements of the low-voltage grid, e.g. machines with different inertias, batteries with different power ratings, grids with different arrangements, which could only be modified in the laboratory with great effort - all this can be changed here simply by mouse click. Faults in live system elements can be mapped in simulations, an advantage for personal safety and equipment protection.

Training and collaboration of student assistants

Our student scientific assistants are supporting scientific staff in the lab on a regular basis. This includes tasks such as the software implementation and control of components in the laboratory using programs such as LabVIEW or MATLAB/Simulink, as well as the installation of electrical components or Hardware - In the laboratory, students can gain practical experience in the field of electrical installations, but also in the field of applicable theory of control and measurement technology.

Diverse working and learning fields in the laboratory

Conductor emulating elements equivalent to up to 1.8 km of low voltage cable

Facts & figures about the grid dynamics laboratory

Various components such as inverters, AC and DC sources and loads as well as a 50 kVA line voltage regulator make it possible to reproduce a complete low-voltage line 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 measuring system with 16-bit measuring resolution and a sampling rate of 500 kS/s enables accurate and precise 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. Some core elements and experimental components that define the core points of the laboratory are listed on the next page:

Overview - Lab equipment

Grid simulator AMETEK MX-45

Fully regenerative grid simulator for simulating different network states with variable network parameters

- 45 kVA connected load
- Voltages up to 300 VRMS and 400VDC
- Currents up to 50 ARMS
- Frequency range 16-800 Hz
- 4-wire connection (unbalanced load)
- Integrated measuring system
- Analog interfaces for precise control of individual phases

OPAL 5700 Real-Time-Simulator

Real-time simulator for Power-Hardware-In-The-Loop applications and delay-free laboratory control

- Analog/digital inputs and outputs for coupling a wide range of laboratory components
- Communication interfaces such as MODBUS, EtherNet, EtherCAT, CAN, TimeStamp, GOOSE, etc.
- FPGA technology for faster command processing

TRIPHASE – Fully programmable inverters

Freely programmable inverters for implementation and investigation of own control models

- Two inverters with 15 kVA rated power each
- 1x 3-core connection, coupled rectifier and inverter, can be used as battery simulator
- 1x 4-wire connection, unbalanced operation, zero-sequence component injection

30 kW coupled machine set

Coupled machine set, consisting of asynchronous and synchronous machine with freely parameterizable inverter

- 30 kW connected load at 1500 rpm nominal speed and 150 Nm nominal torque
- Synchronization unit for connecting external sources to the machine set network
- Generator and motor operation possible

Overview - Services

Behaviour of components during frequency and voltage changes

Overcurrent limitation and short-circuit behaviour of decentralised generation plants

Behaviour of voltage-controlled inverters in island or grid-parallel operation

Effects of variable voltages on control systems such as Q(U) and P(U)

Anti-Islanding-Detection and Vibration Circuit Tests up to 33 kVAr

Development of controls for the provision of system supporting properties fucntions

Investigations into rONT using own simulation model

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Battery Test Laboratories at elenia

A multitude of test and inspection possibilities at cell, module and system level

Due to the increasing demand for electrical energy storage devices, both for mobile and stationary applications, battery technology is becoming more and more the focus of current research projects. Lithium-ion batteries in particular are among the most relevant battery technologies due to their comparatively high energy and power densities, high efficiency and long-term stability. The elenia has battery test facilities at four locations (BLB, InES, BatLab, PTB), which differ in their research focus. At the BLB and the InES, the focus is on investigations at the cell level, with both specially manufactured BLB cells and commercial cells being used. Current research activities include the influence of formation on cell performance, electrical and electrochemical characterization for quality evaluation and long-term cyclisation for the identification of ageing mechanisms.

At the BatLab and the PTB, the focus is on the module and system level. The focus of the investigations is on battery module and system diagnostics. Current projects deal with the characterization of battery modules for the identification of their suitability for SecondLife applications.

A variety of equipment is available at the four locations to test the batteries. In order to guarantee constant ambient conditions during the tests, temperature test cabinets with a wide temperature range are available. To ensure a safe test environment, all test benches are equipped with an F90 temperature cabinet and battery testers, as well as comprehensive safety equipment that can be used in the event of a battery failure. The safety equipment consists an extinguishing system from Wagner, an exhaust air system and a multi-stage emergency filter from Stöbich technology. This allows testing according to the hazard classification for battery faults (EU CAR) up to hazard level 5 (HZ).

With the battery test systems, lithium-ion batteries can be tested with different current and voltage profiles to characterize the electrical properties. On the one hand, capacity tests are carried out at a constant current load in order to determine the energetic properties.On the other hand, current rate and internal resistance tests are possible to assess the electrical performance. Periodic charging and discharging cycles as well as the recording of the decreasing available capacity and the increasing internal resistance can be used to assess the electrical performance.

Special methods such as differential voltage analysis and electrochemical impedance spectroscopy can be used to determine various causes of battery ageing. In addition, calendar ageing in safety cabinets is an object of investigation, e.g. to determine self-discharge over a certain period of time or to quantify the influence of calendar ageing by means of various electrical characterisation tests.

In addition to the classical test procedures for determining the electrical properties of battery cells, battery test facilities also use special pulse methods to parameterize battery models. The focus is on electrical equivalent circuit diagram models, which allows to derive the electrical behaviour of the battery for simulations. By using the temperature test cabinets, battery models can be parameterized from -30°C to +60°C depending on the maximum operating temperature. With the help of electrothermally parameterized battery models, the use of the tested battery cells can be tested for various areas of application.

Overview - Lab equipment

Temperature test cabinets of the company Binder

Temperature test cabinets of the company 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

Temperature test cabinets of the company Weiss

- Test volume 600 l
- -40 °C to 180 °C

Temperature test cabinets of the company Vötsch

- Test volume 34 l
- -20 °C to 80 °C

S* incl. cabinet fire extinguishing system, exhaust air and emergency filter

Battery tester - XCTS series by Basytec

Cell tester by company BaSyTeC

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

Cell and module testers by Digatron and Fuelcon

- 6 channels ± 100 A, 0-6 V
- 3 channels ± 30 A, 5-150 V, connectable in parallel

System tester by Greenlight

- 1 channel ± 600 A, 5-200 V

Impedance spectroscopy by Ametek and Gamry Instruments

- 2 channels ± 20 A, 0-10 V, 10 μHz - 1 MHz
- 24x multiplexer ± 3 A, 0-32 V, 10 μHz - 1 MHz

Overview - Services

Formation of battery cells

Security and performance tests

Investigations of lithium-ion batteries at cell and module level

- Electrical characterization using appropriate analytical methods
- Ageing tests
- Modelling

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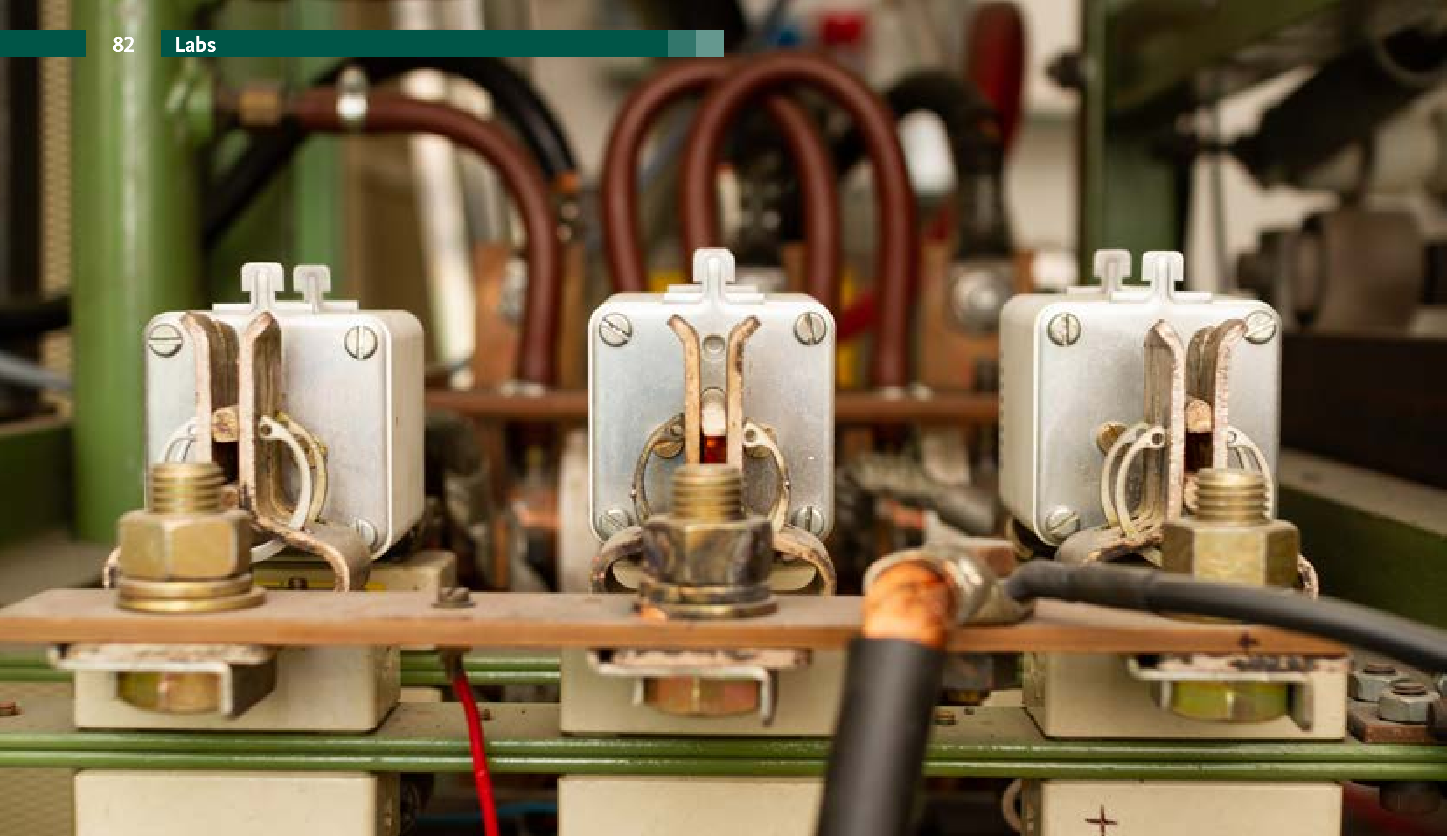


High Power DC Laboratory

Supply of several transformers from the 6 kV grid for the generation of DC voltage via an active rectifier circuit

Introduction

The high power DC lab has been part of elenia's laboratory portfolio for many decades. In the last few years, the use of the laboratory facilities has increased again. The decarbonisation of power generation and the resulting research focus on DC systems, which also includes DC switchgear, is the main reason for the development. The development is reflected by the permanent use of the premises by research projects as well as by industrial projects and service contracts.

Structure and components

The high power DC test lab offers a wide range of tests for testing DC switchgear. The power data and detailed description of the laboratory components can be found in the table below. In the recent past, various topologies of DC switchgear, e.g. mechanical switchgear with different extinguishing mechanisms as well as hybrid switches, have been investigated with the existing test setup. The high number and diversity of the switchgear is due to the large number of adjustable test parameters. Besides the voltage and the current, the time constant can be adjusted by means of the load impedance. The switch-off time can be defined by the sequence control and kept constant over the measurement series. The latest measuring technology allows reliable investigation of switching processes with power semiconductors. The measurement data is transmitted via fiber optic cables.

