Technische Universität Braunschweig

100 1925 2025 elenia Institute for High Voltage Technology and Power Systems

Anniversary edition
100 Years of elenia

elenia Institute for High-Voltage Technology and Energy Systems

With annual report 2024/2025


BS|NETZ
BS|ENERGY Gruppe
Gemeinsam halten wir die Region unter Strom.
Im Labor und in der Praxis. In diesem Jahr feiert BS|NETZ 125 Jahre Stromnetz für Braunschweig, während das elenia auf 100 Jahre Forschungsarbeit zurückblickt. Herzlichen Glückwunsch!
Mehr Infos zu unserem Jubiläum unter www.bs-netz.de
Ein Unternehmen von VEOLIA

Institute for High Voltage Technology
and Power Systems

Anniversary edition

100 Years of elenia

elenia Institute for High-Voltage Technology and Energy Systems

With annual report 2024/2025


100
Jahre

Dear Readership

This year, our institute celebrates its 100th anniversary. To mark the occasion, we are pleased to present this anniversary volume.

In the anniversary volume you will also find a contribution on the institute's history, which was developed — thanks to the Institute of History and the University Archives — through interviews and workshops conducted for this purpose.

In the 1920s, high-voltage technology was regarded as a cutting-edge discipline par excellence — comparable to today's hype around digitalization, data science, and artificial intelligence. In 1924, construction began on the first 220-kilovolt extra-high-voltage transmission line, which connected the lignite region of the Rhineland with the hydropower plants of the pre-Alpine area.

The following year, 1925, a specialized institute was founded to bring together research, teaching, and industrial application of this key technology. While the early years initially focused on expanding three-phase AC transmission networks, during the National Socialist era the institute conducted the first experiments with high-voltage direct current (HVDC) transmission for long-distance transport via underground cables.

Post-war reconstruction and meeting rapidly rising energy demand shaped research in the fields of high-voltage insulating materials and switchgear technology.

The large numbers of students in the 1970s and 1980s, when the baby boomers flooded into universities, also had to be managed. During this phase, research centered on consolidating the grids, further developing technologies, and expanding global exports.

With the end of the Cold War and reunification, East–West collaboration among researchers and lecturers intensified. Later, the gradually prevailing realization that climate change requires a transformation of the energy system led to a high demand for research and teaching to implement the energy and mobility transition. This turning point currently confronts us with the tension between internationalization and research security.

Resilience is becoming an increasingly important criterion. Today, our work focuses on new materials for energy storage and switching devices, grid integration of solar, wind, and electrolyzer facilities, electric mobility, and direct-current technology — always with active involvement in national and international bodies such as VDE ETG, FNN, DKE, ISDEIV, Current Zero Club, CIGRE, and IEC.

Our successes are the result of decades of dedicated teamwork: researchers, lecturers, and staff in technical and administrative roles, alumni, project partners, and funding institutions have jointly and decisively shaped power engineering and our discipline.

At the same time, we once again face profound upheavals — from political course-setting for the Climate and Transformation Fund to issues of research security in a globalized world.

The TU Ethics Committee and the BMBF Working Group on Research Security (Michael Kurrat) are important forums for constructively discussing these challenges.

Declines in first-year enrollments in the engineering sciences require attractive teaching and advising concepts (Dean of Studies Bernd Engel), mentoring programs, and collaborations with the Haus der Wissenschaft.

With this anniversary volume, we also report on our research work and use of funds. We were able to further increase our external funding share through numerous innovative projects. The institute has reached a new peak in terms of its size, with 70 employees at present.

We thank all our colleagues, the TU, our industry and research partners, lecturers, the DFG, the project management agencies, the federal and state ministries, and the PTB for decades of trusting collaboration.

The highlight of the year will be our celebratory event marking our 100th anniversary. We look forward to inspiring talks, personal encounters, and exciting retrospectives — and to benefiting, together with you, from the experiences of the past and looking ahead to the future.

Enjoy browsing through this volume — and for the years to come, we wish you all the best, much success, and above all, good health!

Your team at the elenia Institute for High-Voltage Technology and Energy Systems

Michael Kurrat, Bernd Engel
BRAUNSCHWEIG, IN OCTOBER 2025

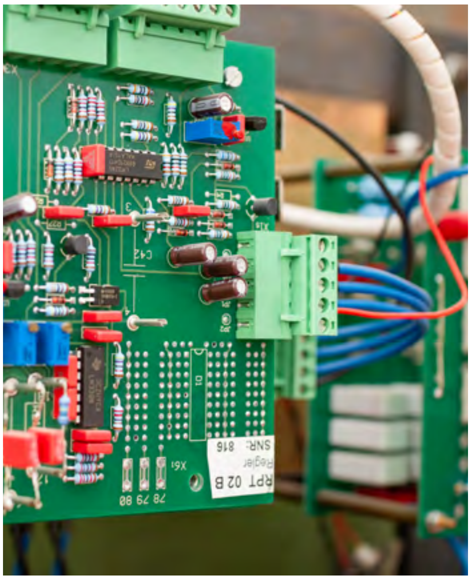
We are elenia

100 Years of elenia

Historical Rewind

Teams

Dissertations



Labs and Workshops

Education

Chronology

We are elenia

Annual Reviews 2024 and 2025

Past and Transformations

Our institute is looking forward to its upcoming anniversary and has already begun initial preparations:

In the archives, all historical records are being reviewed and consolidated to lay the foundation for a high-quality commemorative volume that honors our institute's development, major research projects, and influential individuals.

At the same time, long-planned and necessary renovations to preserve and modernize our institute building have begun, so that our site remains in excellent condition for future generations. In parallel, we are reactivating and updating our address lists to reconnect with former students and staff and to establish a vibrant alumni network.

We are also saddened to share that Prof. Achim Enders passed away on July 13, 2024, at the age of 66. Since 1996, he headed the newly established Institute for Electromagnetic Compatibility, spun out of the Institute for High-Voltage Technology, served as a sought-after expert on the Radiation Protection Commission of the Federal Ministry for the Environment, and was always distinguished by his exceptional dedication to research and teaching. With his scientific foresight and tireless drive, he shaped generations of students and colleagues. His sudden loss fills us with deep sorrow; we will honor his memory and never forget his contributions.

To ensure continuity in research and teaching, the faculty leadership immediately convened a search committee. Until the professorship is filled, colleagues will cover the courses supervised by Prof. Enders. The "Mathematical Methods" lecture, which gives students insight into the close relationship between mathematics and electrical engineering, will continue to be offered by elenia until further notice.

Since April 2025, Prof. Bernd Engel is being Dean of Studies for a two-year term. The biggest challenge is student recruitment. Initial activities began in February 2024 with an Open House featuring an engaging program in the laboratories on Schleinitzstraße. Beyond recruiting, retaining students is equally important. To that end, on May 16 we organized, as a thank-you, a get-together of the student council with the professors at a food truck, with music and a great atmosphere. In ETG Division Q2 — Materials, Insulation Systems, Diagnostics — there were many activities again: highlights included the design and successful hosting of Hight-Voltage Conference 2024, the development and publication of the study "Higher Utilization of Assets," and the successful workshop on September 15–16, 2025. Our sincere thanks to everyone involved.

Our funded projects have developed in different ways. Due to the lack of funds in the Climate and Transformation Fund, battery research in Germany has suffered a major setback. Long-planned collaborative projects have been canceled, and many research staff have left the university. Remedying this disruption to the research ecosystem will require substantial effort, especially against the backdrop of declining student numbers.

New projects and knowledge communities have emerged in collaboration between the "Metrology" and "City of the Future" core research areas and PTB. Individual research projects are evolving into larger initiatives toward a "MetroPolis," with a strong focus on user involvement. We are very grateful to the department of humanities for their contributions.

On the topic of grid connection of offshore wind farms, we secured additional EU projects. Our research focuses on system-level aspects of HVDC transmission and on switching and protection technology. You can find more on this in the teams' research reports.

The federal government's System Stability Roadmap, to which elenia also contributed, shows that an energy system with 100% renewable supply can be operated stably. Elenia is also active in the associated flagship research project SysStab2030 and in the System Stability Forum. A core competency of elenia, developed through several research projects, is the application of grid-forming inverters in the interconnected grid at various voltage levels to replace the inertia of rotating masses from fossil-fueled power plants. We conveyed this in a one-day workshop at the elenia energy lab to the distribution system operator Avacon Netz, with which we have a new collaboration. In addition, together with consentec, we are determining a price proposal for the market-based procurement of instantaneous reserve (inertia) for Germany's four transmission system operators (TSOs).

Elenia is also playing a key role in the Hydrogen Terminal Braunschweig, which was officially inaugurated near the airport on June 24, 2024. Research there will cover the entire process chain — from production and storage to the use of climate-neutral hydrogen. The project is funded by the Federal Ministry of Education and Research (BMBF) with a total volume of over €20 million. Elenia is researching the grid and market integration of the 1 MW electrolyzer in combination with a 1.1 MWh battery storage system, which is connected to the grid via a grid-forming inverter.

The Energy Research Center of Lower Saxony (efzn) continues to develop with elenia's involvement. Since 2024, the state of Lower Saxony and the Volkswagen Foundation have been funding, for five years and with a total of €58.2 million, the collaborative research project ten.efnz from the zukunft.niedersachsen program. This is the largest amount of funding ever approved by the Lower Saxony Ministry of Science and Culture for a cross-location research program in energy research.

A word on the changing times and its impact on the academic system. How do research security and academic freedom fit together? How do researchers and lecturers navigate the risks and opportunities of internationalization? We are contributing to this discussion through our work on the TU Ethics Committee and in drafting a memorandum on research security for the Federal Ministry of Education and Research (BMBF). Both the TU and the BMBF are holding conferences and information events on these topics.

We have been able to build a new team in our administrative office. We additionally recruited Petra Groß-Ulrich and Anika Kolbe for accounting, while the secretariat is now supported by Manja Rücker. A warm welcome to our new colleagues, and our best wishes to Ms. Sylvia Glowania in her new role. We are confident that, with our new team, we can further streamline our processes and support you in the best possible way.

Current employees

Head of the Institute


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

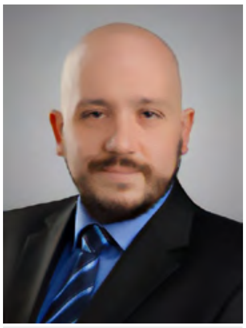

Prof. Dr.-Ing. B. Engel
Managing Director


Dr.-Ing. Dirk Bösche
Technical Director


Dr.-Ing. Frank Soyck
Administrative Manager

Lecturers


Dr.-Ing. Nasser Hemdan


Dr.-Ing. Michael Hilbert


Dr. Stefan Laudahn


Dr.-Ing. Frank Lienesch


Dr. Johann Meisner


Dr. Johannes Schmiesing


Dr.-Ing. Christian Schulz

Office Secretariat and Accounting


Elke Droemer

Petra Groß-Ulrich

Anika Kolbe


Nancy Preuße


Manja Rücker

Team Energy Economics and Energy Management

Team Grid Dynamics and System Stability

Eike Niehs
Team Leader

Tamara Beck

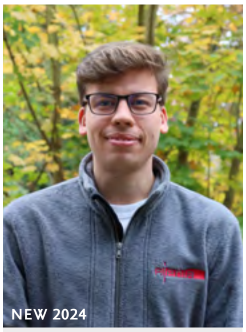
Julien Essers

Merle Ferk

Marcel Lüdecke

Michel Meinert

Kevin Preißner



Kai Schulze

Ajay Kumar Thakur

Henrik Wagner
Working Group Leader

Carsten Wegkamp

Timo Sauer
Team Leader

Stefanie Walujski
Team Leader

Sofie Brammer

Max Gand

Till Garn

Johanna Grobler

Stefan Klöpping

Nelly Gorkow


Frederik Tiedt


Björn Oliver Winter

→ **Team Grid Operation and Grid Planning**


Lukas Ebbert
Team Leader

Gerald Gebhardt


Nils Gräfer


Robin Herman


Hartmudt Köppe


Merten Schuster

→ **Team Battery Technology**


Oliver Landrath
Team Leader

Mara Luisa Hiller


Merit Holdorf
Working Group Leader


Cedric Jackmann


Andreas Laufer

Marvin Nebelsiek

Julius Rieckmann


Anna Rollin

→ **Team DC Systems and Circuit Breakers**


Fabian Benedikt Witt
Team Leader


NEU 2025
Abdolhamid Farshadi

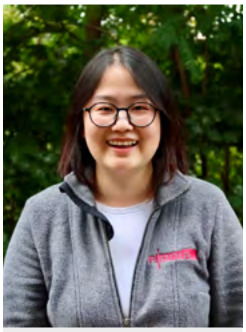

Dr.-Ing. Melanie Hoffmann


NEW 2025
Timo Jelden


NEW 2024
Peer König


Marc René Lotz

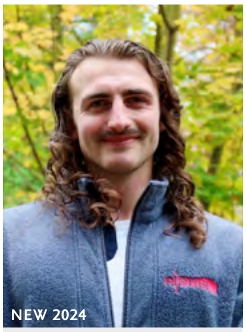

Patrick Vieth


Fanke Zeng

→

Team High Voltage-, Vacuum- and Plasmatechnology


Karen Flügel
Team Leader


NEW 2024
David Cziumplik


NEW 2025
Mats Göhrmann


NEW 2025
Marius Hinz


Maik Kahn


Timo Meyer


NEW 2024
Nils Wilm Rosebrock


Laura Tiedemann

→

Electrical Workshop


Christian Ryll
Workshop Supervisor

→

Mechanical Workshop


Kerstin Rach
Workshop Supervisor


Matthis Grosche


Frank Haake


Julia Musebrink


Claas Narup

IT-Department


Fabian Scholz
Head of IT


Lukas Oppermann
IT Administration

External doctoral candidates

Alexander Dubowik (PTB)
Frank Weinrich (PTB)
Jens Eickelmann (PION Technology AG)
Kira Reuter (Stadtwerke WF)
Matthias Grandel (HS Biberach)
Matthias Schmidt (PTB)
Michael Ulbig (PTB)
Patrick Mansheim (SWM)
Robin Langemann (Landwind)
Torben Jennert (PTB)
Tobias Weinmann (HS Augsburg)

Former employees

Thank you very much for your participation and all the best for your future.