Experiments

The investigations and test evaluations carried out have a different scope. This ranges from simple investigations to determine the switching capacity to the investigation of plasma processes under various test loads. The standard statistical evaluation is usually supplemented by investigations of determined or expected processes.

Outlook

In the future, higher voltages and currents can be generated in a new DC test field. The test field in its current form is already a rarity, but with the new test field the elenia acquires a unique selling point. In addition to the individual switch tests, the future spectrum will be extended by a multi-stage DC demonstration grid. This can be used to investigate the effects of the grid dynamics on the actual situation and various protection algorithms.

Overview - Lab equipment

Transformers

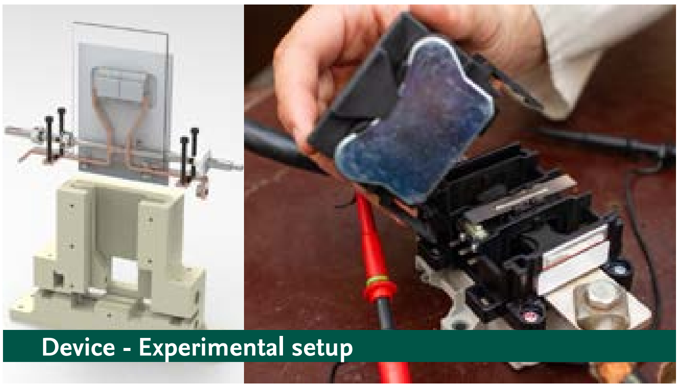
- Connection of the test field directly to the 6 kV distribution grid of the university
- Transformer 1: 500 kVA, 6kV/4*50V
- Transformer 2: 400 kVA, 200V/12*20V
- Transformers safety switches and top switches for starting and stopping investigations
- Currently another transformer is set in the laboratory
- In the course of the SMS II project, a DC demonstration grid will be set up to serve various voltage levels (3 kV, 1 kV, 380 V).

Rectifier

- Generation of direct current from alternating current via an active B6 bridge rectifier circuit
- Thyristor-based rectifier with fuses for reserve protection
- Max. DC test voltage: 560 V
- Max. DC test current: 5 kA
- Ignition angle adjustment
- Variable test duration due to digital sequence control

Measuring equipment (Camera, HBN Transient recorder)

- The logging of electrical as well as optical measurement data during the investigations is possible.
- Transient recorder HBM Gen2i/Gen3T-2:
- 16 measurement channels (isolated, BNC and LWL)
- 12 bit resolution
- 1 MS/s or 25 MS/s Sampling rate
- High speed camera Redlake MotionPro X4:
  - » Resolution 512 x 512 pixels
  - » Black and white or colour photographs
  - » Max. Frame rate of 200 kHz
  - » Min. exposure time 1 µs



Device - Experimental setup

A wide range of topics can be covered:

- Development, optimisation and switching tests with DC and hybrid switches, switchgear coordination, HV on-board power supply and automotive switchgear, investigation of the burn-up behaviour of plastics by switching arcs
- The demonstration grid consisting of SMS II is intended to enable a comprehensive investigation of the processes in DC distribution grid and of novel protection concepts for these.

Overview - Services

Development and optimization of DC switches and hybrid switchgear

Investigation of the switching characteristics of commercially available DC switching devices

Investigation of DC grid topologies

Development of a new DC protection system

Burn-up behaviour of plastics based on thermal arcs

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High Power Test Laboratory

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

The synthetic test facility of the institute is used for research activities regarding vacuum circuit-breaker for high-voltage level. For this purpose, trip tests are performed to determine the trip behaviour of the circuit-breaker. To establish the vacuum circuit-breaker on the high-voltage level two vacuum interrupters are installed in series in order to achieve the required dielectric strength.

A special vacuum receiver was designed for this purpose, which enables variable contact strokes. At this vacuum switch switch-off tests are carried out. For this purpose, the switch is first subjected to a high short-circuit current. The switch is opened during the current flow and a metal steam arc is created. After extinction of this arc, the switch is stressed by a damped voltage oscillation (transient voltage). The short-circuit current and the transient voltage occur during a disconnection process in the grid, which can be triggered by a mains fault. To generate the short-circuit current, a high-current capacitor bank is used. This bank is operated with a maximum voltage of 3 kV and thus generates a half of the Sinusoidal current oscillation of a maximum of 63 kA (rms) at an Frequency of 35 Hz / 50 Hz. The high-voltage capacitor bank generates the transient transient voltage, which can be controlled via a triggered spark gap switched shortly before the current zero crossing. The capacitor bank can be charged up to 150 kV. For safety reasons the bank is charged up to a voltage of up to 90 kV. This results in a peak value of the voltage of 137 kV. The remaining elements of the High voltage circuits are of modular design, which means that different Voltage slopes and frequencies can be generated. The frequency of the transient voltage is between 5 and 10 kHz, which corresponds to the frequencies in the medium and high-voltage level during the grid fault case and even beyond to increase the stress on the switch.

The metal vapour arc created during the experiments is observed through a sight glass and a high-speed camera. This process characterizes the arc and checks it on the basis of different model ideas. For most of the contact piece geometries, such as those of the transverse magnetic field contact (TMF contact), the arc rotates with a very high speed of up to 1000 m/s on the contact surfaces, which rise to different phenomena. These rapid phenomena are displayed by the high resolution (1024 x 1024) and maximum frame rate of 800 kfps of the camera.

Overview - Lab equipment


High current capacitor bank

Generation of a high current for stressing circuit breakers

- Max. Charge voltage 3 kV
- Max. Current 63 kA(RMS)
- Circular frequency 35 Hz / 50 Hz
- Energy 500 kJ


High voltage capacitor bank

Generation of a high voltage for testing the reconsolidation of the switching path

- Max. 137 kV TRV
- TRV frequency 5 to 10 kHz
- Energy 9.8 kJ


Vacuum test switch

Investigation of plasma phenomena between switching contacts possible

- Special vacuum receiver
- Vacuum pump ($p < 10^{-7}$ hPa)
- Variable stroke up to 40 mm
- Series connection of two circuit-breakers possible


High-Speed Camera

For the visual analysis of the electric arcs a high-speed camera is available

Nova S6 by Photron
- Resolution up to 1024 x 1024 pixels
- Black & White Shooting
- Maximum frame rate 800 kfps
- Maximum exposure time of 200 ns

Overview - Services

Power Testing
- Testing of circuit-breakers up to UN=72.5 kV
- Short-circuit test 1-phase

Analysis of Contact Geometry
- Investigation of novel contact geometries

Thermographic examination
- Investigation of surface temperatures of various materials

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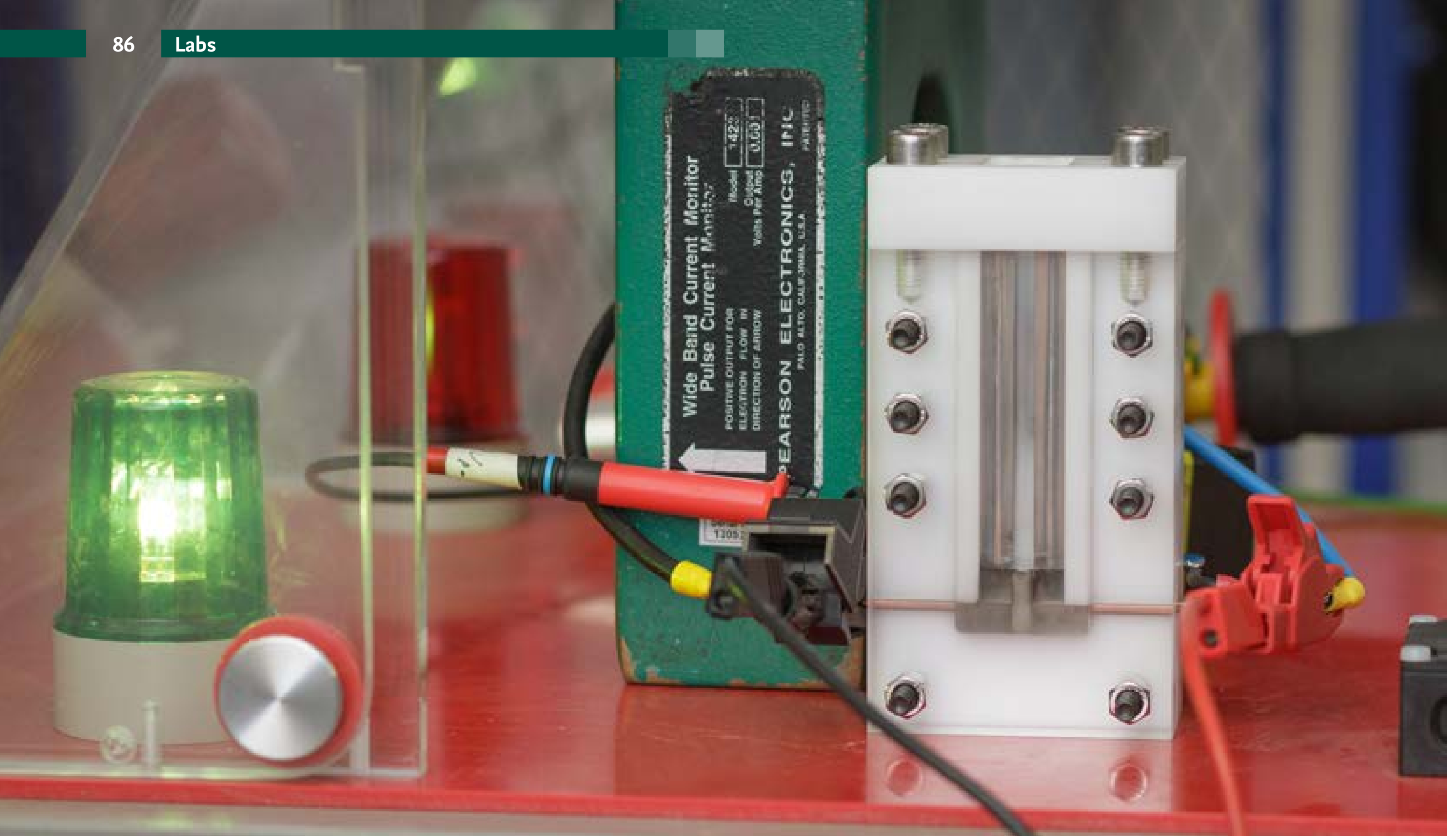


Lightning Protection Laboratory

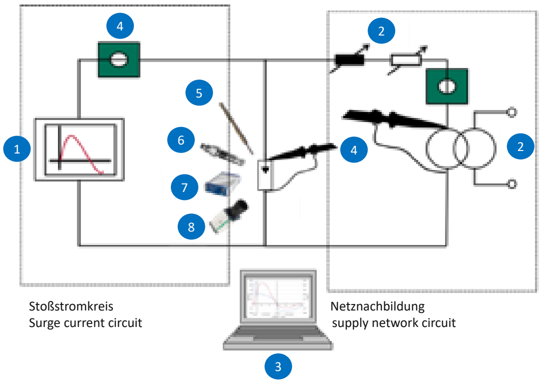
AC power test field with high short-circuit power and surge currents of up to 25 kA

Lightning current arresters (type 1 arresters) are used as coarse protection and ensure the safe operation of electrical and electronic equipment. They limit occurring overvoltages which are the result of lightning strikes or switching operations in the electrical grid. In the case of spark gap based lightning current arresters a plasma between two electrodes is created if a characteristical overvoltage occurs. This causes a short-circuit to the grounding system, which creates a potential equalization and high energies can be dissipated. The requirements for modern lightning current arresters include a high breaking capacity, in addition to the actual discharge process and the associated high energy absorption capacity. Due to the short-circuit to the earthing system interactions with the connected supply grid occur, so that a line-driven short-circuit current can flow through the plasma path (so-called follow current). After the successful derivation process, this follow current should extinguish as quickly as possible. For the investigation of lightning current arresters different surge voltage and surge current generators are available at elenia. Particularly noteworthy is the "Lightning Protection Lab". In this laboratory, in addition to a surge current a low voltage grid can be connected in parallel. Therefore the low-voltage grid is connected via three power transformers to the medium-voltage grid on the 6 kV level. This allows both the surge current as well as the follow current to be analyzed. Figure 1 shows the simplified schematic diagram of the laboratory.