2023
Muhamet Alija
Enno Peters
Lars Claaßen
Jonathan Ries

2024
Felix Klabunde
Tobias Jesberger
Torben Jennert
Sylvia Glowania

2025
Jan Zimball
Sascha Wasner
Mattias Hadlak
Lily Kahl
Gavin Drüner
Cornelius Biedermann
Gian-Luca Di Modica

Student employees 2024/2025

A big thank you goes to our student helpers, thank you very much for your support!

2024

Alonso, Aleixo
Alrawashdeh, Ahmad
Al Saleh Al Hariri, Moha
Arora, Nikhil
Bautz, Yannick
Berman, Valentin
Bettermann, Carl
Binti Ahmad Ramzi, Nur Aina Najwa
Bin Raja Nahar
Brinkmann, Jonas
Bollhorn, Steffen
Bormann, Debwashis
Bhume, Nitesh
Burgdorf, Mads
Callsen, Jan Jakob
Dammann, Benedict Noel
Dieckmann, Nico
Elte, Justus
Fehrs, Tabea
Fesefeldt, Julius
Funk, Martin
Giesselmann, Keno
Gramzow, Malte
Grygiel, Leonie
Haounani, Anas
Hartau, Nils
Haschke, Felix
Hemdan, Asmaa
Heßler, Laura
Immer, Jennifer
Keles, Ismail
Jantzen, Lennart
Kiptanui, Collins Kiprop
Kocur, Katharina Camilla
Kuete Nzonang, Jennher
Kuipou, Franklin
Krüger, Henning
Körtje, Maximilian
Lehmann, Jerome
Li, Chenfeng
Liu, Jiakun
Machens, Helena-Celine
Manzoor, Hina
Meinecke, Manuel
Meyhöfer, Adrian
Mohadeseh, Ebrahimi
Nguyen, Duc Anh
Otgonpurev, Erdene
Pandey, Shivam
Pape, Marlene
Pensky, Emma
Protze, Linus
Qualo, Leonie
Rajbeer Singh, Sahib Singh
Raut, Siddhesh
Reuning, Fabian
Rieckmann, Julius
Rosebrock, Nils
Rothert, Johannes
Rai, Sampras
Singh, Shivank
Scheler, Nils
Schmidt, Tjark
Schomburg, Marlon
Schulze, Kai
Teng, Zhi
Vahidi, Ali
Viere, Steffen
Viradia, Yash
Vivek, Keerthiveettil
Lützow, Constantin
Wang, Ziang
Webel, Rika
Weinand, Maurice
Weinrich, Matteo
Wilde, Lukas
Zalewski, Laura
Zamorano, Guillermo
Zhang, Kui
Zurmühlen, Andre
Zhou, Zhenghan

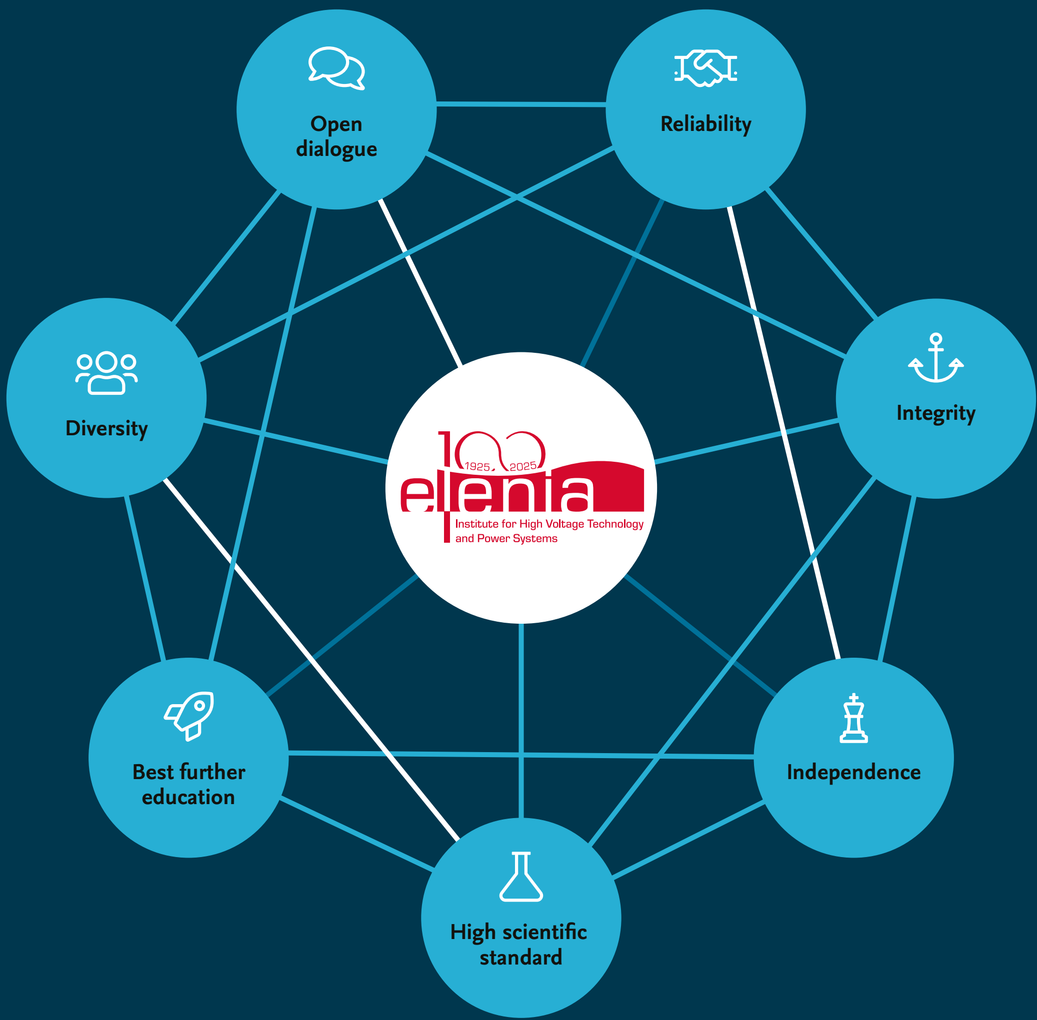
2025

Alonso, Aleixo
Alrawashdeh, Ahmad
Bautz, Yannick
Binti Ahmad Ramzi, Nur Aina Najwa
Bin Raja Nahar
Brinkmann, Jonas
Burgdorf, Mads
Bormann, Debwashis
Brökerbaum, Adrian
Callsen, Jan Jakob
Dammann, Benedict Noel
Dieckmann, Nico
Elte, Justus
Gasek, Daniel
Gramzow, Malte
Grygiel, Leonie
Hartau, Nils
Hemdan, Asmaa
Heßler, Laura
Hermsen, Claas
Immer, Jennifer
Jantzen, Lennart
Kiptanui, Collins
Kiron, Islam
Körtje, Maximilian
Kuipou, Franklin
Lehmann, Jerome
Li, Chenfeng
Machens, Helena-Celine
Meyhöfer, Adrian
Meinecke, Manuel
Otgonpurev, Erdene
Oestereich, Finnja
Protze, Linus
Qualo, Leonie
Rothert, Johannes
Rajbeer Singh, Sahib Singh
Stefanek, Pierre
Scheler, Nils
Schmidtke, Louisa
Victor, Nina
von Lützow, Constantin
Wache, Johannes
Weinrich, Matteo
Wilde, Lukas
Zamorano, Guillermo
Zhang, Kui
Zurmühlen, Andre


WIR GRATULIEREN HERZLICH ZUM JUBILÄUM!
amprion
WIR SIND DA.
DAMIT DIE ZUKUNFT KLIMANEUTRAL WIRD.
JETZT BEWERBEN!

Facts and figures

Values and goals

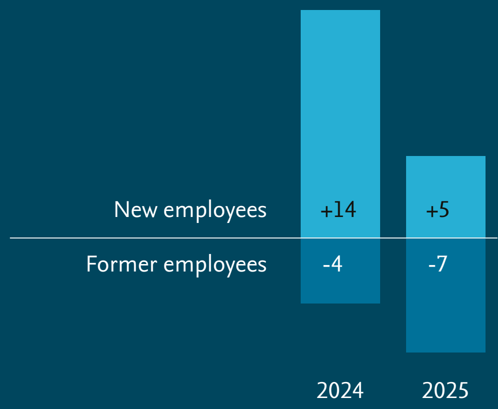


“Achieving excellence in research and teaching and actively shaping the future of energy technology”

The years in numbers

Employees

- 2 Professors
- 2 Administrative and technical management
- 5 Office staff
- 7 Assistant lecturers
- 5 Mechanical workshop staff
- 1 Electrical workshop staff
- 2 IT staff
- 51 Research associates
- 48 Students assistants



Location

Braunschweig (Lower Saxony)
since 1925

Braunschweig
- 1 University
- 6 Faculties
- 87 Courses
- 133 Institutes
- 2.000+ Scientists
- 15.632 Students

Student Work

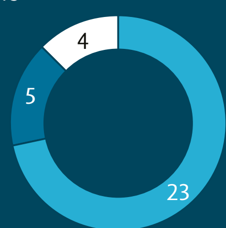
Bachelor
- 23 (2024)
- 14 (2025)

Master
- 54 (2024)
- 33 (2025)

Studies
- 10 (2024)
- 7 (2025)

Teaching

- Lectures
- Internship
- Seminars



Paths to elenia

Stefanie Walujski

I started my Bachelor's degree in Electrical Engineering at TU Braunschweig in 2016. I was looking forward to the diverse and varied courses, even though some of the content was a real challenge at first. As I found it difficult to decide on a specialisation, I applied as a student assistant at elenia to gain practical experience and find out more about my interests. I was so impressed by this collaboration that I decided to write my Bachelor's thesis at elenia. This gave me my first opportunity to work independently and gain my first insights into research at the institute.

After my bachelor's degree, I studied for a master's degree in electrical engineering and my student assistant position became a laboratory engineer position at elenia. While campus life at the university was largely cancelled due to the coronavirus pandemic, we "lab ings" stuck together all the more. Thanks to flexible working hours and close proximity to the lecture halls as well as online lectures, we were able to combine study and work quite well. In the team "Grid Dynamics and System Stability", I was able to get actively involved in the research projects, acquire practical skills and take part in the technical discussions. I travelled to Paris for a semester abroad, where I got to know new perspectives and made new friends through the exchange with international students. Back in Braunschweig, I wrote my Master's thesis at elenia, in which I focused on the system stability of the electrical grid.

Although at first, I could hardly imagine pursuing a doctorate after completing my Master's degree, both the topic of my Master's thesis and a thematically linked research project convinced me to stay at elenia. What I particularly enjoy about doing a doctorate is being able to concentrate on a topic in a well-founded and targeted manner and being able to set my own research focus that contributes to the current state of knowledge. The exchange within the team is essential in order to regularly reflect our own results and develop new ideas. It is particularly enriching that we not only work together constructively and learn from each other, but also have a good time together on many different occasions. I can look back on an exciting and interesting first year as a research assistant and look forward to new experiences and challenges in the future.

Stefanie Walujski


elenia


LABstar
MBRAUN
KEYENCE
VHX
MB 10 COMPACT
MBRAUN

Cedric Jackmann

My path to elenia began – though I didn't realize it at the time – with my studies in Electrical and Information Engineering at Ostfalia University of Applied Sciences in Wolfenbüttel. What shaped me most during this period was my bachelor's thesis. Through an open topic announcement, I came to the Physikalisch-Technische Bundesanstalt (PTB) in Braunschweig, where I had the opportunity to complete both my project work and my bachelor's thesis in the field of battery explosion protection. It was during this time that my interest in battery technologies was first sparked – a topic that continues to fascinate me to this day.

Through the close cooperation between PTB and elenia, I became aware of the institute. During my subsequent master's studies in electromobility at TU Braunschweig, I was given the opportunity to work as a laboratory engineer in elenia's battery team. This role allowed me to gain extensive hands-on experience over the course of two years: I built, characterized, and analyzed battery cells, accompanied experimental series, and actively participated in various projects. At the same time, I gained valuable insights into the institute's daily operations and the academic environment.

My master's thesis built directly on these experiences and also focused on battery technology. The transition to my current position as a research associate was therefore seamless. Today, I have the privilege not only to support elenia scientifically but also to help shape it – through research, teaching, project work, and everyday institute life. The opportunity to work on forward-looking research topics while contributing to the education of future generations is something that deeply fulfills me.

I hope that through my work I can not only strengthen the institute but also make a meaningful contribution to the advancement of battery technology and, in turn, to the energy transition. For me, the path to elenia was – and continues to be – a journey born of curiosity, strengthened through practical experience, and carried forward by research and commitment.