The surge current is generated by a surge current generator (1). 8/20 µs impulses with up to 25 kA but also 10/350 µs pulses with up to 600 A can be generated. The grid supply provides three 130 kVA parallel-connected transformers (2). For adjustment of the ohmic-inductive ratio of the grid, resistance- as well as inductor-banks are available (2). To analyze these very fast plasma processes a stable and time-discrete measurement technology is necessary. Five measuring probes with an amplitude resolution of 14-bit at a sampling rate of of 100 MS/s are available. The measuring probes are connected electrically isolated via fibre optic cables to the measuring system (3). Furthermore, additional measuring equipment is available, e.g. Pearson probe, high voltage probes (4), potential probes (5), pressure sensors (6), spectrometers (7) and High-speed cameras (8). The current goal of the research is to improve the plasma properties after the surge current load in the transition to the follow current. Using the methods described in Figure 1 experimental investigations take place. Derived models can be validated by simulation. Based on these methods pressure, temperature and conductivity of the plasma in a high dynamical range can be determined.

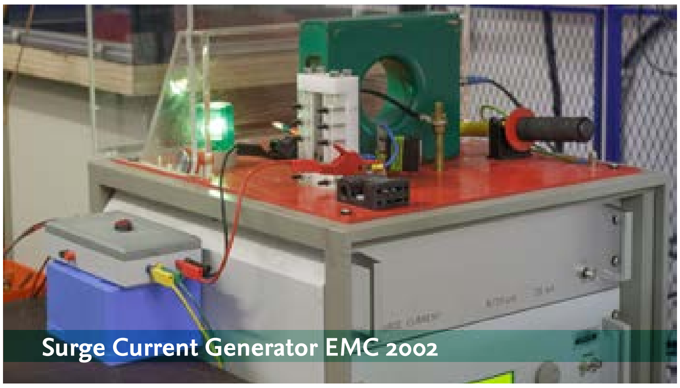
Research makes it possible to characterize the spark arresters and thus to create a target-oriented development of overvoltage protection.

Overview - Lab equipment



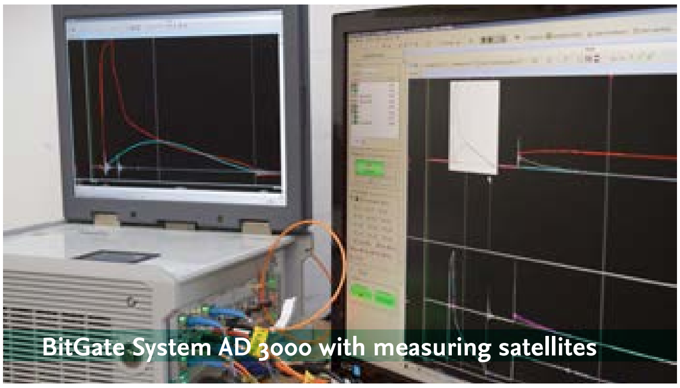
Experimental field for the identification of plasma processes

1. Surge current generator EMC 2002
2. Low-voltage grid up to 750 VAC with adjustable power factor (cos φ)
3. BitGate System
4. Voltage and current measurement
5. Conductivity via potential probes
6. Pressure measurement
7. Spectroscopy
8. High-speed camera


Surge Current Generator EMC 2002

Surge current generator for investigation of spark gaps with up to 25 kA

- Max. charging voltage of 10 kV
- Max. energy 1500 Ws
- Different curve shapes possible
- Max. surge current of 25 kA
- External control possible


BitGate System AD 3000 with measuring satellites

High-resolution measurement system for simultaneous recording of the electrical parameters

- 5 measuring channels
- 14 bit resolution
- Sampling rate up to 100 MS/s
- Signal transmission using optical fibres


High-speed camera Nova S6

High-speed camera for analysis of plasma distributions

- Resolution up to 1024 x 1024 pixels
- Black & white recording
- Maximum frame rate of 800 kfps
- Minimum exposure time of 200 ns
- External triggering possible

Overview - Services

Measurements at the low-voltage grid with voltages between 50 V and 750 V

Prospective short-circuit currents up to 15 kA at 250 VAC

Investigation of spark gap arresters with surge currents up to 25 kA (8/20 µs) or 600 A (10/350 µs)

Variable setting of cos φ (inductive)

Various grid synchronisation angles, triggering of surge current to 1° accuracy

Diagnosis of highly dynamic plasma properties (pressure, temperature and conductivity)

Contakt

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High Voltage Laboratory

High-voltage test facilities for components of low-, medium- and high-voltage technology

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 small test field in which a new test field for performance tests is set up , 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 andnew ones can be manufactured in the workshop of the institute. Among other things a cryostat is available for measurement campagnes up to $\hat{U}$ = 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 . In the third area, the small test field, a high-performance direct current test field is under construction. After completion test campaigns with a voltage of max. 12 kV (DC voltage) at a maximum of 30 kA are planned. Details can be found in the report "Universal Power Switch".

Overview - Lab equipment


Surge Generator

Fully regenerative grid simulator for the emulation of various Grid states with variable grid parameters

- 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


AC voltage transformer

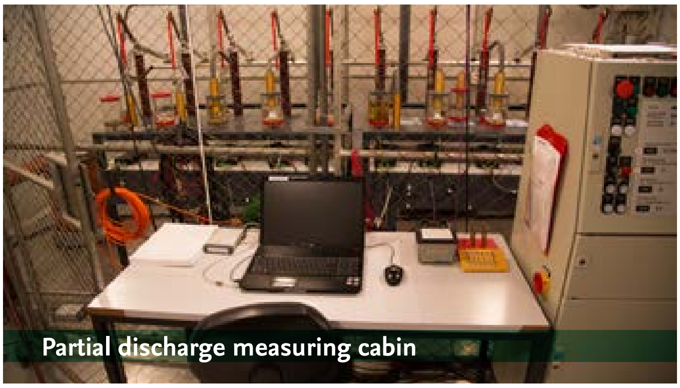
Real-time simulator with high computational power for Power-Hardware-In-The-Loop applications and delay-free laboratory control

- 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


Greinacher cascade and vacuum test vessel

Freely programmable full-scale power-converter for implementation and analysis of custom designed control models

- 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


Partial discharge measuring cabin

Coupled machinery set, consisting of asynchronous and synchronous machine with parameterizable inverter

- 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

Overview - 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

Contact

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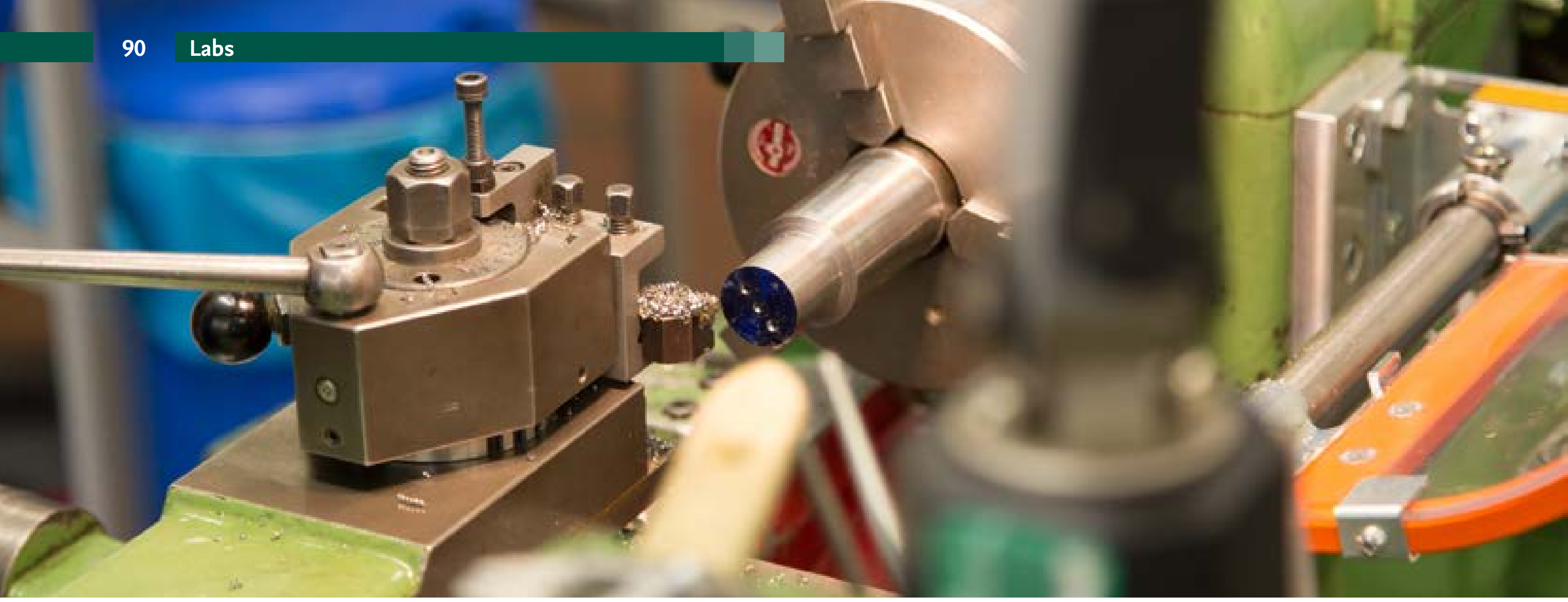


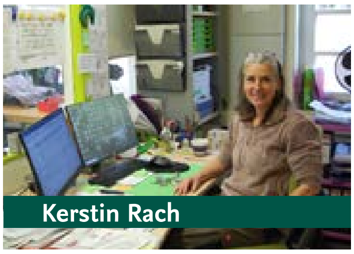
Mechanical Workshop

We support all scientific employees of elenia in their research with our expertise in the design, construction and mechanical manufacture of test facilities, test setups, components and test objects. Our service also includes the conversion and new construction of various laboratories and facilities relevant to research.