Cedric Jackmann

100 Years of elenia

Anniversary Party Program

Day 1 — October 1, 2025

elenia X perience

14:00 **Arrival and Reunion**
Entrance Area, Schleinitzstraße 22/23

14:30 **Welcome and Introduction**
Lecture Hall SN23.1 - Schleinitzstraße 23 (2nd Floor)

Prof. Dr.-Ing. Kurrat & Prof. Dr.-Ing. Engel
High-Voltage Engineering and Energy Systems 1925 to 2025

15:00 **Presentations**

Prof. Dr. Ing. Lindmayer
Electrical Power Systems

Prof. Dr.-Ing. Jens Tepper
Hallendorf

Laboratory Visits

Open tours oft he High-Voltage Hall and additional laboratories

16:00

Evening Program

18:30 **Sparkling Wine Reception**
Dornse – Altstadtmarkt 7, 38100 Braunschweig

19:00 **Words of Welcome**
Prof. Dr.-Ing. Bernd Engel (Head of Institute, elenia, TU Braunschweig)
Representative of the City of Braunschweig

Gala Banquet
22:00 Conclusion of the Evening Program

Day 2 — October 2, 2025

elenia 100 Anniversary Colloquium

09:00 **Reception and Admission**
Audimax – Pockelsstraße 15

09:30 **Opening oft he Anniversary Colloquium**

Words of Welcome
Prof. Dr.-Ing. Michael Kurrat (Head of Institute, elenia, TU Braunschweig)
Welcome Addresses
Prof. Dr. Angela Ittel (President, TU Braunschweig)
Prof. Dr.-Ing. Eduard A. Jorswieck (Dean, Faculty of Electrical, Information, and Energy Engineering (EITP), TU Braunschweig)
Prof. Dr. Sebastian Lehnhoff (Spokesperson oft the Executive Board, Energy Research Center of Lower Saxony (EFZN))
Dr.-Ing. Britta Buchholz (Chair of the Board, Power Engineering Society (ETG), VDE)
Dr.-Ing. Jürgen Reinert (Chief Executive Officer, SMA Solar Technology AG)
Dipl.-Ing. Stefan Böning (Director, Grid Field Operations Offshore, Tennet)
Dr.-Ing Martin Thedens (Chairman, VDE District Association Braunschweig)

10:40 **Keynote Lectures**
100 Years of elenia – A Retrospective
Prof. Dr.-Ing. Michael Kurrat (Head of Institute, elenia, TU Braunschweig)

100 Years of elenia – A Perspective from the History of Technology
Prof. Dr. Christian Kehrt (Chair of the History of Science and Technology, TU Braunschweig)

100 Years of elenia – A Look Ahead
Prof. Dr.-Ing. Bernd Engel (Head of Institute, elenia, TU Braunschweig)

11:40 **Group Photograph**

12:00 **Standing Reception**

13:00

Closing Reception at elenia

13:30 **Barbecue at elenia**
Schleinitzstraße 23a, parking area by the Oker River (toward Mühlenpfordtstraße)

16:00

Historical Rewind

100 Years of the Institute for High Voltage Technology and Energy Systems

Prof. Dr. Christian Kehrt, 02.11.2025
Institute of History, TU Braunschweig

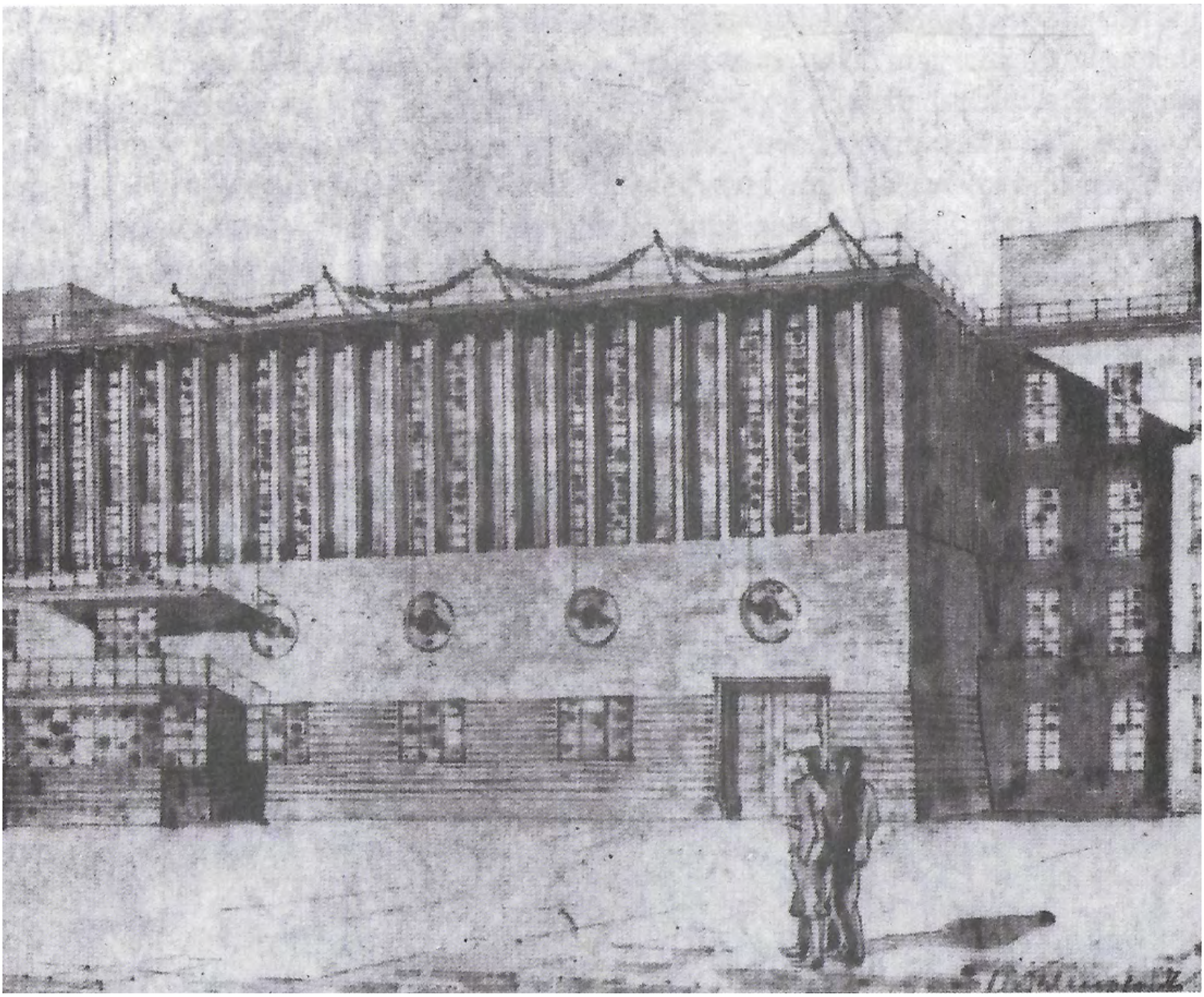


Figure 1: Design for the new building of the Electrical Engineering Institutes by Prof. Mühlenpfordt (1926/27). In: Prof. Timmerding (ed.), Die Technische Hochschule Braunschweig. Braunschweig, 1931, p. 100.

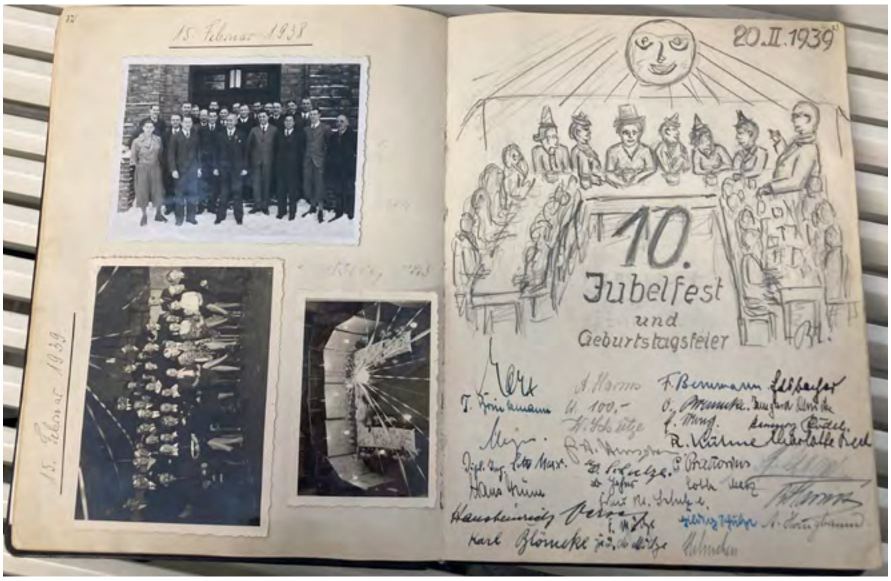


Figure 2: The institute's chronicle reports a lively institute life and dates the founding year to 1929, which was duly celebrated after ten years on February 20, 1939. Source: Institute Chronicle, elenia Institute.

The *elenia Institute for High Voltage Technology and Energy Systems* at TU Braunschweig looks back at a long and distinguished history[01]. Over the course of a century, successive heads of the institute have shaped its research and teaching through periods of political, economic, and academic turbulence. Despite these challenges, they succeeded in establishing key areas of expertise that continue to define the institute's reputation today. Among these focal points are studies on the dielectric strength of insulating materials, investigations into the electric arc as a switching and rectifying element, and — most notably — pioneering research on high-voltage direct current transmission (HVDC). This line of research, initiated as early as the interwar period, remains central today in the context of power grid expansion driven by renewable energy.

Equally influential has been the institute's commitment to practice-oriented, experimental laboratory education, which has profoundly shaped generations of electrical engineering students. The following account focuses on the formative years of the 1920s, when Erwin Marx established a research and teaching tradition that made the Institute for High Voltage Technology known far beyond Braunschweig. If one takes the ceremonial opening of the Electrical Engineering Institutes as the point of reference, the centenary of the High Voltage Institute dates to 1929. Alternatively, one could trace the beginnings of electrical engineering in Braunschweig back to 1890, when Wilhelm Peukert was appointed to the first chair of electrical engineering at the Technical University of Braunschweig. The choice of 1925, however, emphasizes the emergence of an independent research tradition inaugurated by Erwin Marx's appointment in that year. This interpretation was also endorsed by Dieter Kind on the occasion of the formal handover of the institute to his successor Hermann Kärner in 1977:

"Its exact founding date cannot be reconstructed, but it is reasonable to equate it with the commencement of Professor Marx's duties in October 1925." [02]

The Appointment of Erwin Marx in 1925

Key developments in the history of the elenia Institute were set in motion during the mid-1920s, when the 32-year-old engineer Erwin Marx (1893–1980) was appointed to the Chair of Electrical Measurement and High Voltage Engineering at TU Braunschweig. Already well known within the electrical engineering community, Marx brought with him an impressive combination of scientific expertise and industrial experience. Born in Saxony, Marx began his studies in electrical engineering at the TH Dresden in 1912. His education was interrupted by voluntary military service during the First World War. Resuming his studies in 1919, he became an assistant to Privy Councillor Görges and earned his doctorate in 1921. That same year, he married his fellow student Charlotte Günther, one of the first women to study electrical engineering at TU Dresden.

Following his academic training, Marx gained valuable industrial experience at Siemens-Schuckert, the Elektrotechnische Werke Dresden, and eventually as head of the electrical testing laboratory at Hermsdorf-Schomburg Isolatoren GmbH in Thuringia — a company specializing in industrial porcelain and electrical insulators. There, he conducted pioneering experiments using high-voltage impulses to test the dielectric strength of porcelain insulators. These investigations led to the invention of the now-famous surge - voltage generator, or "Marx Generator". By connecting multiple capacitors in series, Marx's circuit was able to generate high and ultra-high voltages, which were then released in a single impulse discharge. This made it possible to test the breakdown strength of insulating materials, providing crucial insights into their safety and reliability.

The development of this voltage multiplication principle cemented Marx's reputation.

3

Personal-Nachweisung.

Name: M a r x — Vorname: Erwin

Dienstbezeichnung: Professor — Behörde: Technische Hochschule Braunschweig

1	Geboren	am 15.II.1893 zu Mautitz Kreis bei Riesa in Sachsen
2	Eltern (Name, Vorname und Geburtsname der Mutter)	Paul Marx Anna Marx geb. Gey
3	Bekenntnis	ev.luth.
4	Familienstand	verheiratet mit Charlotte geb. Günther
5	Kinder	1 Sohn 2 Tochter
6	Militärdienst:	
	Eintritt	4.8.1914 als Kriegs-Freiwilliger
	Truppenteile	Res.Inf.Rgt. 241; Gren.Rgt. 100
	Ausgeschieden als	Leutnant d.Res. und Kompanie-Führer
	am	21. Dezember 1918
	Dauer der Dienstzeit	4 Jahre 4 Monate.
7	Zivildienst:	
	Datum der Vereidigung	29.8.1934.
	Welche Jahre gelten infolge Teilnahme an Feldzügen als Kriegsjahre?	1914 bis 1918

Figure 3: NLA WO [Niedersächsisches Landesarchiv, Wolfenbüttel], 12 Neu 16a, No. 97, Personnel File of Erwin Marx.

On 1 October 1925, he was appointed as Full Professor of Theoretical Electrical Engineering, High Voltage Technology, and Electrical Measurement, succeeding Prof. Dr. Wilhelm Peukert (1855–1932). At the time, interest in electrical engineering studies was considerable, but Braunschweig lacked modern facilities and laboratories. Under Peukert, the discipline had been housed only provisionally in the basement of the university's main building. The establishment of a modern laboratory infrastructure was therefore a central priority.

The Construction of the New Electrical Engineering Institutes

In close collaboration with the then rector and professor of architecture and building design Carl Mühlenpfordt (1878–1944), it was finally possible to modernize and significantly expand the facilities for electrical engineering. With financial support from the small and financially modest State of Braunschweig the TH Braunschweig acquired for 250,000 Reichsmark the site of the former *Hauswaldt Chicory Coffee Factory*. The location — situated between the river Oker and the university's main building — proved ideal. Within just eighteen months, the former factory was transformed into one of the leading educational and research buildings for electrical engineering in Germany. The new complex was a successful synthesis of functional design and traditional aesthetic form, characterized by the use of red brick stones. Within the architectural oeuvre of Carl Mühlenpfordt, whose style balanced expressionism and the emerging *Neue Sachlichkeit* (New Objectivity), this building represents a highlight and one of the most interesting buildings of his career.

Figure 5: Construction site of the new Electrical Engineering Institutes. Source: elenia Institute.

The demands of high voltage technology, as well as those of the Institute for Electrical Machines (Prof. Unger) and the Institute for Telecommunications Technology (Prof. Pungs), required extensive space for cables, electric motors, measuring instruments, transformers, and large-scale experimental installations — some of them outdoors — with the necessary testing grounds and safety precautions. The new high-voltage hall reached a height of 14 meters. The three institutes were interconnected by cable networks but could also operate independently. Each was equipped with its own workshops, offices, and libraries. The lecture hall was integrated directly into the experimental hall, enabling a vivid, practice-oriented form of teaching.

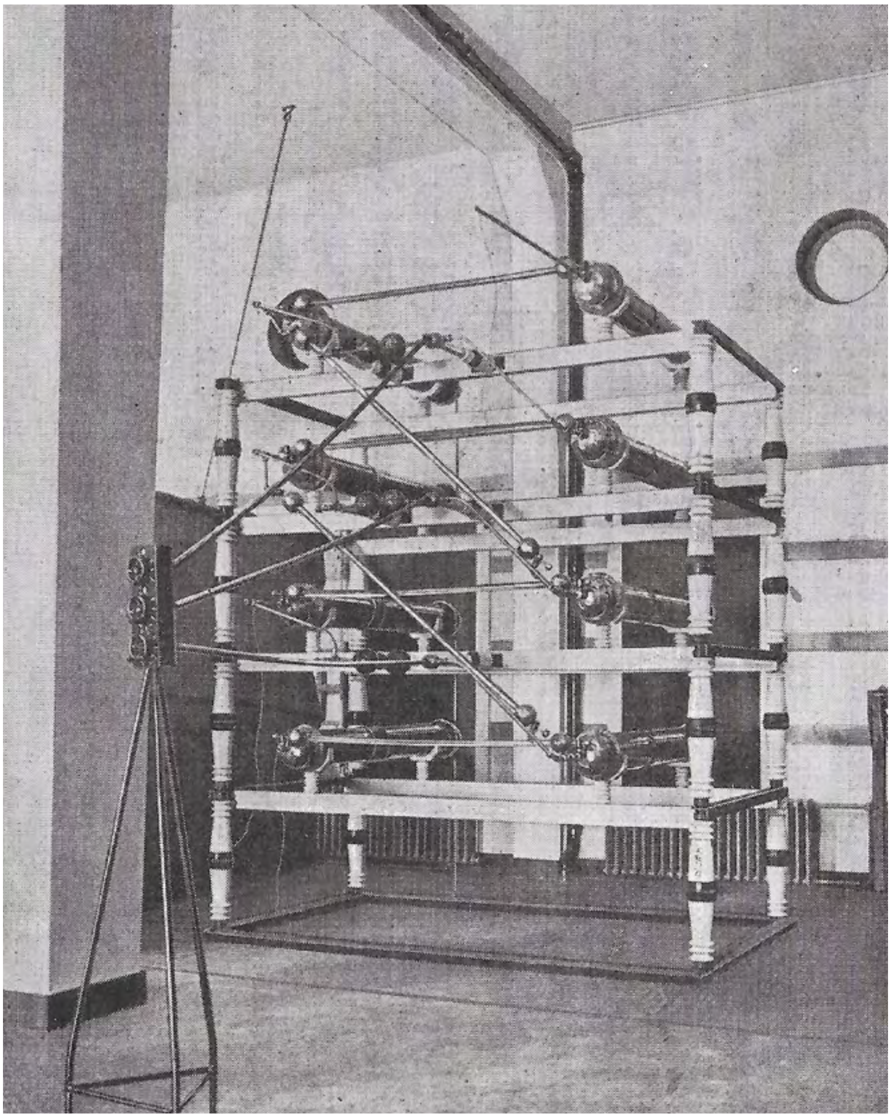


Figure 4: Marx-Generator in the large High-Holtage experimental facility (Hochspannungshalle) at TH Braunschweig. Source: Technische Hochschule Braunschweig (ed.): Die neuen elektrotechnischen Institute der Technischen Hochschule. Braunschweig 1929, p. 45.

The construction of the new Electrical Engineering Institutes symbolized the spirit of optimism that characterized the 1920s, before the onset of the Great Depression in October 1929. During this brief but favorable period following war and hyperinflation, the TH Braunschweig succeeded in implementing a forward-looking program in electrical engineering. This spirit of renewal was also reflected in the founding of the Braunschweig District Association of the German Association of Electrical Engineers (VDE), whose first chairman was likewise Erwin Marx.

On 15 February 1929, the new institutes were officially inaugurated amid great public interest. Distinguished guests from science, industry, and politics attended the event, including Nobel laureate Max von Laue (1879–1960). The carefully planned and widely attended opening ceremony extended over several days and featured a diverse cultural program: banquets, theater visits, public lectures, guided tours of the new facilities. The celebrations were held in conjunction with the Lessing Year, reflecting an effort to link culture and technology more closely—a strategy typical of the era, intended to enhance the social prestige of the engineering profession. The new, state-of-the-art institutes were presented with pride and hailed as *"unique in Germany."* The *Braunschweigische Landeszeitung* headlined the event under "Festival Days for the Carolo-Wilhelmina":

> *"In particular, the Institute for High Voltage Engineering possesses facilities that may well be unique in the entire world, so that our venerable university—which had long ranked among the last of Germany's technical universities in terms of attendance—has now, in a single stroke, advanced to first place in terms of modern equipment."*[03]

As part of the inauguration celebrations, Erwin Marx and his staff conducted spectacular high-voltage demonstrations—audible and tangible experiments producing discharges of up to two million volts. The generation of sparks, flashes, current surges, and electrical breakdowns astonished and fascinated the audience. In these performances the engineer and scientist appeared almost as a magician at the control panels of modern technology, mastering and directing the mysterious forces of electricity—a powerful image of scientific authority and technological progress in the late 1920s.

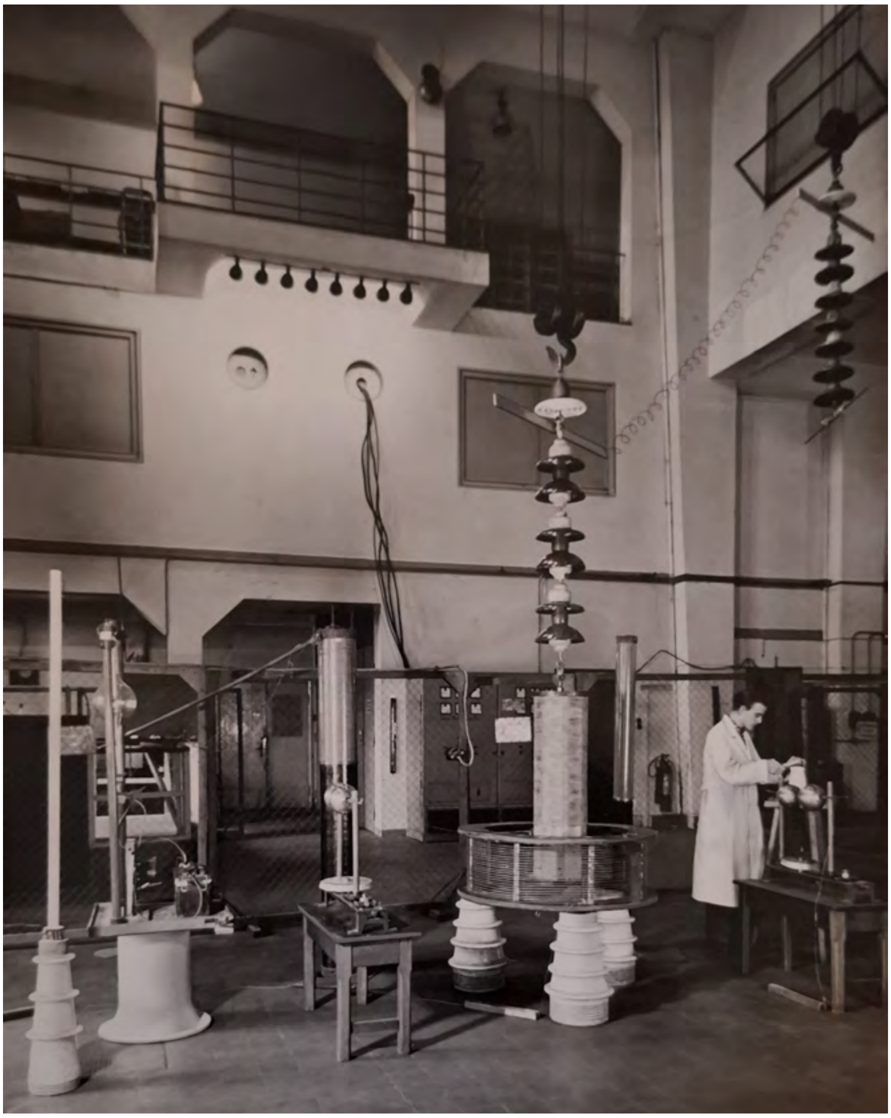


Figure 6: Large experimental hall, 1929. Source: elenia Institute.

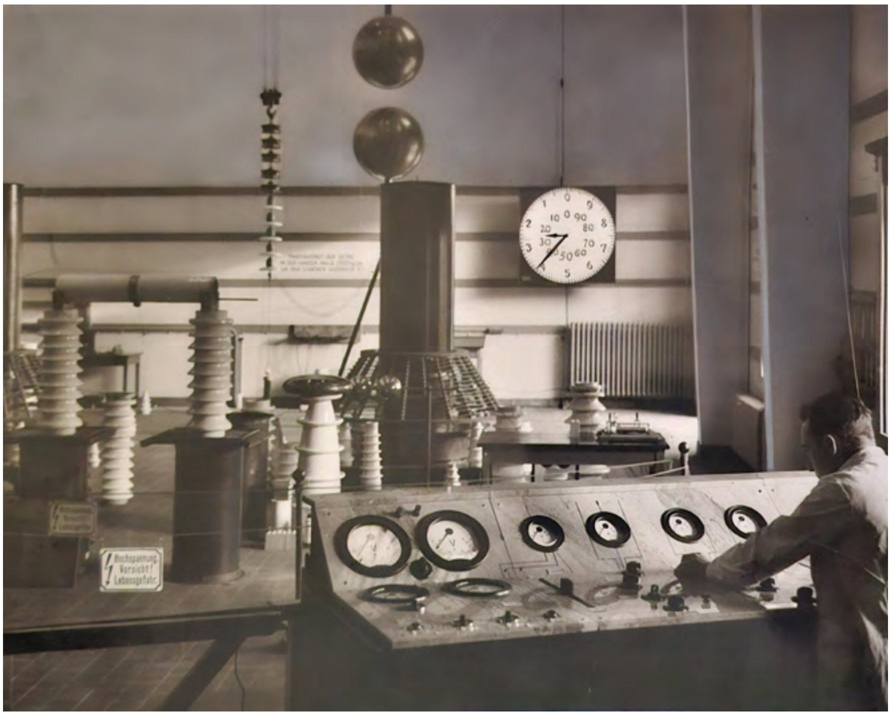


Figure 7: Control panel with Tesla transformer, large experimental hall, 1929. Source: elenia Institute.

A Systematic Research Program on High-Voltage Direct Current Transmission

Erwin Marx developed a comprehensive research program that he announced in several publications and pursued consistently until the end of the war in 1945. He was supported by substantial funding, a staff of around 100 employees, and additional large-scale experimental facilities in Salzgitter-Hallendorf and Lehrte-Misburg. Against the backdrop of an expanding interconnected power grid in Germany and the growing demand for electrical energy, the goal was to establish the scientific and technical foundations for increasing the operating voltage of the power networks and to study the disturbances caused by surge voltages and breakdown discharges in order to ensure the operational reliability of the overall system.

"The aim of these investigations is, on the one hand, to increase the operational safety of high-voltage installations through appropriate design of all components, and on the other hand, to save on materials, construction costs, and space in the erection of buildings, transmission lines, and high-voltage equipment."[04]

The Braunschweig researchers sought to develop a technical alternative to the established alternating current (AC) transmission system, which faced physical, technical, and economic limitations over long distances. At the center of this ambitious and visionary research program on High-Voltage Direct Current (HVDC) transmission stood the high-voltage arc rectifier, conceived and repeatedly patented by Erwin Marx.