The following examples from last year are particularly worth mentioning:

- Set-up and modification in the performance test field
- High-performance capacitor bank for the project "Experimental investigation of a double-break with TMF contacts in vacuum". Vacuum double-break test switch for the project EULAS
- Universal Power Switchgear II
- Laboratory construction and rebuilding for the project Optimized cell formation "OptiZellForm"
- Model structure for transient analysis of lines

The employees of the mechanical workshop at a glance:



Kerstin Rach

Master mechanic in the mechanical engineering trade
Workshop manager and trainer

"The work and support of the scientific staff, including their research and the support of the staff and trainees in the mechanical workshop, is as unique and exciting as the people behind it. This individuality is what makes my work so appealing and challenging".

k.rach@tu-braunschweig.de

Frank Haake

Precision Mechanic

"I don't think about problems, I think about solutions."

f.haake@tu-bs.de

Reinhard Meyer

Precision Mechanic

"One of my major projects was the construction of a "vacuum double-break test switch". In addition to turning, milling, CF flanges (cutting rings), soldering contacts (vacuum) and frame manufacturing, the assembly was very interesting."

Julia Musebrink

Precision Mechanic
Mechanical Engineering

"The projects offer interesting and varied work."

j.musebrink@tu-bs.de

Alessa Damrath

Trainee precision mechanic 3rd apprenticeship year

"I really enjoy working here because the work is incredibly varied and I'm faced with new challenges every day".

a.damrath@tu-bs.de

Electrical Workshop

In addition to the usual day-to-day business, we can look back quite satisfactory on around 28 smaller and some larger orders completed in 2019. We thank you for the good cooperation in 2019 and look forward to an exciting new year with hopefully many challenging projects.

Selected projects of the electric workshop from the year 2019:

Repair

Control unit CNC milling machine

Improvisation

Integration of a test setup into the safety circuit of the HV lab

Construction

Tesla transformer

Construction

Arduino controlled traffic light for presentation time management

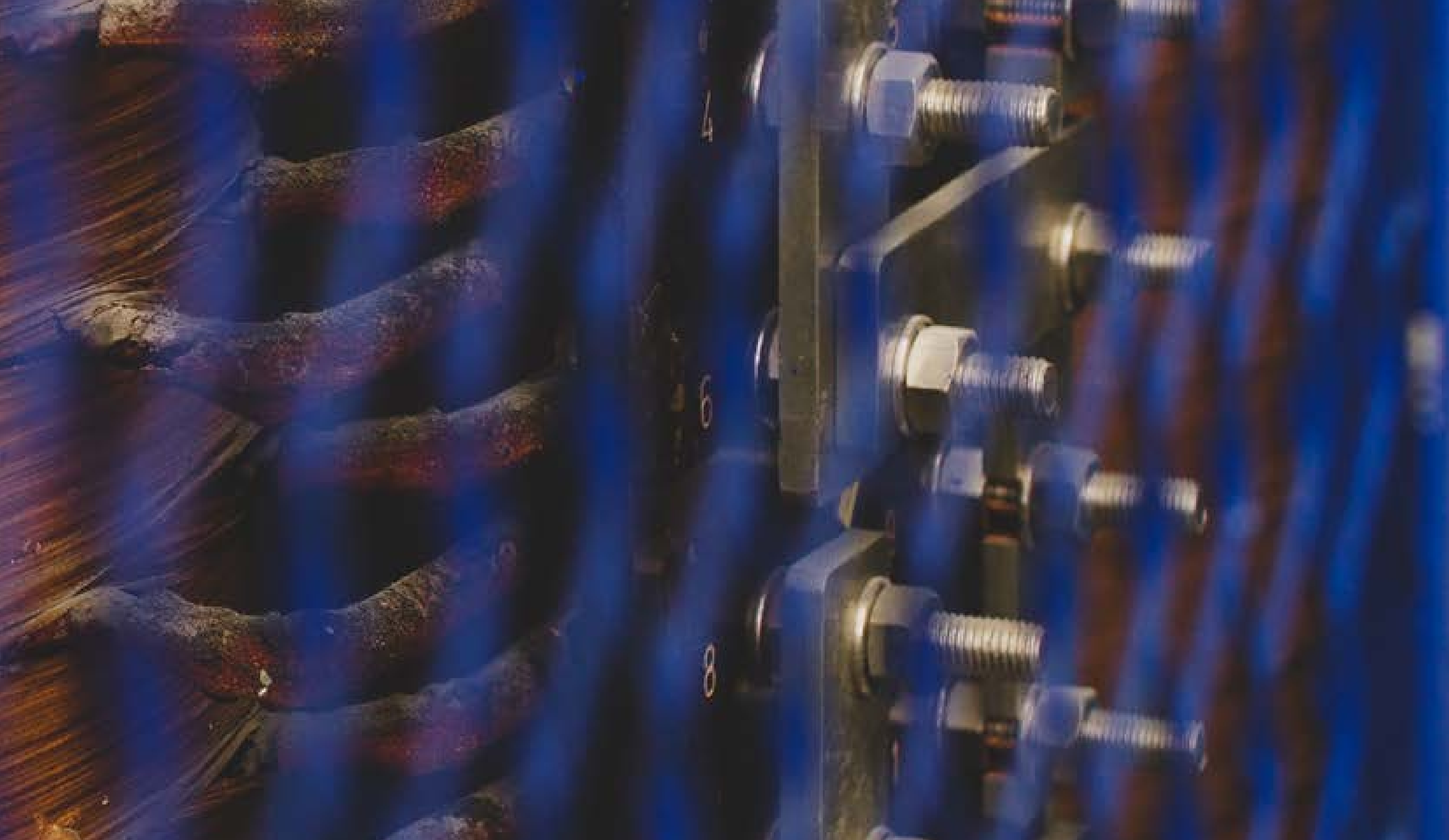
Construction

Laboratory distribution for the **elenia-energy-lab**

Teaching

4

Teaching at elenia



Lectures have a high priority at elenia. In addition to various lectures, we also offer a range of labs and seminars that can be attended by students. The lectures include basic courses as well as many advanced courses. External lecturers from the industry are also frequently appointed either for an entire lecture or for individual sessions. Our laboratories provide a broad spectrum of experiments, which we directly implement from our scientific work into our teaching. The Laboratory Experiment Smart Shop was redesigned this year for the Electromobility Practical Training Course.

Lectures

WORKGROUP
ENERGY SYSTEMS

RENEWABLE ENERGY TECHNOLOGIES

Contents of the lecture
Basics of the design of the power supply system and components
Technical principles of grid operation and system services
Overview of the electricity market and the influences on the energy transition

Lecturer Prof. Dr.-Ing. Bernd Engel

TECHNOLOGIES OF DISTRIBUTION GRIDS

Contents of the lecture
Structure and role of distribution grids in energy supply
Equipment, protection concepts, system services
Historical, present and future developments in the distribution grid

Lecturer Dr.-Ing. Johannes Schmiesing (avacon AG)

INNOVATIVE ENERGY SYSTEMS

Contents of the lecture
Conventional and sustainable generation of electrical energy
Sector coupling and its contribution to the energy system transition
System services and future requirements

Lecturer Prof. Dr.-Ing. Bernd Engel

FUNDAMENTALS OF POWER ENGINEERING FOR UI

Contents of the lecture
Introduction to complex ac calculation
Three-phase systems with focus on star and delta connection
Mediation of the theoretical basics of network equipment

Lecturer Prof. Dr.-Ing. Bernd Engel (i.a. together with Prof. Kurrat)

ELECTRICAL ENGINEERING I FOR MENG.

Contents of the lecture
Introduction and teaching of electrical engineering basics
Calculation of electrostat. fields, DC circuits, stat. magnetic fields
Consolidation of the teaching content through experimental presentation

Lecturer Prof. Dr.-Ing. Bernd Engel

ENERGY ECONOMICS AND MARKET INTEGRATION RE

Contents of the lecture
Energy-economical basics and regulatory framework of RE integration
System services through renewable energies
Guest lectures by experts from the industry

Lecturer Prof. Dr.-Ing. Bernd Engel

ELECTRIC RAILWAYS & EQUIPMENT OF RAIL VEHICLES

Contents of the lecture
Traction power supply, electric traction, brakes, auxiliary systems, Signalling and security systems, control technology, vehicles, passenger information, Catenary and battery buses, Future developments

Lecturer Prof. Dr.-Ing. Bernd Engel

Not shown: Systems engineering of photovoltaics (Prof. Engel)

WORKGROUP
ENERGY TECHNOLOGIES

ELECTRICAL POWER SYSTEMS I & II

Contents of the lecture (EA I)
Cable and network forms, equivalent circuit diagrams of equipment, synchronous machine, etc.
Grid calculation method, KS current calculation

Lecturer Dr. Ernst-Dieter Wilkening

Contents of the lecture (EA II)
Load capacity of equipment, switchgear, switching devices and protection technology, behaviour of the mains voltage after interruption of the current flow

Lecturer Dr. Ernst-Dieter Wilkening

DESIGN AND CALCULATION OF DIRECT CURRENT SYSTEMS

Contents of the lecture
Basic knowledge of the structure of direct current grids and their components
Independent calculations for operating behaviour and faults
Knowledge of permissible system states during operation and the safety regulations

Lecturer Prof. Dr.-Ing. Michael Kurrat

STRUCTURE AND FUNCTION OF STORAGE SYSTEMS

Contents of the lecture
Basic knowledge of the structure and functionality of storage systems
Knowledge of storage characteristics, design for double layer capacitors, battery storage, charging infrastructure and hydrogen technologies

Lecturer Prof. Dr.-Ing. Michael Kurrat

TECHNOLOGY OF TRANSMISSION GRIDS

Contents of the lecture
Components of electrical power engineering e.g. overhead lines, cables and transformers
Stability, fault cases, network forms, network planning and system analysis
Power plant types such as conventional and renewable energy generation plants

Lecturer Dr.-Ing. Christian Schulz

NUMERIC CALCULATION METHODS

Contents of the lecture
Fundamentals for the numerical solution of linear systems of equations
DGL 1st order (initial value problems) and partial DGL
Computer exercise

Lecturer Prof. Dr.-Ing. Michael Kurrat

HIGHT VOLTAGE TECHNOLOGY I & II

Contents of the lecture (HST I)
Design criteria for power transmission systems
Insulation coordination in HV AC and DC systems
Basic principles of gas discharge

Lecturer Dr.-Ing. Michael Hilbert

Contents of the lecture (HST II)
Thermal and mechanical load capacity of
Operating equipment, switchgear/switchgear and protection technology, Behaviour of the voltage after current interruption