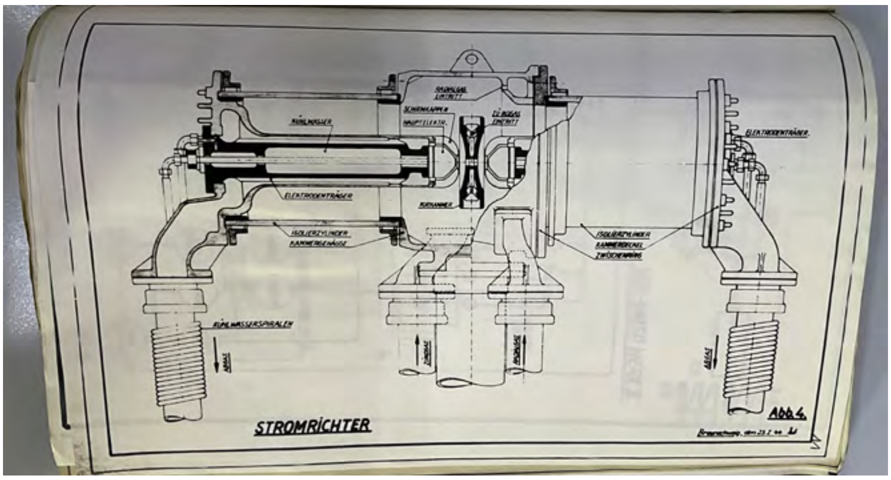


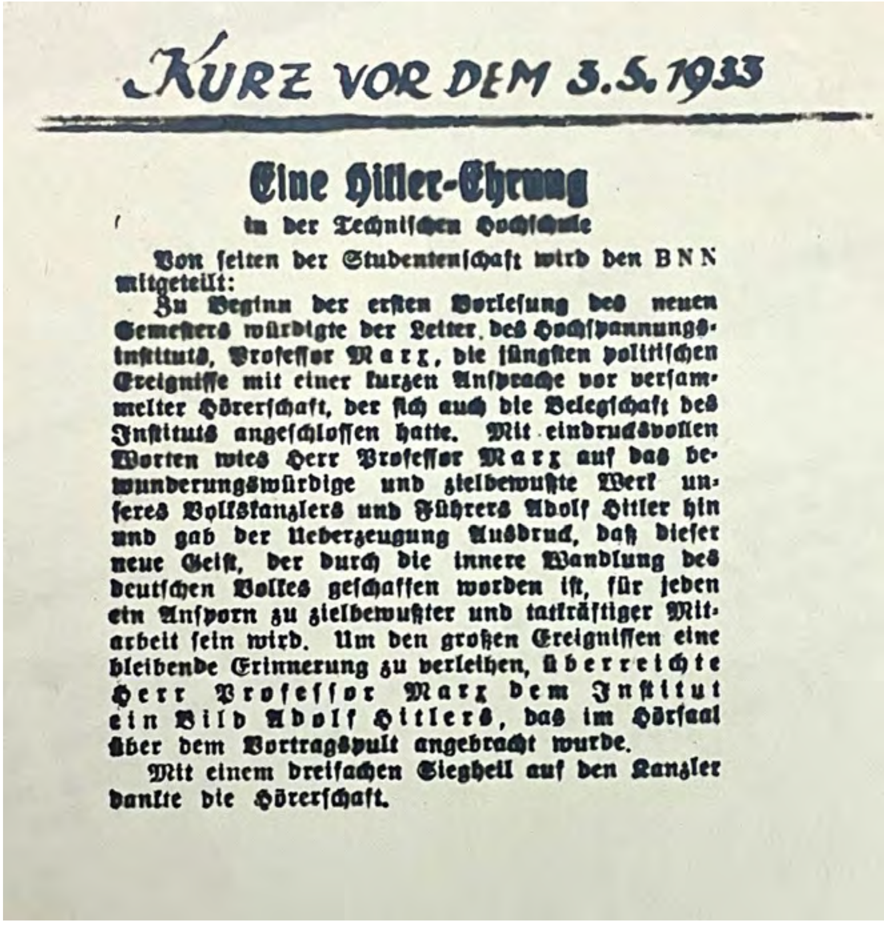
Figure 8: Arc rectifier. Source: Adil Erk, Untersuchung einer Gleichstrom-Hochspannungsanlage für 80 kV und 16 MW mit einer Lichtbogen-Hochdruckanlage. Doctoral dissertation, submitted June 24, 1944, defended June 7, 1946, p. 11.

The arc rectifier, intensively studied in Braunschweig until the end of the war in 1945, was intended to form the technological basis for a visionary HVDC network capable of transmitting electrical energy over distances of up to 1,000 kilometers. This high-pressure arc rectifier appeared to overcome certain limitations of existing technologies—such as the rapid burnout of thermionic cathodes and the complex production of vacuum tubes—thus representing a technically promising alternative to the rectifiers already available on the market. In the high-pressure arc valve, which was suitable for very high voltages, the electrical arcs were extinguished by means of compressed air. As early as 1932, he published a programmatic book on the arc rectifier with Springer, although the technology was still in the experimental stage. His aim was evidently to publicize the potential of this new approach and to stimulate further research.[05]

The ultimate goal was to move this technology beyond the stage of fundamental research and, in collaboration with major electrical engineering companies such as AEG, to bring it to market readiness. Marx envisioned that the establishment of a future European "supergrid" based on direct current would provide a cost-effective, simple, and robust system with high efficiency. Cheap hydroelectric power from Norway could, in this vision, supply the electrification of households and railways, as well as the growing power demands of heavy industry in Germany.

Erwin Marx as a Key Figure in National Socialist Armaments Research

Contrary to his later statements during the denazification process, Erwin Marx was without doubt a supporter and representative of National Socialism. This is evidenced by his membership in the SA in the autumn of 1933, in the NSDAP in 1937, and in several other Nazi organizations.[06] As a member of the Senate of the Technical University (Technische Hochschule, TH) of Braunschweig, Marx withdrew his signature from a declaration of solidarity with Gustav Gassner (1881–1955), who had been threatened by National Socialists and ultimately forced to resign as rector during the fiercely contested Braunschweig university conflict of 1933. On several occasions, Marx demonstrated himself to be a convinced National Socialist and a proponent of the regime.



KURZ VOR DEM 3.5.1933

Eine Hitler-Ehrung

in der Technischen Hochschule

Von seiten der Studentenschaft wird den BNN mitgeteilt:

Zu Beginn der ersten Vorlesung des neuen Semesters würdigte der Leiter des Hochspannungsinstituts, Professor Marx, die jüngsten politischen Ereignisse mit einer kurzen Ansprache vor versammelter Hörerschaft, der sich auch die Belegschaft des Instituts angeschlossen hatte. Mit eindrucksvollen Worten wies Herr Professor Marx auf das bewunderungswürdige und zielbewußte Werk unseres Volkskanzlers und Führers Adolf Hitler hin und gab der Ueberzeugung Ausdruck, daß dieser neue Geist, der durch die innere Wandlung des deutschen Volkes geschaffen worden ist, für jeden ein Ansporn zu zielbewußter und tatkräftiger Mitarbeit sein wird. Um den großen Ereignissen eine bleibende Erinnerung zu verleihen, überreichte Herr Professor Marx dem Institut ein Bild Adolf Hitlers, das im Hörsaal über dem Vortragspult angebracht wurde.

Mit einem dreifachen Siegheil auf den Kanzler dankte die Hörerschaft.

Figure 9: Erwin Marx presents a portrait of Adolf Hitler to the Institute of High Voltage Engineering at the beginning of the 1933 semester. Source: Braunschweiger Neueste Nachrichten, in: UABS B7 374, May 1933, fol. 220.

With the National Socialist drive toward an autarkic military state (Maier), the research carried out in Braunschweig in the field of high-voltage engineering attracted substantial armaments and military interest.[07] Plans for a European high-voltage direct current (HVDC) network — already discussed internationally during the Weimar Republic — were now being vigorously advanced within the framework of National Socialist armament and autarky policies. The transmission of large amounts of electrical energy, which after the occupation of Norway appeared feasible through hydroelectric power, made Marx's HVDC concepts directly relevant to the war economy, particularly for energy-intensive sectors such as ammonia synthesis, the production of light metals, synthetic rubber, and synthetic fuel. The possibility of laying high-voltage lines underground, thereby protecting them from aerial attacks, also played a role in the Reich Air Ministry's support for HVDC long-distance transmission research.

Marx's professional advancement was due not only to his publicly expressed sympathies for National Socialism but above all to his scientific and technical research. In 1937, he became the most influential electrical engineer within the Reich Research Council (*Reichsforschungsrat*). As Sören Flachowsky has noted, Erwin Marx was a key "multifunctional actor" within the National Socialist scientific system.[08] As head of the electrical engineering division of the Council, he oversaw fifty-five electrical engineering institutes across the Reich and directed research and development on armament-related electrical devices for the Wehrmacht, including proximity fuses, radar equipment, high-frequency instruments, and jamming transmitters.

The Braunschweig high-voltage engineer received funding in the millions from the German Research Foundation (DFG) and from the Reich Office for Economic Expansion, which coordinated the research objectives of the Four-Year Plan. Only with Helmut Maier's source-rich dissertation in the early 1990s was Marx's key role in the Nazi armament system comprehensively analyzed and documented.[09] The war-related significance of his institute is also evident in a number of then-classified doctoral dissertations produced under Marx's supervision, which were funded by the state during the war and assigned high levels of urgency.

Although AEG had already abandoned the operation of HVDC networks based on arc rectifiers in 1937 due to technical difficulties, Marx succeeded in 1940 — with state support from the Reich Air Ministry, the DFG, and the Reich Office for Economic Expansion. He tried to built an experimental facility in Hallendorf. Situated directly adjacent to the Hermann Göring Reichswerke in Salzgitter, which supplied the necessary power, the site comprised a 110 kV test installation with a converter and blower house, as well as an outdoor switchyard. After a bombing in 1944, the facility could not be put into operation. In 1942, however, a newly completed line between Misburg and Lehrte enabled the first long-term test at 110 kV, transmitting around eleven megawatts of power supplied by Preussag AG. Adil Erk — who would later, in 1968, become the founding director of the Institute for Electrical Power Systems at the TH Braunschweig—conducted experiments for his doctoral research there between 1943 and 1944. Recent investigations by Stella Flatten, a research associate at the Institute for Architecture-Related Art at TU Braunschweig, together with student Max Kolditz, have provided documented evidence that, beginning in 1943, a French national was forced to work at the Institute for High-Voltage Technology.[10]

The End of the War in 1945 and a Difficult New Beginning

The end of the war in 1945 marked a profound caesura in the history of the TH Braunschweig and its institutes of electrical engineering. The previously substantial support from the National Socialist state came to an abrupt halt, resulting in the loss of research opportunities and large-scale experimental facilities in the Braunschweig, Hannover, and Salzgitter region. While the university's main building suffered heavy destruction during the Second World War, the buildings of the Institute for High-Voltage Engineering emerged almost unscathed—partly because sections of the institute had been relocated to Gifhorn, Meine, and Peine. In the immediate post-war period, however, the institute's rooms were occupied by other departments and institutes, and some of its instruments were stolen or sold off.

Normal operations were barely possible, especially since Erwin Marx was issued a professional ban (Berufsverbot) by the British occupation authorities on 30 June 1945. During the denazification process he was classified in Category III and suspended from duty.[11] On the instruction of Professor Unger, Marx's name was to be removed from the institute's letterhead and from the large black nameplate in the north tower. Proposals to abolish Marx's vacant professorship entirely were, however, met with firm resistance from Professor Pungs (1883–1979).

Soon, voices began to grow—both from political circles and from former colleagues and staff—advocating for the reinstatement of Erwin Marx. His expertise and research were considered indispensable for reconstruction efforts and, increasingly, for the coming period of economic recovery. While Professor Gassner, as rector, initially opposed his return, Marx was eventually reinstated as a university lecturer after a protracted legal and institutional struggle, accompanied by numerous official statements and petitions.

By 1949, the matter was settled: Erwin Marx was reinstated to his post and was soon able to play a decisive role once again in shaping both his institute and the university as a whole, serving successively as dean and eventually as rector during a critical phase of institutional expansion. His ability to resume his academic career exemplifies the broader continuity of scientific experts and elites from the National Socialist era into the Cold War period. During the years of economic growth, the Nazi past was largely suppressed under the narrative of the engineers' "apolitical expertise." Consequently, Marx's considerable scientific and institutional influence continued well into the 1950s.

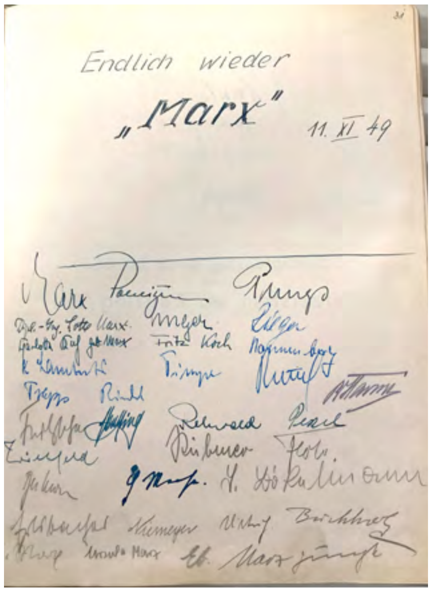


Figure 10: "Marx at last returns." Source: Chronicle of the elenia Institute, November 11, 1949.

In 1952, Franz Moeller (1897–1970) was appointed to a fourth chair in electrical engineering—alongside Pungs, Unger, and Marx—covering electrical measurement technology and the fundamentals of electrical engineering. While the number of new enrollments in electrical engineering stood at 250 in 1950, this figure rose to 883 by 1968 as a result of university expansion and educational reforms. By the mid-1980s, enrollment in electrical engineering exceeded 1,800 students. At the same time, financial constraints and budget cuts imposed by the state of Lower Saxony repeatedly pushed the Institute for High-VoltageTechnology to the limits of its capacity.

Conclusion: Continuities and Transformations in Research Traditions

Marx's Students

Despite a temporary professional ban, the internationally renowned Braunschweig high-voltage expert established, between 1925 and 1961, an era marked by numerous students, 84 supervised dissertations, 50 publications, about 90 patents, and—by 1945 alone—71 successful DFG (German Research Foundation) grant applications. The decades-long influence that Erwin Marx exerted on research and teaching is particularly evident in the personal continuities that extended far into the second half of the 20th century. One example is Adil Erk (1915–2003), who came from the Turkish-speaking town of Derbent in Azerbaijan (then part of Russia). Erk studied electrical engineering at the TH Braunschweig between 1940 and 1942, in the middle of the war, and completed his doctorate with a dissertation on the DC transmission system at Lehrte–Misburg. He married Erwin Marx's daughter in 1961 and, from 1969 to 1980, was Professor of High-Voltage Systems and Power Engineering at TU Braunschweig. On January 1, 1968, he founded the new Institute for Electrical Power Systems.

Another of Marx's students was Prof. Dr.-Ing. Karl Brinkmann (1911–2005), originally from Meine, who later served in industry, including as a board member for Siemens. He studied electrical engineering in Braunschweig from 1930 to 1935, earned his doctorate with a dissertation on "Capacitor Converters with Spark-Free Switching Devices," and qualified as a lecturer (habilitation) at the Technical University in the early 1950s. He remained closely connected to the institute for over 50 years as a lecturer with his course Electrical Energy Economics and Power Plants and also led a collaborative research project on the electromagnetic compatibility (EMC) of biological systems for more than 25 years.