Lecturer Prof. Dr.-Ing. Michael Kurrat

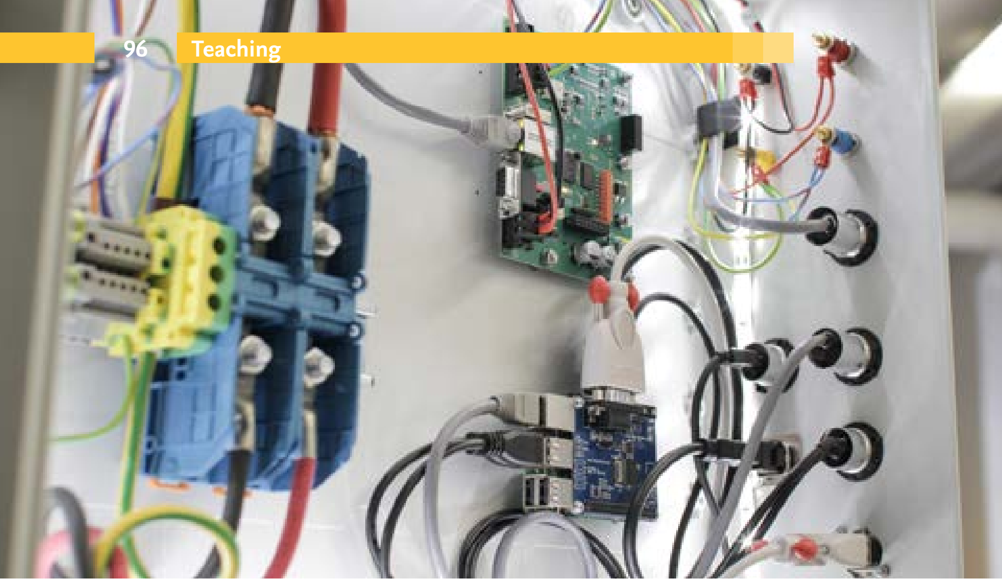
FUNDAMENTALS OF POWER ENGINEERING + GENT UI

Contents of the lecture
Principles of high voltage technology
Complex calculations for Y and Δ circuits, overhead lines, transformers and generators

Lecturer Prof. Dr.-Ing. Michael Kurrat

Contents of the lecture (GENT UI)
Basics of electric and magnetic fields
Calculations for direct current circuits, charging and Discharge processes, R-L-C with alternating current

Lecturer Prof. Dr.-Ing. Michael Kurrat
(i.a. together with Prof. Engel)



Lab Course: Smart Charging

A new laboratory experiment for the Electromobility Practical Course

Electromobility is an important part of the mobility and energy transition. The increasing number of electric vehicles and the rapid expansion of charging infrastructure will, however, pose challenges for existing energy distribution grids. An approach towards integrating a large number of electric vehicles into existing networks is smart charging. This involves actively adapting the charging capacity on the basis of current grid conditions and the simultaneous communication with the electric vehicle. Within the scope of the new laboratory test, students will be introduced to the smart charging of electric vehicles in a realistic environment. This experiment is the first at the TU Braunschweig to address the area of charging electric vehicles. It represents a practical supplement to existing lectures in the field of electrical engineering and to the Master's course in electromobility as a new experiment of the mandatory lab practical. Such hands-on experience can be of great advantage for later professional life, especially for graduates in the field of electromobility. Altogether, students will gain an insight into the world of electromobility.

Facts about the lab practical course

The laboratory practical course Smart Charging of Electric Vehicles was financed from funds for improving study quality with a total of 10100 euros. The experiment was set up in the winter semester 2018/2019 and was actively supported by the electrical workshop of elenia and Marvin Kruse, a former scientific assistant at elenia. The experiment will be carried out for the first time in the winter semester 2019/2020 as part of the Laboratory Master Electromobility course. The main target group of the course are students in the master's programmes in electrical engineering and electromobility.

Course description

The test participants will learn the basics of charging processes in the lab course. For this purpose, the holistic charging process will be discussed. This is divided into four parts. The first part is the initialization of charging and charging communication. This ensures standard-compliant data exchange between charging station and electric vehicle in accordance with ISO 15118 or DIN SPEC 70121. The second important part of charging an EV is power transmission. It must be designed and adapted for safe and fast charging. The charge control system, which is another important part of charging, provides further support in this regard. The last of the four points that the students learn from this practical course is grid-oriented charging, which continues to gain in importance as the number of electric vehicles and their charging capacity is increases. The aim of grid-oriented charging is to keep the electricity grids stable despite charging processes.

The experimental setup consists of a self-constructed DC charging station. A DC source from the elenia grid dynamics laboratory is used as the charging device for the charging station. The communication and control technology consists of a charging station controller, which takes over the standard-compliant communication with the electric vehicle, and a Raspberry Pi. The Raspberry Pi, for example, implements the grid-oriented charging algorithms. Furthermore, a toy car was equipped with a communication controller for electric vehicles and communication interfaces. The figure below shows the Bobbycar equipped with charging technology.

The procedure is divided into several parts. First, the theoretical knowledge required to understand the tests is taught using the test setup. These include, for example, the different charging modes, standardised charging plugs and charging

Bobbycar equipped with charging technology communication. The knowledge is then put into practice in two experiments. In the first experiment, a charging process is first simulated with the Bobbycar in order to demonstrate to the students the basics of communication during a charging process in a practical and comprehensive way. Then, in the second attempt, a real charging process is carried out on the institute's own e-golf. The DC charging station of the experimental set-up is used for this purpose. Among other things, this experiment will test grid-compatible operating modes such as active power control. During the two experiments, the students perform various practical tasks, such as reading the PLC signal of the charging cable with an oscilloscope, translating CAN messages and adapting the program code of the Raspberry Pi.

Extension possibilities of the experimental setup

In the future, the laboratory test can be extended with an alternating current charging station, which will allow students to gain further insights into the charging techniques of electric vehicles. Furthermore, a measuring system can be integrated into the structure. This would enable extensive metrological investigations during the laboratory tests and increase the practical experience gained by the students.

Lab Practical Course
Smart Charging
of Electric Vehicles

Contact
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funded by "Studienqualitätsmittel"

Lab practical courses and seminars of the elenia

Overview

PRACTICAL COURSE
ANALYSIS, SIMULATION AND PLANNING OF GRIDS

PRACTICAL COURSE
HIGH VOLTAGE TECHNOLOGY

PRACTICAL COURSE
INNOVATIVE ENERGY SYSTEMS

PRACTICAL COURSE
ELECTRIC MOBILITY

PRACTICAL COURSE
NUMERIC CALCULATION METHODS

STUDY SEMINAR
INNOVATIVE ENERGY SYSTEMS

DOCTORAL SEMINAR
HIGH VOLTAGE TECHNOLOGY
SUSTAINABLE ENERGY SYSTEMS

Contents

Electric Mobility

Contents of the practical course
Simulation of electric drive trains
Design of power electronics
Charging process and technology of EV

Lecturer Prof. Dr.-Ing. Michael Kurrat

Numeric Calculation Methods

Contents of the PC practical
Typical simulation programs
Create and evaluate models with Comsol Multiphysics and LTSpice.

Lecturer Prof. Kurrat

Innovative Energy Systems

Contents of the practical course
Experiments on solar cells, inverters, battery storage, island grids and energy management

Lecturer Prof. Dr.-Ing. Bernd Engel

Innovative Energy Systems

Contents of the seminar
Lecture series and presentation training on energy technology and energy management topics

Lecturer Prof. Kurrat, Prof. Engel

Analysis, Simulation, Planning of Grids

Contents of the practical course
Introduction to grid calculation
Load flow and short circuit calculations
Quasidynamic simulations

Lecturer Prof. Dr.-Ing. Bernd Engel

High Voltage Technology

Contents of the practical course
HV measurement, insulation and DC technology, lightning impulse voltage
Use of Augmented Reality

Lecturer Prof. Dr.-Ing. Michael Kurrat

Doctoral Seminars

Contents of the seminars
Understanding systems thinking
Comprehension of system theory
Sustainable energy systems

Lecturer Prof. Kurrat, Prof. Engel

Experiences of a Master student

The experiences of the master thesis of Timo Meyer

My studies at the TU

Before I started my master's degree at the TU Braunschweig, I completed my bachelor's degree in electrical engineering in Osnabrück with a focus on energy technology and automation. I wanted to continue my master's degree with a focus on energy technology. The wide range of courses offered at the TU Braunschweig led me to the TU. I quickly realized that I was fascinated by the topic of energy distribution, components and in particular high-voltage technology. Therefore I decided to write my thesis at elenia.

First contact with the elenia

As a student assistant I took over simulation tasks at elenia together with a fellow student. I simulated electric fields, temperatures and pressure equalization processes for different geometries. Working hours were flexible and I had access to the computer room at the department. This was ideal if you wanted to make the most of the time between lectures. I liked the work so much that I wanted to do another small HiWi job with more practical orientation. So I helped to set up test circuits in the synthetic power test field as well as to investigate the switching processes of vacuum circuit breakers.

The way to my master thesis

Out of the many topics offered at elenia, I was particularly interested in vacuum switching technology. I talked to my supervisors from the HiWi job about current research topics, my wishes in the master's thesis and currently advertised theses. After a short period of reflection, I decided on a topic. In October 2018 I started my master thesis "Design, construction and characterization of a high-voltage test circuit for the generation and measurement of transient return voltages".

The work as a master student

The master thesis started with a kick-off meeting between me and my supervisors, in which all work loads were discussed and a rough schedule was developed. My working time was flexible because I had access to the synthetic power test field and the computer room. I could also work from home or in the library. In regular meetings with my supervisors I presented the current status of the master thesis and discussed the next steps. I was able to work very independently and implement my own ideas, and when I couldn't get any further, my supervisors were there to help and advise me. Other staff members were also willing to help me. The team at elenia is very supportive and offers a large number of theses, which are displayed on the notice board at the institute. You can also find many HiWi jobs (www.elenia.tu-bs.de/stellenangebote) and theses on the elenia website (www.elenia.tu-bs.de).


Timo Meyer, M.Sc.

Modelling of losses in the context of simultaneous multiple use

Due to the increasing number of PV-coupled storage systems in the private sector, more and more efficient and at the same time grid-serving storage operation strategies are being investigated. One possibility to make use of the technical potential of a home storage system is simultaneous multiple use. This enables the simultaneous use of a battery storage system by the owner and an external party. Before this utilization strategy can be introduced, billing-related challenges must be clarified.

In my master thesis I modelled the relevant loss mechanisms in a technology-oriented way and investigated the economic effects. For a realistic data basis I measured a physical storage system in the energy management laboratory. I learnt that working diligently in the laboratory is essential to resolve unforeseeable technical challenges. The results showed that the most relevant factors for billing for simultaneous storage systems are conversion losses, control losses and standby losses in descending order. These three loss mechanisms were subsequently modelled within the inverter model of the elenia simulation environment (eSE). The biggest challenge for me was the introduction to eSE, as I had not had any experience with simulation environments before. However, the help tool provided and the support of my supervisor enabled me to become familiar with eSE relatively quickly.

In addition to the loss mechanisms, I implemented simultaneous multiple use as an operating strategy for PV storage systems and the distribution of conversion losses in different scenarios in eSE. The result of my work was, that the simultaneous use of storage systems reduces the annual conversion losses and thus the electricity costs for the storage owner, independent of the allocation method. I enjoyed modeling the most in my master thesis, because I was given a lot of freedom in which way to model the relevant processes. Over time, I became aware that I had to make important decisions for my model independently, and that this sometimes meant making the wrong decision.


Mattias Hadlak, M.Sc.

Student theses at elenia 2019

Student Research Theses

Gloria Kreft	Analyse der Einflussfaktoren in der Formierung und SEI-Bildung von Li-Ionen-Batterien
Bente Andersson	Wirtschaftlichkeit von Batteriespeichern im Primärregelleistungsmarkt

Bachelor Theses

André Rehbock	Erstellung eines Batteriemodells für ein Lithium-Ionen-Batteriemodul in MATLAB/Simulink
Nils van Ohlen	Simulation und Entwurf einer regenerativen Wasserelektrolyse mit dem Lastprofil eines Windparks am EWE Standort Huntorf
Marten Thomes	Systematische Konzeptentwicklung von DC-Systemen mit anschließender Modelica Implementierung
Duy Khanh Pham	Development of a Systems Engineering Based Assessment Methodology for DC Systems
Fenglin Zhou	Development of a software-based analysis tool for the evaluation of measurement data of spark gaps during surge current tests
Wai-Yee Choi	Entwicklung einer Benutzeroberfläche für eine Flottenlademanagementsimulation
Henrik Netz	Analyse des dynamisches Verhaltens spannungseinprägender Wechselrichter bei symmetrischen Netzfehlern
Violetta Zimmermann	Analyse des Verhaltens spannungseinprägender Wechselrichter bei netzseitigen Spannungszeigersprüngen im Labor
Xiaoxiong Wang	Entwicklung einer modularen Steuerungsumgebung zur Untersuchung von energetischen Komponenten für Prosumer-Haushalte
Philipp Jassmann	Verbrauchs- und Nutzungsanalyse der Hybridflotte bei BS|Energy

Master Theses

Keyuan Luo	Modelling of HVDC Grid Topologies and DC Breakers in MATLAB/Simulink
Frederik Anspach	Untersuchung zur Auslegung von DC-Schalterkonzepten in Gleichspannungsbordnetzen (Pierburg)
Robin Drees	Simulative Anforderungsableitung zur elektro-thermischen Auslegung von Hochvolt-Batteriesystemen (VW)
Patrick Rinder	Konzeptionierung und Programmierung eines Batteriemanagementsystems für Lithium-Ionen-Batteriemodule auf Basis eines PXI-Systems
Tianzhu Cang	Measurement uncertainty determination of novel high-voltage impulse dividers (PTB)
Nils Müller	Standortanalyse der öffentlichen Ladeinfrastruktur in Braunschweig (BS|Energy)
Thomas Steens	Lastprognosen zur Einbindung von Elektromobilität in das Energiemanagement von Bestandsgebäuden (DLR)
Mattias Hadlak	Modellierung und Evaluation eines Wechselrichterverlustmodells im Kontext der Mehrfachnutzung von PV-Speichersystemen
Louis Bültemann	Bewertung der Qualität von Lithium-Ionen-Batteriezellen mittels differentieller Spannungsanalyse
Sebastian Wolf	Entwicklung eines Verfahrens zur Optimierung der Blindleistungsflüsse im Verteilungs- und Übertragungsnetz
Saeed Ghorbanpour Besheli	Entwicklung und Untersuchung von Betriebsstrategien von STATCOM-Anlagen an der AC-Netzanbindung von Offshore-Windparks
Martin Wernicke	Untersuchung der Potenziale und Möglichkeiten zur Einbindung industrieller Blindleistungskompensationsanlagen in das Blindleistungsmanagement der Netzbetreiber
Christoph Steinmann	Entwicklung einer Verfahrensweise zur Analyse des Blindleistungspotenzials von Stromnetzen
Karen Flügel	Untersuchung der Blitzstoßspannungsfestigkeit einer kombinierten Schirm- und Steueranordnung für eine Vakuum-Doppelunterbrechung
Jan Hölk	Untersuchung der Alterung von Lithium-Ionen-Batterien durch dynamische Belastung mit Stromprofilen in Entladerichtung
Joseph Broer	Innovative Konzepte zur Bereitstellung des Offshore Windpark Eigenbedarfs unter Berücksichtigung von HGÜ-Netzanschlusstopologien
Jan-Niklas Krokowski	Präqualifikation von Photovoltaikanlagen für den Regelleistungsmarkt
Marc Kappelt	Konzeptionierung, Entwicklung und Integration von künstlicher Intelligenz für Prognosen innerhalb eines dynamischen Flottenlademanagements
Götz-Nikolaus Grobelny	Erweiterung eines spannungseinprägenden Regelungsverfahrens für Wechselrichter um eine Strombegrenzung für Kurzschluss- und kurzzeitige Überlastsituationen
Alexander Larisch	Bereitstellung von Momentanreserve mittels Heimspeichersystemen im Niederspannungsnetz
Stefan Czybik	Analyse der im Verteilungsnetz eingesetzten Wide Area Network-Technologien auf deren IT-Sicherheit, Reichweite und Anwendungspotenzial
Thanh Nguyen	Balancing markets in the context of developing countries: Setup of a concept, simulation and application in a case study
Léon Beuchel	Erstellung synthetischer Lastprofile für den Energiebedarf von Ladebereichen für Elektrofahrzeuge
Steffen Meyer	Erstellung synthetischer Lastprofile für den Strombedarf von Gebäudelasten unter Berücksichtigung von Energieeffizienzmaßnahmen
Timo Meyer	Entwurf, Aufbau und Charakterisierung eines Hochspannungsprüfkreises zur Erzeugung und Messung transienter Wiederkehrspannungen
Dennis Altmann	Bewertung von Lithium-Ionen Batterien für 2nd-Life Anwendungen mittels elektrochemischer Impedanzspektroskopie und Pulse-Fitting Methode
Adrian Göbel	Eigenbedarfsversorgung und Schutzauslegung für ein neues GuD-Kraftwerk (VW Kraftwerke)
Jörn Wolters	Entwicklung von Verfahren zur Inselnetzerkennung durch spannungseinprägende Umrichter
Holger Teichmann	Hotspotsanalyse Elektromoblität in Braunschweig (BS|Netz)
Tom Bender	Modellbasierte Einflussgrößenanalyse von E-Fuels als Ergänzung zur Elektromobilität (IAV)
Henrik Wagner	Untersuchung von NOVA-Maßnahmen für Elektromobilität-Hotspots
Philipp Kiemele	Veränderungen in Planungsgrundsätzen aufgrund der steigenden Elektromobilität (BS|Netz)

Events

5

At elenia we are not only working at the computer or in the laboratories, we are also active beyond the boundaries of the department, which is reflected in this year's diverse events. In addition to the discussions on research projects and dissertation topics within the two working groups, we have also exchanged information extensively across the different research areas. As the host of the first EFZN Research Day, we hosted participants from all over Lower Saxony at the TU Braunschweig in February. The promotion of young researchers is also not neglected at elenia with events for high school graduates and students. The first elenia Open Research Day in particular was met with great enthusiasm by all participants. We are already looking forward to the academic and fun-packed events in 2020.

Special Events

Reports on selected events of the year 2019

Niedersachsen Technikum, January 25th, 2019
As part of the Lower Saxony Technical Centre of the TU Braunschweig, eleven technically interested high school graduates were guests at elenia on 25 January. After a brief introduction to the department, the young women were given an insight into the practice of our diverse research areas. The high voltage laboratory proved to be particularly exciting, however, our elenia energy labs, the battery laboratory and emilia - our E-Golf - also attracted a great deal of interest. We hope to have brought the technical courses of study, especially electrical engineering, a little closer to the high school graduates and to be able to welcome some of them later at elenia.

EFZN Research Day, February 19th, 2019
Energy research in Lower Saxony - this was the focus when the EFZN branch in Braunschweig invited to the EFZN Research Day in the House of Science on 19th February. The event was attended by about 60 guests and was primarily aimed at young researchers. In addition to lectures on "Networked Energy Systems", "Sustainable Energy Storage and Power2X" and "Energy Transition in Aviation", a poster session offered the opportunity to gain insights into the research fields of the other EFZN branches and to build valuable new contacts. In the following years, the event will be continued as a series at the other EFZN locations.

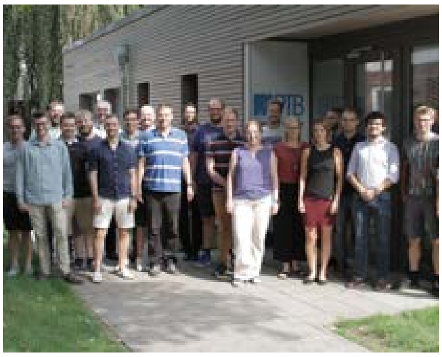
Joint focus group day of the elenia, May 14th, 2019
On 14. May 19, the elenia researchers met at PTB to discuss their research. All three research focal groups of the elenia were represented, consisting of the smart grids, electromobility and the components of energy supply. In total, more than 40 scientists under the leadership of the three mentors Prof. Michael Kurrat (elenia), Prof. Bernd Engel (elenia) and Dr.-Ing. Frank Lienesch (PTB) took part and presented their research priorities in a poster session with an open discussion. The event was a resounding success.

elenia Open Research Day - by employees for students, May 25th, 2019
The goal of the first Open Research Day was to bring research at elenia closer to the students. With around 30 interested guests, our expectations were clearly exceeded. After a brief overview of the department and our fields of research, there was a guided tour of the laboratories in small groups. The explanations and demonstrations on laboratory equipment and investigations led to exciting discussions. Finally, we answered questions about the everyday life of a researcher at elenia and ended the evening with a barbecue in front of our high-voltage laboratory.

NFF-Cup 2019, June 24th, 2019
For the fifth time the NFF Football Cup took place and elenia this year was represented by a very large and very talented team. In an exciting quarter final match against the IDS there was an invalid throw-in respectively shot in the last minutes which led to an opposing goal and thus ended the tournament for the "Team elenia". In the final, the "Team IWF" won 2-to-1 against " Team IK". For the fifth year in a row, an institute that had not won the trophy before was able to win. Preparations for the next tournament are already underway. It's nice that elenia enjoys working together as a team even beyond working hours.

Whitsun Excursion, June 11th-13th 2019
Once again this year, we went to Amsterdam for our traditional three-day excursion together with students and the Department of EMC. On the outward journey we visited the Kema in Arnhem. Europe's largest testing institute for energy technology components gave us many insights into its test laboratories. On the second day we were allowed to visit the ESA in Noordwijk. The day agenda offered many topics around space travel. Highlights were the prequalification for electrical components for use in space and a presentation of the Galileo navigation system. Of course, we were presented with opportunities to join ESA after graduation. As part of our cultural programme, we visited Amsterdam's museums on the third day. All in all, we can look back on a very successful excursion and are already looking forward to the 2020 excursion.