This research direction paved the way, in the mid-1990s, for the appointment of Professor Achim Enders (1957–2024) and the establishment of the Institute for Electromagnetic Compatibility. This move cleverly addressed financial constraints imposed by the state, which ultimately led to the renewed merger of the previously separate institutes for High Voltage Technology and Power Systems, which had been divided since 1968.

The Hallendorf Experimental Facility (1962–2007)

This experimental facility played an important role in research and teaching. With the appointment of Dieter Kind as Erwin Marx's successor in 1962, the facility was acquired by the State of Lower Saxony. Jürgen Salge, who had studied electrical engineering at TU Braunschweig in the 1950s and completed his doctorate with Erwin Marx in 1963 on The Migration of High-Current Arcs in Narrow Gaps at Low Pressure, became head of the Hallendorf branch from early 1972 until his retirement.[12] There, he conducted plasma physics research in long-term cooperation with the Jülich Research Center, particularly in the context of work on the TEXTOR fusion reactor (1983–2014).[13] In total, more than 40 successful doctoral dissertations were completed in Hallendorf. However, as part of renewed austerity measures by the State of Lower Saxony, the facility—used for research for decades—was decommissioned and sold in 2007.

Dieter Kind and the Physikalisch-Technische Bundesanstalt (PTB)

The defining figure of Dieter Kind represents both continuity and transformation. Initially, Erwin Marx closely cooperated with his successor, filing several patents together and contributing his expertise in high-voltage arc technology to the development of innovative, oil-minimized circuit breakers. As semiconductor switching elements replaced mercury-vapor rectifiers as the key high-voltage technology, Kind redirected the institute's research toward testing technology and organic insulating materials. When he became President of the Physikalisch-Technische Bundesanstalt (PTB) in 1975, Kind not only deepened and expanded cooperation with the PTB but also remained affiliated with the institute as an honorary professor.

Professor Salge had already taken over the plasma physics research in collaboration with the Jülich Research Center and continued it until his retirement in 1996. Kind's

Figure 11: The well-staffed elenia Institute in the 1990s

Figure 12: International Symposium on Discharges and Electrical Insulation in Vacuum, August 30 – September 3, 2010, Braunschweig

successor, Professor Kärner (1932–2016), significantly advanced research on solid insulation, surge protection, and vacuum high-voltage technology until 1998.

In teaching, Kärner also established the field of electromagnetic compatibility. After the reunification of the institutes into the Institute for High Voltage Technology and Electrical Power Systems, Professor Lindmayer took over as head in 1998. He continued Professor Salge's plasma physics research and brought in strong expertise in low-voltage and vacuum switching devices. High-voltage research was continued by Professor Stietzel, who sadly passed away much too early.

A New Research Tradition: Decentralized Power Generation, E-Mobility, and Grid Expansion

A new research direction was established by the institute's subsequent heads: Professor Michael Kurrat (since 2001, successor to Professor Kärner) and Professor Bernd Engel (since 2011). While continuing the classical research focus on high-voltage technology, they also addressed emerging technical, economic, and societal challenges linked to the energy transition toward renewable sources. Already in the 1990s, these new research trends began to emerge, following decades of focus on centralized power generation based on fossil fuels and nuclear energy. This reorientation toward sustainable energy systems and electromobility led to a successful expansion of the institute, marked by an increasing number of staff members, doctoral dissertations, and third-party funding projects.[14] At the same time, the institute's research on grid expansion and renewable energy once again connects back to high-voltage direct current (HVDC) transmission, the visionary field already explored by Erwin Marx in the 1930s.[15]

The circle closes with the Dieter Kind Doctoral Award, established by Dr.-Ing. Harro Lührmann in grateful memory of his doctoral advisor.

This brief overview of the institute's recent history makes it clear that this is only a first step. A more comprehensive historical study is necessary, and we call upon all alumni and partners to contribute to this effort. A workshop is planned for 2026, and the alumni network of TU Braunschweig offers numerous opportunities for former members to stay connected.

We welcome spontaneous contributions to the institute's history via email at our address:

symposium-elenia@tu-braunschweig.de

References

01 I would like to thank Nelly Gorkow, Annabella Sartison, Prof. Kurrat, Prof. Engel, and Prof. Maier, as well as several contemporary witnesses, for their helpful support and information.

02 Ansprache von Herrn Professor Dr.-Ing. Kind zur Institutsübergabe am 1.7.1977, Jahresbericht des Instituts für Hochspannungstechnik. Braunschweig 1977, p. 4.

03 Braunschweigische Landeszeitung, 14. Februar 1929.

04 Marx, Erwin: Aufgaben und Ziele der Hochspannungselektronik. Vorgetragen im Braunschweiger Bezirksverein des Vereins Deutscher Ingenieure. In: Z-VDI (1927) 38, p. 1325.

05 Marx, Erwin: Lichtbogen-Stromrichter für sehr hohe Spannungen und Leistungen. Berlin, Heidelberg 1932, p. iii.

06 He gave lectures in an SA uniform, and in the summer semester he unveiled a portrait of Adolf Hitler at the High Voltage Institute while shouting "Sieg Heil." In 1936, together with Ludwig Klagges, he opened the Außeninstitut for public communication with the city and concluded the event with a commemoration of the Führer. In 1939, as part of a Reich celebration, he delivered a eulogy to the Führer and wrote a contribution on high voltage technology on the occasion of Adolf Hitler's 50th birthday. Reference: Marx, Erwin: High Voltage, Electrical Installations, Machines. In: Deutsche Wissenschaft. Arbeit und Aufgabe. (German science reports to the Führer and Reich Chancellor on its work on the occasion of his 50th birthday). Leipzig 1939, pp. 239–240. He acted in occupied Poland as a representative of the occupation regime and, in 1944, gave lectures in the General Government in Warsaw and Kraków.

07 Maier, Helmut: Forschung für den "autarken Wehrstaat". Technische Hochschulen im "Dritten Reich". In: Noyan Dinçkal, Christof Dipper und Detlef Mares (Hg.): Selbstmobilisierung der Wissenschaft. Technische Hochschulen im "Dritten Reich". Darmstadt 2010, p. 25–45.

08 Flachowsky, Sören: Von der Notgemeinschaft zum Reichsforschungsrat. Wissenschaftspolitik im Kontext von Autarkie, Aufrüstung und Krieg. Stuttg. 2008, p. 19

09 Maier, Helmut: Erwin Marx (1893 - 1980), Ingenieurwissenschaftler in Braunschweig, und die Forschung und Entwicklung auf dem Gebiet der elektrischen Energieübertragung auf weite Entfernungen zwischen 1918 und 1950. Stuttgart 1993.

10 Further research is needed to determine whether forced laborers were employed in the context of armaments research and the expansion of the high-voltage testing facilities during the Second World War.

11 Franz Moeller temporarily assumed responsibility for the institute's administration and lectures, as did Karl Brinkmann.

12 Jürgen Salge studied electrical engineering at the Technical University of Braunschweig from 1953 to 1958 and received his diploma in 1958. In the same year, he began working as a research assistant at the Institute for High Voltage Technology and Electrical Installations. Upon completing his doctorate in 1963, he was appointed Senior Engineer. In 1966, he advanced to Curator (or Academic Councillor), and in 1969 to Senior Academic Councillor. He completed his habilitation in 1971, receiving the venia legendi for high voltage engineering. On October 26, 1971, the Senate approved Salge's appointment as Head of Department and Professor at the Institute for High Voltage Engineering and entrusted him with the leadership of the "High Voltage Technology" department (Minutes of the Senate meeting, October 27, 1971).

13 At the Institute for Plasma Physics of the Jülich Nuclear Research Center, plasma–wall interaction problems in controlled nuclear fusion were studied as part of the large-scale TEXTOR experiment. Within the framework of the collaboration with the Institute for Plasma Physics at the Jülich Nuclear Research Center, the magnetization circuit for TEXTOR and the basic design of the circuit with its respective components were developed by the Institute for High Voltage Engineering at the Technical University of Braunschweig.

14 The expansion of teaching and research activities is reflected in the number of scientific staff, which increased from 15 in 2001 to 53 in 2023. Source: elenia Institute.

15 The name elenia Institute, used since 2011, is based on a renewed merger of the institutes for Electrical Power Systems and High Voltage Technology, which had been separated since 1968, in 1996, and on a programmatic reorientation toward decentralized grid expansion, energy technologies, and electromobility in the context of the energy transition, which was realized with the appointments of Professors Kurrat in 2001 and Engel in 2011.

Teams

Team Battery Technology

Merit Holdorf, Mara Luisa Hiller, Cedric Jackmann, Oliver Landrath,
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Electromobility is a key technology for a successful energy transition and benefits significantly from the continuous development of rechargeable battery cells.

Battery cells are not only of central importance for electric vehicles, but are also used in numerous other areas. In addition to consumer electronics such as smartphones, laptops, and tablets, as well as portable medical technology, they are used in stationary energy storage systems, industrial plants, and aviation.

Research into battery cells focuses on increasing energy density, extending service life, and improving safety. Advanced electrode materials for lithium-ion cells and alternative battery technologies, such as solid-state or sodium batteries, help to optimize the performance of modern energy storage systems. Computer-aided simulation methods and machine learning enable the behavior of battery cells under different operating conditions to be analyzed in detail and targeted improvements to be made.

Sustainability is playing an increasingly important role in battery technology. Environmentally friendly manufacturing processes and effective recycling strategies are necessary to optimize the entire life cycle of batteries from an ecological perspective.

The elenia battery team as part of "Braunschweig Labfactories for Batteries" research center

Elenia is a member of the ‚Braunschweig Labfactories for Batteries and more' (BLB) research center, which covers the entire value chain from material and electrode production to cell manufacturing, system integration, and recycling to close the material cycle. BLB brings together the expertise of a total of 14 institutes from the Technical University of Braunschweig, the Technical University of Clausthal, Leibniz University Hannover, the Fraunhofer Institute for Surface Engineering and Thin Films IST, and the Physikalisch-Technische Bundesanstalt Braunschweig (PTB). Figure 1 shows the BLB+ battery cell process cycle. Corresponding research contributions by the elenia battery team are highlighted with the elenia logo at the relevant process steps.

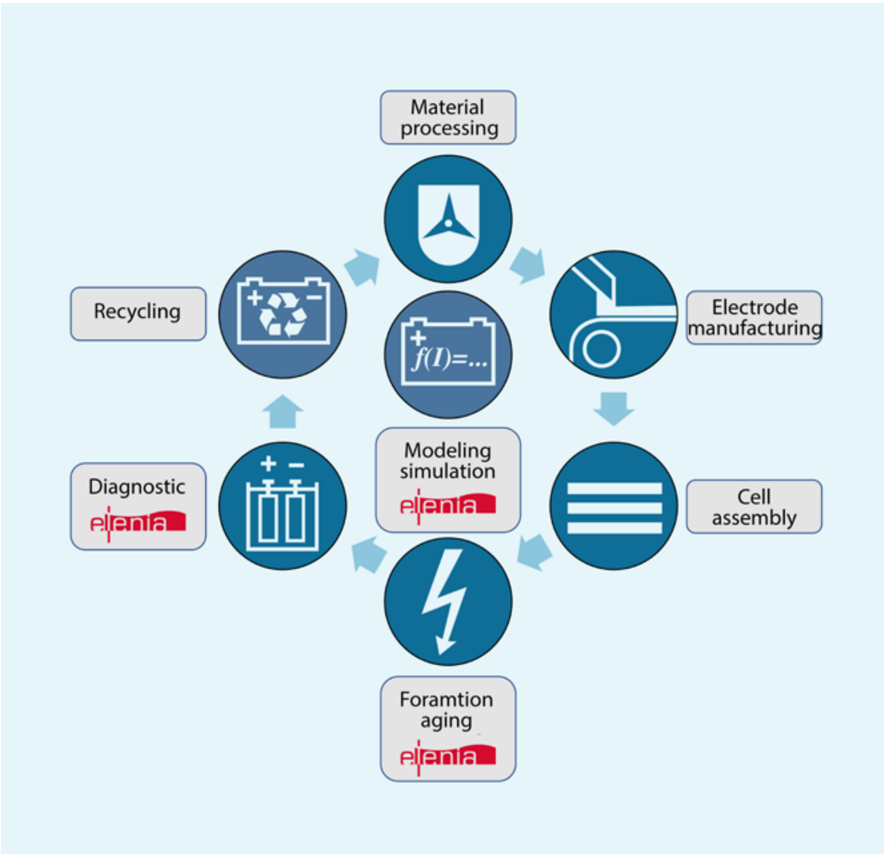

Figure 1: Research contributions by the elenia battery team along the battery cell process cycle at the 'Battery LabFactory Braunschweig' research center

After material processing, electrode production, and cell assembly, the battery cells undergo electrochemical activation, which is the primary focus of the elenia battery team's research. During this process, the battery cells undergo their first charging and discharging cycles, and electrolyte decomposition causes a passivating layer to form on the negative electrode, which is crucial for the functionality, performance, and safety of a battery cell. Due to the long occupancy time of the battery test channels, formation accounts for about one-third of production costs. The battery team at the elenia Institute is therefore investigating strategies and model-based approaches to reduce formation time and thus lower production costs. In doing so, it must be ensured that the performance, aging behavior, and safety of the battery cells are not negatively affected by the changed formation. To this end, elenia conducts electrochemical characterizations, pressure (gas formation, external cell tension) and temperature tests, among other things, which can be assigned to the field of diagnostics.

In addition to quality assurance in cell production, testing innovative cell material systems, and evaluating them with recycled electrode material, elenia is working on operando methods to adapt cell operation in such a way that cell degradation mechanisms are minimized or safety-critical conditions are identified in good time.

In addition to cost, safety, and range, the shortest possible charging time is an important factor for the social acceptance of electromobility. The elenia battery team is therefore working on the model-based derivation of aging-dependent fast charging strategies for battery cells. To this end, cell material system-specific operating limits are determined experimentally and model-based along the aging state of the cells, and the fast-charging profiles are derived on this basis.