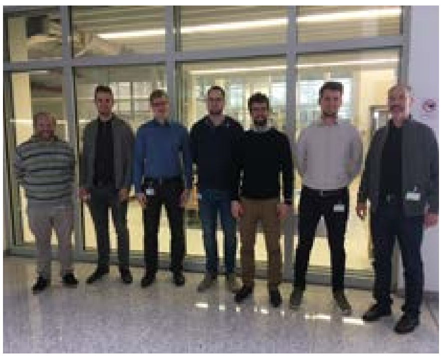
AG-Workshop Workgroup Energy Systems, August 30th, 2019
This year the workshop of the AG-Energy Systems took place in the close neighborhood of the institute, in the premises of the Physikalisch-Technische Bundesanstalt. There, every researcher of the workgroup had the opportunity to present his or her field of research. Afterwards in the "World Café" in small discussion rounds creative ideas were gathered for questions related to the project, so that everyone could benefit from something for their research project. Besides the technical part of the event, canoeing and swimming took place on the Oker in perfect weather. The evening ended on an Oker raft with drinks and a barbecue. group Energy Systems



AG-Workshop Workgroup Energietechnologien, September 16th-19th, 2019
The AG-Workshop Energy Technologies this year took place in Sächsische Schweiz. Therefore the teambuilding activities took place in the Dresden area. Among others, the old town of Dresden and the famous Basteibridge were visited. Individual and general research questions were discussed by all members of the AG. Methods of a World Café and Open Space were used for a creative exchange. The result was a broad portfolio of answers to various questions which were compiled by us and stored in our knowledge database.

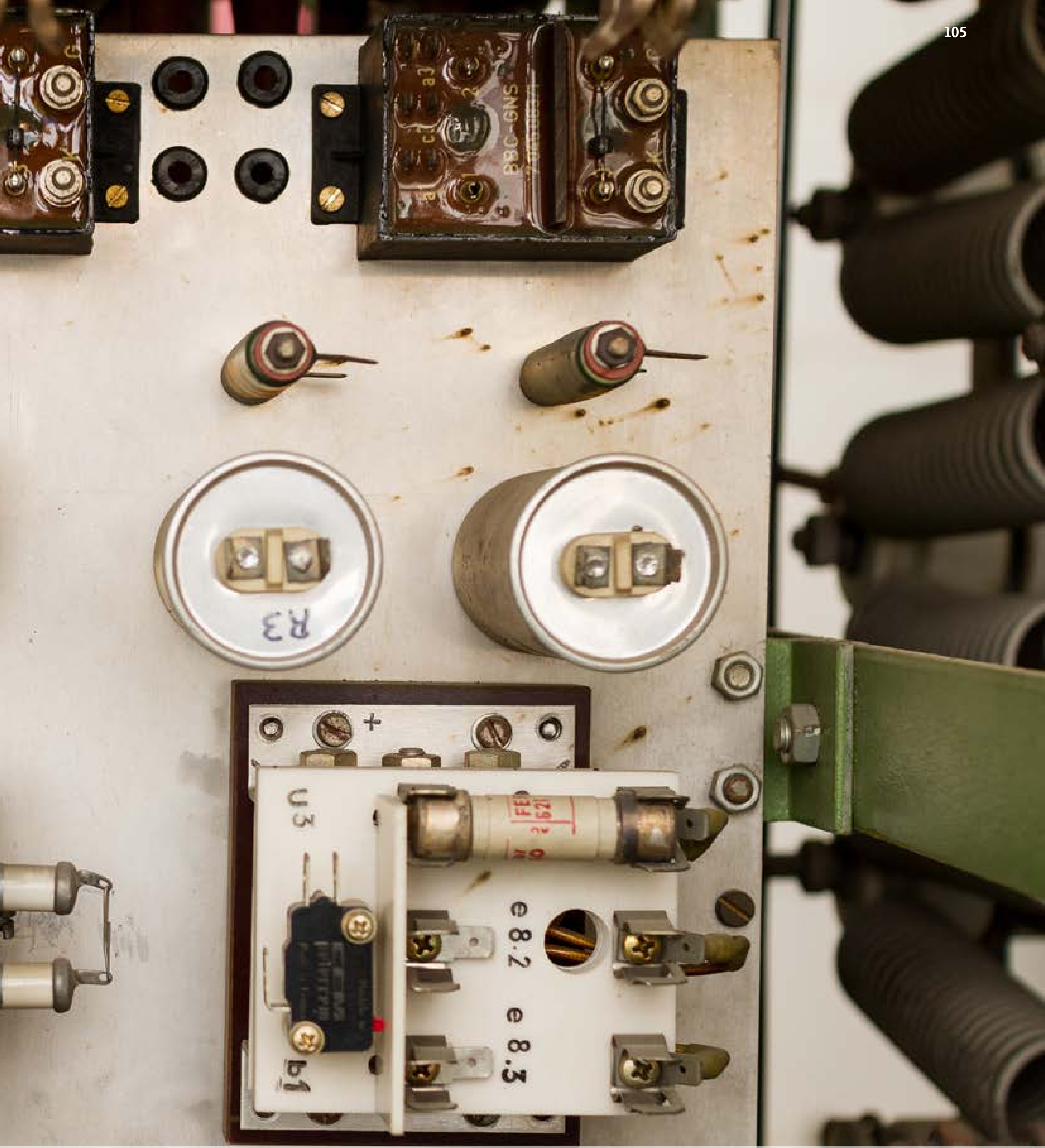
Department's Workshop Goslar, September 25th, 2019
This year's Department Workshop 2019 included a varied schedule. In the morning we visited the Energy Campus Goslar including a guided tour through the laboratories of the research center. Among them were the laboratories of the active distribution grid, the battery and sensor test centre as well as the storage laboratory. The program continued in the afternoon with a city tour in Goslar under the theme "On the tracks of the Goslar Gose", in which the traditional and old brewing art of the Goslar Gose was explained. The event ended with a joint barbecue at the elenias automobile laboratory.

Workshop Novizen 2019, November 27th, 2019
6 new doctoral candidates from the AG Energy Technologies joined forces in mid-2019 to form the "Novizen" team. Together, they raised the question of whether it would be possible for the team to develop the research questions for the doctoral thesis in the first year. The novices organise themselves and use modern management tools. They evaluate the results themselves and receive quarterly feedback and methodological support from the supervisor. In the final phase of the first year, a two-day workshop took place in November at Phoenix Contact in Blomberg. The novices presented and discussed the current status of the individual doctoral projects. The exposé and rough planning of the doctorate in the first year seems to be within reach for the novices.



Chronology

6



At the end of each year, most people look back on the past twelve months and reflect on them. At the end of our annual report, we would like to do exactly this again in collaboration with you from the perspective of elenia. On the last pages you have already learned a lot about the year 2019 at elenia: new employees, completed and ongoing research projects, laboratory set-ups and reconstructions, news from teaching and much more. As a whole year tends to bring with it so many events, which cannot all be presented in detail, the concluding chronology provides an overview of the most important events.

The year 2019 at elenia

17.01.2019
acatech AG meeting (De-)central energy supply, Frankfurt
Prof. Engel

18.01.2019
Excursion system technology of photovoltaics to SMA Solar Technology, Kassel, Kassel
Prof. Engel, Winter, Students

23.01.2019
VDE New Year reception, Braunschweig
Prof. Kurrat

23.-25.01.2019
Conference Battery Forum Germany, Berlin
Brockschmidt, L.Hoffmann

28.01.2019
FKR (Faculty Board), Braunschweig
Prof. Kurrat

29.01.2019
Mentor meeting, Braunschweig
Prof. Kurrat,Pronobis

30.-31.01.2019
Future Power Grids Conference, Berlin
Prof. Engel

31.01.2019
Niedersachsentechnikum, Braunschweig
Employees

08.02.2019
BWG, Braunschweig
Prof. Kurrat

11.02.2019
Doctoral Examination Marco Lindner, TU München, München
Prof. Engel

12.02.2019
PV-Regel Closing workshop, Kassel
Osterkamp, Seidel, Prof. Engel, Rauscher, Reinhold

13.-14.02.2019
Faculty retreat EITP, Wöltingerode
Prof. Kurrat, Prof. Engel

15.02.2019
ETG-Board meeting, Frankfurt
Prof. Engel

18.02.2019
Special-FKR, Braunschweig
Prof. Kurrat

19.02.2019
EFZN-Research Day, Braunschweig
Whole Department

19.02.2019
EFK General Assembly, Braunschweig
Prof. Kurrat

20.02.2019
HEV 2019 – Hybrid- und Elektrofahrzeuge, Braunschweig
Prof. Engel

20.02.2019
Senate, Braunschweig
Prof. Kurrat

21.02.2019
FNN-Infoday for VDE-AR-N 4105, Kassel
Prof. Engel, Marggraf, Biedermann

22.02.2019
EFZN-Supervisory Board/Advisory Board Meeting, LUH
Prof. Kurrat

25.-26.02.2019
Exchange of experience Low voltage test bays, Braunschweig
Peters, Klosinski, Prof. Kurrat

26.02.2019
Exchange of experience test facilities, Braunschweig
Prof. Kurrat, B. Weber

26.02.2019
Kick-off-Meeting Realignment of ETG department V1, Frankfurt
Prof. Engel

27.02.2019
External Young Docs meeting, Braunschweig
Prof. Kurrat, Young Docs

28.02.2019
DFG Round Table: Electric Flying, Aachen
Prof. Kurrat

05.-15.03.2019
Employee feedback, Braunschweig
Prof. Kurrat

11.03.2019
BMWi Reactive Power Commission 3rd meeting, Berlin
Prof. Engel

13.-14.03.2019
DaLion 4.0 Kick-Off, Braunschweig
Prof. Kurrat, LHoffmann

14.03.2019
Capital Conference on Electric Mobility, Berlin
Pronobis, Wussow

14.03.2019
NEDS Quarterly Meeting, Hannover
Prof. Engel, Seidel, Reinhold

18.03.2019
Women of Wind Energy Deutschland Round Table, Braunschweig
MHoffmann, Seidel, Brockschmidt, Pronobis

18.-20.03.2019
PV-Symposium, Bad Staffelstein
Prof. Engel

19.03.2019
Doctoral Examination O. Binder, Braunschweig
Prof. Kurrat

21.03.2019
FNN Gridcamp, Berlin
Prof. Engel

26.03.2019
NEDS Final project symposium, Hannover
Prof. Engel, Reinhold, Kahl, Herr, Seidel, Osterkamp

26.03.2019
EFZN-Board meeting, Hannover
Prof. Kurrat

27.-28.03.2019
5. ProZell Research Colloquium, München
Prof. Kurrat, Drees, LHoffmann

02.-04.04.2019
Conference Power Plant Battery, Aachen
Lienesch, Brockschmidt, Drees, LHoffmann

04.04.2019
BMWi-Reactive power commission, special meeting of grid operators, Berlin
Prof. Engel

05.04.2019
Doctoral Examination Nijan Yogal, Braunschweig
Prof. Kurrat

12.04.2019
IKTfree: KickOff, Oldenburg
Prof. Engel, Rebak, Osterkamp

15.04.2019
FKR, Braunschweig
Prof. Kurrat

02.05.2019
acatech AG meeting (De-)central energy supply, Berlin
Prof. Engel

04.05.2019
Ceremonial opening of the megawatt power laboratory of Fraunhofer ISE , Freiburg
Prof. Engel

07.-08.05.2019
ETG Congress, Stuttgart - Esslingen
Prof. Engel, Pronobis, Reinhold, Ries, Biedermann, Di Modica, Wussow

14.05.2019
Focus Group Day, Braunschweig
Prof. Kurrat, Prof. Engel, WiMi

20.05.2019
Q-Integral: KickOff, Braunschweig
Prof. Engel, Merten Schuster, Hartmudt Köppe

21.05.2019
Excursion to BLB (structure and function of storage systems), Braunschweig
LHoffmann, Pronobis, Students

23.05.2019

elenia Open Research Day, Braunschweig
Employees and Students

23.-24.05.2019
FNN-Funding Committee meeting, Berlin
Prof. Engel

27.05.2019
FKR, Braunschweig
Prof. Kurrat

28.05.2019
BMWi-Reactive Power Committee, Berlin
Köppe, Wussow

03.06.2019
BMWi-AG System security, berlin
Prof. Engel

04.06.2019
dena-Workshop Must-Run & Secured Power, Berlin
Prof. Engel

05.06.2019
6. Meeting dena-Platform System Services, Berlin
Prof. Engel

06.06.2019
BMWi-Reactive Power Committee, Berlin
Prof. Engel

11.-13.06.2019
Pfingstexkursion, Amsterdam
Kühn, Prof. Kurrat, Weber

17.06.2019
3. PhD day of the Battery LabFactory Braunschweig (BLB), Niedersächsisches Researchszentrum Fahrzeugtechnik (NFF), Braunschweig
Brockschmidt, Drees, LHoffmann, Rusanto

18.06.2019
Conference knowledge exchange PxC, Blomberg
Prof. Kurrat

19.06.2019
Excursion Elektrische Bahnen zu Dinghan SMART Railway Technology und Bombardier Lokomotivenwerk, Kassel
Prof. Engel

19.06.2019
BLB General Assembly, Braunschweig
Prof. Kurrat, Drees, LHoffmann

21.06.2019
NFF-Cup, Braunschweig
Employees and Students

25.06.2019
Excursion Energylabs (structure and function of storage systems), Braunschweig
Pronobis, LHoffmann, Students

25.-26.06.2019
2. Braunschweiger Energy seminars (10th superconductor seminar 2nd direct current seminar), Braunschweig
MHoffmann, Hill

26.06.2019
Session ETG FB V1 Central and distributed generation, Frankfurt
Prof. Engel

28.06.2019
VDE-Assembly of delegates, Kassel
Prof. Engel

29.06.2019
TU-Night, Braunschweig
Weber

01.07.2019
FKR, Braunschweig
Prof. Kurrat

02.07.2019
Excursion to PTB (structure and function of storage systems), Braunschweig
Lienesch, LHoffmann, Pronobis, Students

02.07.2019
ETG/ITG-Board meeting, Frankfurt
Prof. Engel

03.07.2019
Signing Cooperation: IDA Adm, Braunschweig
Prof. Kurrat

05.07.2019
PV-Wind-Symbiose: Final meeting, Freiburg
Prof. Engel, Hartmudt Köppe

05.07.2019
Study seminar, Braunschweig
Prof. Kurrat, Alija

09.07.2019
ETG-Department meeting Q2, Frankfurt
Prof. Kurrat

10.07.2019
ABB-Research Centre, Schweiz
Prof. Kurrat, Kühn

12.07.2019
50. Doctoral Anniversary, Braunschweig
Prof. Kurrat

17.07.2019
Doctoral Examination Tobias Marseille, Braunschweig
Prof. Kurrat

14.08.2019
FNN-Workshop Destination System 2030, Dortmund
Prof. Engel

19.08.2019
Doctoral Examination Stephan Diekmann; Braunschweig, Prof. Engel

26.-31.08.2019
ISH Conference, Ungarn
Kühn

29.-30.08.2019
AG-Energy systems retreat, Braunschweig
Workgroup Energy Systems

04.09.2019
7. Meeting dena-Platform System Services, Berlin
Prof. Engel

04.09.2019
Municipal Relay Marathon, Braunschweig
Employees

05.09.2019
U-Quality: KickOff, Braunschweig
Prof. Engel, Cornelius Biedermann, Gian-Luca Di Modica, Till Garn

09.-13.09.2019
Symposium on Physics of Switching Arc, Nove Mesto na Morave, Czech Republic
Alija, Peters, Weber

11.09.2019
KickOff DCind2, Lemgo
Hill

11.-12.09.2019
6. ProZell Closing colloquium, Braunschweig
Prof. Kurrat, Drees, LHoffmann

13.09.2019
Doctoral Examination Wolfram Kruschel, Uni Kassel Kassel, Kassel, Prof.

Engel

16.-19.09.2019
AG Workshop Energy Technologies, Sächsische Schweiz
Prof. Kurrat + AG ET

18.09.2019
EFZN: Management Board and Supervisory Board meeting, Hannover
Prof. Engel

19.09.2019
FVV EIT, Braunschweig

Prof. Kurrat

23.09.2019
IKT-Free: FNN-Expert Workshop, Berlin
Prof. Engel, Rebak

25.09.2019
Departmental Workshop at Energiecampus Goslar, Goslar
Whole Department

05.-10.10.2019
International School on Low Temperature Plasma Physics: Basics and Applications, Bad Honnef
Alija, Peters

08.10.2019
Doctoral Examination N. Hill, Braunschweig, Prof. Kurrat

11.10.2019
BWG (Braunschweigische Wissentschaftl. Gesellschaft)-Plenary Assembly, class session, Braunschweig
Prof. Kurrat

14.10.2019
EMOB Integration Symposium, Dublin
Prof. Engel, Wussow

15.-16.10.2019
Solar Integration Workshop, Dublin
Prof. Engel

16.-17.10.2019
Grid integration Week, Dublin
Prof. Engel

21.-22.10.2019
SDZ-closed conference, Wöltingerode
Prof. Kurrat

21.-22.10.2019
SE2A Research Conference,
Kopp

25.10.2019
Faculty graduation ceremony, Braunschweig
Prof. Kurrat, Prof. Engel, Absolventen

30.10.2019
Doctoral Examination Daniel Unger; Braunschweig, Prof. Engel

04.11.2019
Digital Solar & Storage , Brüssel
Prof. Engel

04.-06.11.2019
IBPC 2019 (International Battery Production Conference) ,
Prof. Kurrat, Brockschmidt, Drees, LHoffmann, KRyll

05.-06.11.2019
Austrian symposium for photovoltaics and electricity storage, Wien
Wussow

06.11.2019
FNN Forum meeting, Berlin
Prof. Engel

06.-07.11.2019
DaLion4.0 Project meeting , Braunschweig
Prof. Kurrat, LHoffmann

07.11.2019
Doctoral Examination Martin Wünsch, RWTH Aachen
Prof. Kurrat

07.11.2019
Doctoral Examination Georg Agenendt; RWTH, Aachen, Prof. Engel

11.11.2019
FKR, Braunschweig
Prof. Kurrat

11.-12.11.2019
NFF-Strategy Workshop, Wöltingerode
Prof. Kurrat

13.11.2019
BMWi-AG System security, Berlin
Prof. Engel

13.-15.11.2019
Project meeting Netzregelung 2.0, Kassel
Prof. Engel, Rauscher, Winter

15.11.2019
Visit MPS Göttingen, Göttingen
Prof. Kurrat, Präsidentin

19.-20.11.2019
Energy days, Wien, Wussow

21.11.2019
Profs@Turntables, Braunschweig
Prof. Engel, Diverse

22.11.2019
ETG-Board meeting, Frankfurt
Prof. Engel

25.11.2019
Doctoral Examination Roesky, Braunschweig, Prof. Kurrat

26.-27.11.2019
Training Novices, Blomberg
Prof. Kurrat, Anspach, Claaßen, T. Meyer, Peters

26.11.2019
FNN-Workshop Grid Booster - Multitool for the integrated energy system transformation, Berlin
Prof. Engel, Winter

29.11.2019
Doctoral Examination Ole Marggraf; Braunschweig, Prof. Engel

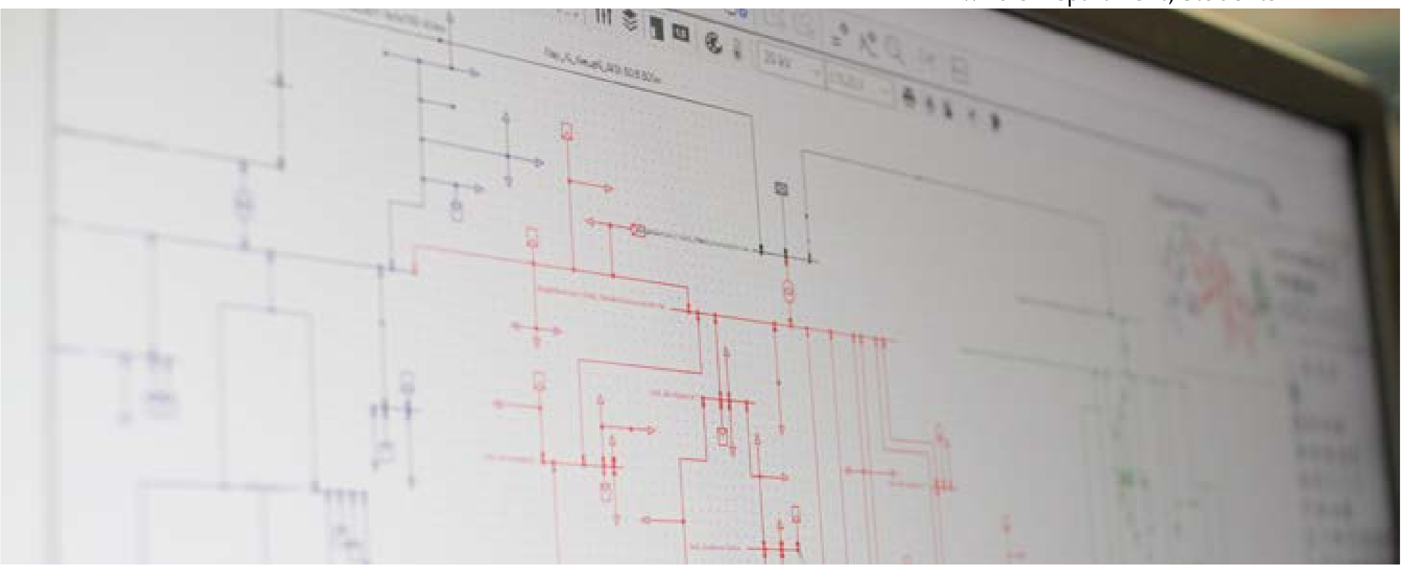
03.12.2019
Q2 Annual General Meeting, Frankfurt
Prof. Kurrat

03.-04.12.2019
FNN-Congress Grids, Nürnberg Engel
Prof. Engel

05.12.2019
ETG/IZBE-Symposium Electrical equipment of railway vehicles, Dresden
Prof. Engel

16.12.2019
FKR, Braunschweig
Prof. Kurrat

19.12.2019
Christmas party 2019, Braunschweig
Whole Department, Students



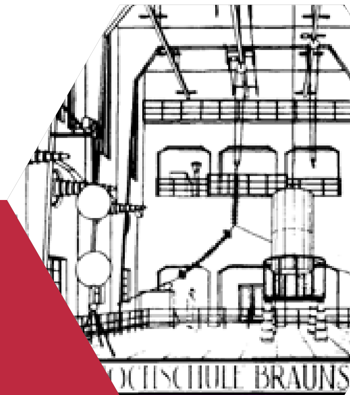
Research

Labs

Portrait

Chronology

Teaching



Events

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