In order to close the material cycle in battery technology, it is necessary to recycle battery cells, which raises a number of research questions.

The elenias battery team is testing the extent to which recycled electrode material influences the performance of battery cells and which components that can enter the recycled electrode material during the recycling process have a negative impact on cell performance. This will enable recommendations to be made as to which substances should be removed during material processing.

Research into alternative battery technologies: lithium-sulfur

As part of a research institution, the battery team naturally also deals with alternatives to established battery technologies. Lithium-sulfur batteries, for example, are known to have great potential. They are advertised with a theoretically achievable maximum gravimetric energy density of around 2500 Wh/kg, even though it is also known that this value is not even remotely achieved in the laboratory. In addition to energy density, material costs and availability as well as environmental friendliness also play a decisive role in determining whether a technology is considered promising. In these respects, the lithium-sulfur battery with sulfur and carbon as a composite for the cathode material has additional advantages. However, these obvious positive aspects are offset by very low cycle stability compared to lithium-ion batteries. The biggest challenges are dendrite growth on the anode side, which can lead to internal short circuits, and rapid capacity loss due to the dissolution of active material, which can precipitate elsewhere. As part of the **FestPoLiS** research project, elenia is therefore investigating the aging behavior of lithium-sulfur batteries with a solid electrolyte. This electrolyte, which is based on synthetic polymers, is designed to inhibit degradation mechanisms. The poorer conductivity of the polymer electrolyte compared to liquid electrolytes is compensated for with functionalized nanoparticles.

Figure 2: Materials in a lithium-sulfur battery

Graduate Research Training Group CircularLIB "CircularLIB" – Determining the condition of batteries with additives from recycling

According to EU directives, batteries manufactured from 2031 onwards must contain a certain percentage of recycled materials. Unlike conventional lead-acid batteries, lithium-ion batteries consist of many components. During recycling, the various components (including active material, lithium, housing and conductor parts) become mixed during the shredding process. In some cases, the individual components cannot be easily processed to 100% purity, resulting in contamination. The influence of this contamination on the service life of batteries is being investigated at elenia. The overarching goal is to be able to develop a prognosis. Which elements are critical, and which are tolerable to a certain extent? This will enable manufacturers to optimize their recycling efficiency.

In addition, active material from various resynthesis processes is evaluated electrochemically. Thermal, mechanical, and chemical processes for purifying graphite are compared. The influence of different proportions of the resynthesized material is also analyzed.

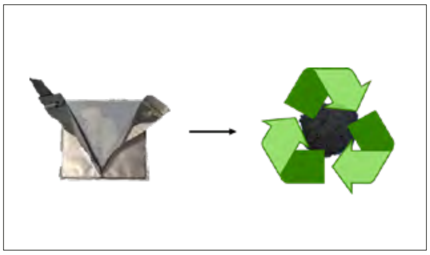

Figure 3: Schematic representation of the recycling of active material from an aged and opened pouch cell

Project PolySafe

The **PolySafe** project pursues an approach that increases intrinsic safety through innovative metal-polymer composite current collectors. The polymer contained in the current collectors softens or melts in the event of an internal short circuit, destroying the electronic conduction path, which ultimately limits the event locally and prevents thermal runaway of the entire cell. In addition, the combination of a metal layer and polymer substrate offers advantages in terms of weight and thickness, thus enabling the economical use of material resources.

Among other things, the project analyzes the quality and performance of cells manufactured on the basis of the metal-polymer composite current collector (Al@PET-CC) in comparison to cells that have a metal current collector (Al-CC) as a reference. The investigation is being carried out using, among other things, the C-rate test, which has shown that the cell variations have a comparable discharge capacity at current rates of 0.2C to 3C.

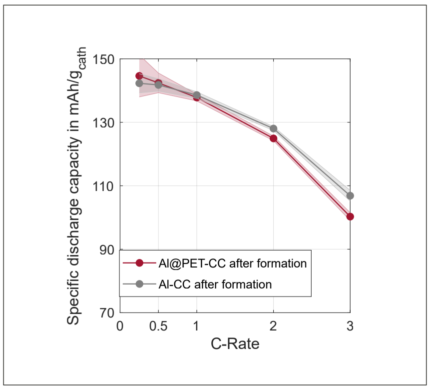

Figure 4: Comparison of specific discharge capacities

Adaptive fast charging strategies – Model-based evaluation of the operating limits of different cell systems for the design of aging-adaptive fast charging strategies

The requirements for the fast-charging capability of battery cells depend on the respective application, but are often limited by the material system and cell design. In addition, cell properties deteriorate as the battery ages. Fast charging processes in particular can lead to accelerated aging. For this reason, operating limits are often set very conservatively in order to avoid safety-critical processes and accelerated aging processes such as lithium plating. A promising alternative is to determine aging-dependent operating limits in order to adjust the fast-charging strategy accordingly. However, this approach is associated with challenges because aging-related adjustment of operating limits depends on conditions of the material and cell system that cannot be measured directly.

The **FastChargeLongLife** project addresses this challenge and develops a methodology for the model-based evaluation of different cell material systems in terms of maximum charging operating limits depending on the state of aging. To achieve this goal, a coupled model approach is used, which combines real-time capable equivalent circuit models and detailed physicochemical degradation models (see Figure 5). Model-based scalability of the material data is provided in order to transfer the model parameters from small cell formats in 3-electrode format to large-format pouch cells. Based on the model-based operating limits, aging-adaptive fast charging strategies are derived that avoid safety-critical degradation effects. This is done for different cell material systems, which can then be compared with each other in terms of their aging-dependent fast charging capability. The optimized fast charging strategies improved charging time and service life by more than 10 % compared to state-of-the-art fast charging strategies without aging-dependent adaptation.

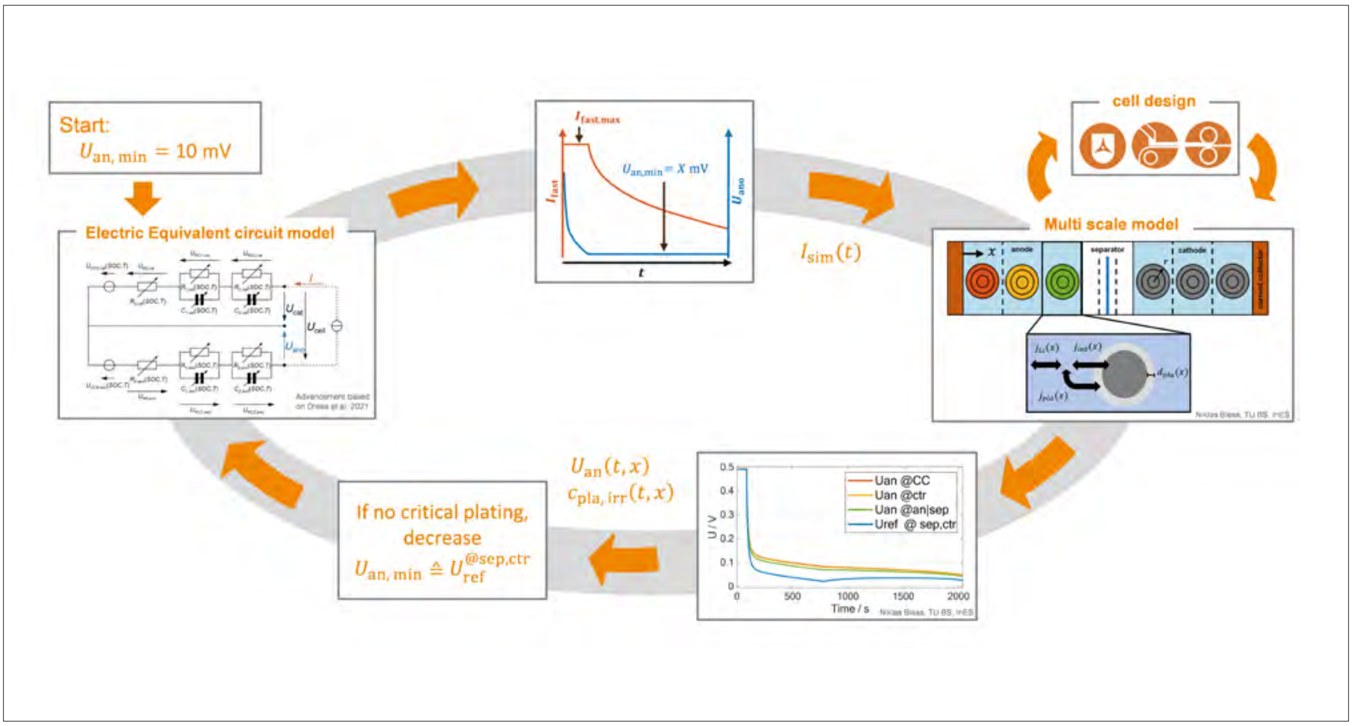

Figure 5: Model coupling between electrode equivalent circuit model and physicochemical model


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gratuliert zum Jubiläum
seit zehn Jahrzehnten gemeinsam verbunden
e-diale
Zukunft
Neugierig?
Jetzt Mitglied werden:
VDE
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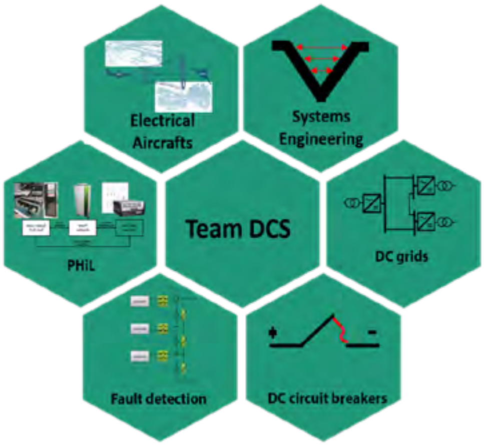
Fachverband
Normungsorganisation
Prüfstelle

Team DC Systems and Circuit Breakers



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The DC Systems and Circuit breakers team researches holistic approaches and methods for designing DC systems.

Direct current (DC) grids are becoming increasingly important in the context of the energy transition. The use of direct current increases efficiency when connecting DC components such as photovoltaic systems, battery storage systems, and computer systems, and when transmitting energy over long distances. However, the use of direct current poses new challenges for grid protection. Fault currents rise more quickly due to lower inductance values compared to alternating current (AC) grids. In addition, unlike alternating current, direct current fault currents do not extinguish on their own as they lack a zero crossing. Furthermore, the conversion processes in direct current grids are controlled exclusively by power electronics based on semiconductor components, which generally have a lower thermal load capacity than the transformers typically used in alternating current systems. Fault protection and the lack of standardization with regard to protection and grid planning are among the biggest challenges hindering the widespread use of DC and hybrid AC/DC grids.

Hybrid circuit breakers

Hybrid circuit breakers, which combine mechanical switching devices with power semiconductors, offer a promising approach. Mechanical switches achieve low conduction losses and galvanic isolation, while power semiconductors enable fast switching operations with low arc formation.

In the concept under investigation, the arc generated during the switching-off process plays a decisive role. In particular, after the arc has extinguished, there is a significant change in the dielectric strength of the switching path, which depends heavily on the properties of the decaying arc. A specially developed test setup that realistically simulates the hybrid switching-off process enabled a systematic investigation of parameters such as contact distance and current level. The replica of the mechanical switching path can be seen in Figure 1. In addition, alternative methods were developed and tested to further investigate reconsolidation.

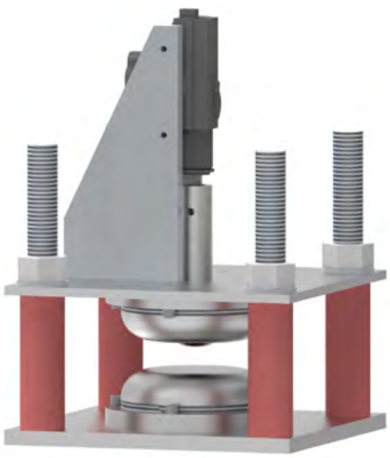

Figure 1: Replica of the mechanical switching section

The test setup is used, among other things, to investigate the solidification rate of various gases. The setup has been expanded to include a test vessel (see Figure 2) that enables tests to be carried out under variable pressures of up to 11 bar. Electrical and optical measurements as well as high-speed camera recordings make it possible to analyze the influence of different test gases on the dielectric recovery of the switching path. The findings provide important starting points for the targeted optimization of switching devices, not only for the low-voltage direct current (LVDC) range, but also for the high-voltage alternating current (HVAC) range.

Another area of research is the investigation of alternative nozzle materials for high-voltage AC switches. The thermal stress caused by the arc on the nozzle wall inside the switch leads to material outgassing. This desired effect contributes to the extinguishing of the arc. The aim is to use materials with the lowest possible toxicity and climate-damaging properties. The extent to which alternative materials have similar properties to the Teflon used to date in terms of durability and extinguishing behavior is being investigated.

Figure 2: Test container for examination under various environmental conditions

The breaker-less protection concept

The “breaker-less protection concept” represents an interesting alternative to the breaker-based DC protection described above. This method, shown in Figure 3, is characterized by its high speed and robustness. Modern power electronics have the intrinsic ability to limit currents to any maximum value after a fault occurs (e.g., buck converters, full-bridge MMC, back-to-back VSC). If the fault persists, it must be detected despite the current limitation and the converter must be switched off. As soon as current values are reached that allow the opening of galvnic disconnectors (residual circuit breakers), the fault is galvanically isolated by these. After successful fault isolation, the healthy part of the system can be quickly put back into operation.

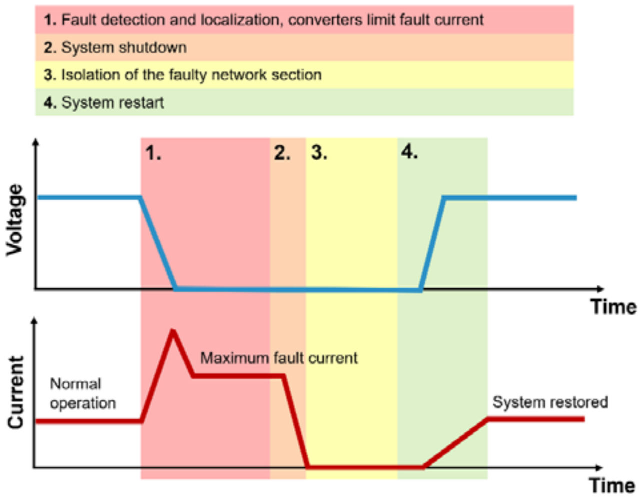

Figure 3: The breaker-less protection concept in the event of a fault

Development of a systematic DC protection design process

The existence of two fundamentally different protection strategies (breaker-based and breaker-less) requires a uniform planning process for DC protection with regard to standardization, which combines and takes both methods into account. At this point, we will build on the work of CENELEC (CLC/TS 50654-1). The design process developed is divided into three steps as shown in Figure 4 and is based on the system engineering V-model shown.

After identifying the requirements for network protection, boundary conditions for power flow during and after the fault clearing process are analyzed at the conceptual level and the desired behavior of the network is defined in accordance with CENELEC (CLC/TS 50654-1). At the system level, desired protection action sequences are defined at specific points in the network, initially without taking into account their implementation by protective devices. Fault localization mechanisms are selected so that these desired protection responses can be implemented during operation. The timing of all protection measures is also taken into account to ensure correct interaction. At the component level, the protection devices are placed in the network to implement the protective action sequences defined at the system level. Finally, the protection devices are dimensioned and the trigger thresholds are selected in such a way that the desired response of all components is enabled. Following the design of the protection system, verification and validation take place using the right-hand side of the V-model, as shown in Figure 4.

The planning process developed is used in EU projects such as PROSECCO and Inter-oPEn, among others.

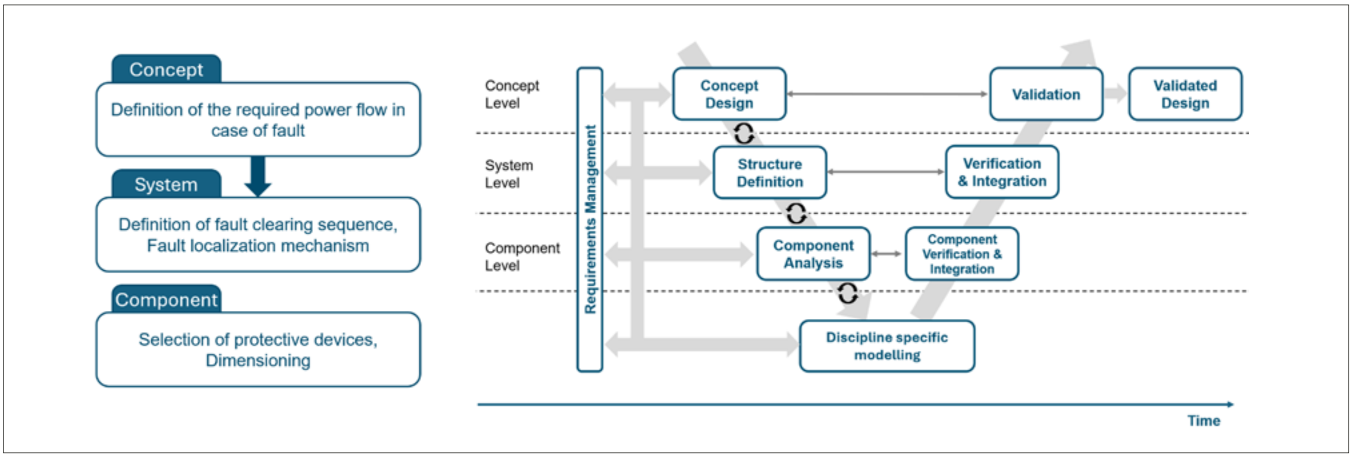

Figure 4: Planning process for DC protection based on the developed V-model from systems engineering

PHiL-simulation of HVDC systems

Research work on future high-voltage direct current (HVDC) systems in the field of control and protection technology has reached a stage of development where demonstrations of the components and systems developed in laboratory-scale environments are essential in order to further increase the Technology Readiness Level (TRL).

Due to increasing system complexity, for example with planned multi-terminal networks and DC hubs, the interactions between AC/DC systems and converters – in this case modular multilevel converters (MMC) – must also be analyzed in more detail in the laboratory environment.

Power hardware-in-the-loop (PHiL) simulations can be used to implement these complex system topologies and interaction studies. Figure 5 shows a schematic representation of such an application as implemented at elenia.

A scaled MMC is connected on the AC side via a network simulator and a transformer. On the DC side, the connection to a PHiL-MMC simulation is established via implemented cable replicas. The laboratory components are referred to as hardware of interest (HOI). A similar converter station, whose model was developed in-house, is simulated on a real-time simulator.

The resulting Model of Interest (MOI) is connected to the linear power amplifier via a PHiL Interface-in-Software (PIS) in such a way that power exchange between HOI and MOI is possible and there is feedback between the two systems, allowing them to interact as if they were electrically coupled.

This setup has already been used to successfully demonstrate control and protection concepts, for example to validate the conformity of fault ride-through concepts with the relevant grid codes. Interactions of MMCs during various faults were also analyzed to derive the need for further control and protection algorithms.

Overall, the demonstrator provides an essential environment for increasing the TRL in the field of HVDC systems. PHiL simulations are essential for analyzing even complex topologies and interactions.

The configuration is currently being expanded on the hardware side with an additional, likewise scaled MMC and another power amplifier to create a bipolar point-to-point connection in order to better represent real systems. Through the use of PHiL, the cable replicas can also be simulated, bringing the behavior even closer to that of a real long-distance line. In addition, this makes it possible to map various short-circuit scenarios at any point along the line. A flexible hardware design combined with real-time simulations also enables the representation of hybrid AC/DC networks with multi-terminal systems. DC switches can also be integrated into the setup, further complementing the HOI.

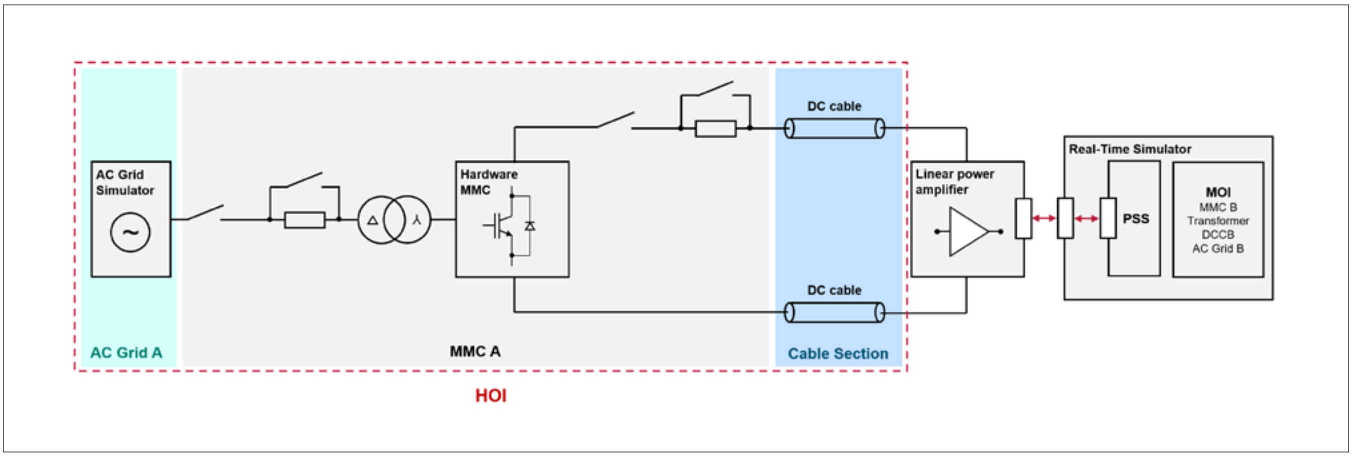

Figure 5: Schematic representation of the laboratory environment with PHiL simulations

Electric Aircraft

Electric aircraft, in which traditional hydraulic and pneumatic systems are (partially) replaced by electrical systems, is a promising approach to reducing greenhouse gas emissions. Such a change requires a fundamental redesign of the traditional onboard power network topology. The central question is how such a system can be designed effectively. A commonly used approach is systems engineering, in which the V-model (Figure 6) represents the typical development process.

In each phase, there are many aspects to consider, such as requirements analysis, defining interfaces, making assumptions, and documenting risks.

In general, there is uncertainty, for example, the standards and specifications that guide research and development are not yet fully matured. As a result, assumptions often have to be made, which introduces additional risks. A significant risk arises, for example, when the design does not comply with the standards or specifications that are published at a later stage. For this reason, it is crucial that all steps in the development process are clearly defined and well documented. Assumptions, decisions, and their rationale should be traceable so that later changes, such as adjustments to requirements, standards, or specifications, can be implemented in the design flexibly and efficiently.

An extension of systems engineering is Model-Based Systems Engineering, in which documentation is created in the form of visual models. This makes the documentation not only more organized but also easier to understand.

Figure 6: Rolls-Royce's concept for Vertical Aerospace; source: Rolls-Royce

Team e³ – Energy Management, Energy System Modeling and Energy Economics

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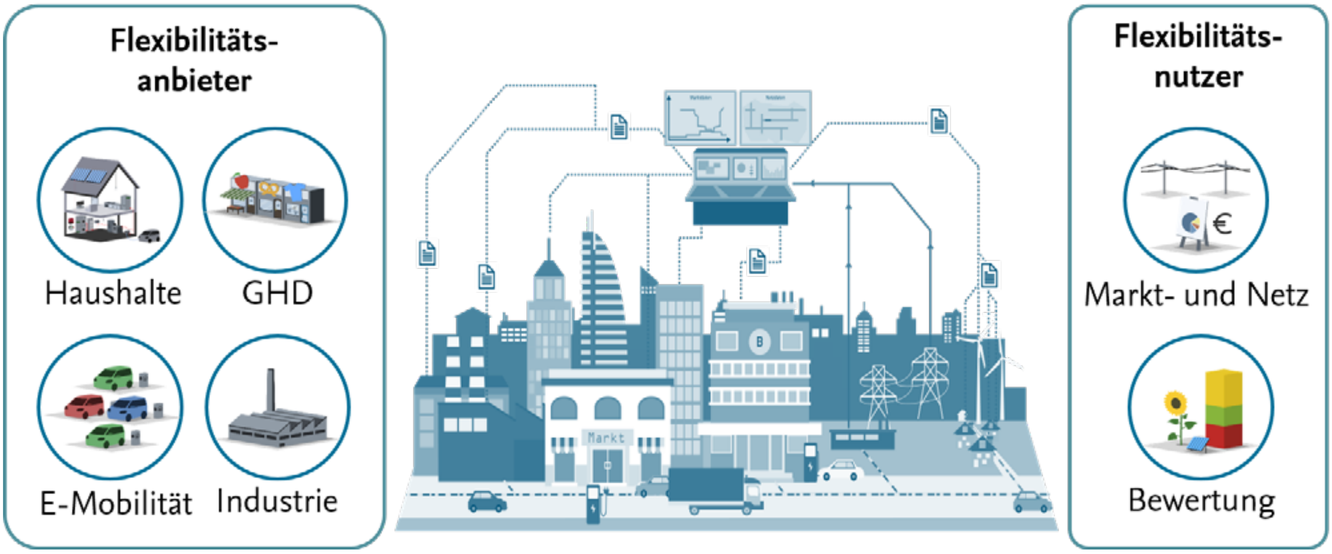

The transformation of the energy system towards a decarbonized, decentralized, and digitized structure is putting not only technical but also social and economic systems to the test.

Amidst these challenges, the interdisciplinary team e³ is dedicated to researching, modeling, and implementing solutions for a sustainable energy system. Our focus is on a holistic view of three core areas: energy management, energy system modeling, and energy economics. The objective is to provide concrete, scientifically based input for the design of a flexible, resilient, and sustainable energy system.

The interaction between technology, market, and users forms the methodological foundation of our work. We are developing innovative approaches that intelligently control energy flows, efficiently utilize market mechanisms, and systematically integrate digital infrastructures. Our research is closely interlinked with laboratory experiments, cooperative field trials, and simulation-based analyses – always with the aim of providing practical and sustainable solutions.

Energy Management – Control at the Intersection of Technology, Market, and Users

Controlling energy flows in an increasingly volatile and decentralized energy system requires new concepts that combine technical feasibility, economic efficiency, and user acceptance. In the field of energy management, the team e³ is researching how flexibility—i.e., the targeted shifting of energy generation, consumption, or storage—can be activated for various applications (e.g., system-oriented or grid-oriented).

The focus is on the development of Home Energy Management Systems (HEMS) that use forecasts, price signals, and grid status information to determine the optimal operating mode for prosumer households, commercial units, industrial plants, or modern associations such as energy communities or neighborhoods. These systems take into account technical restrictions as well as individual comfort limits and economic objectives.

A key component for implementing smart control approaches is the widespread use of intelligent measuring units with smart meter gateways. These open up new possibilities for smart energy management. The team e³ is investigating how relevant measurement and control data can be integrated into energy management via the various interfaces of the smart meter gateway. The resulting approaches and the various players are being tested in realistic conditions in the elenia energy management laboratory.

The team's research covers both centralized and decentralized control concepts and optimization algorithms. A particular focus is on how these systems can be integrated into existing infrastructures and how interfaces with grid operators, aggregators, and market players need to be designed to ensure economical and safe operation. In addition, the team is investigating the multi-use of residential battery storage systems in terms of revenue and value stacking, with the aim of fully exploiting the techno-economic potential. Application- and user-oriented approaches are being explored in this context.

The team is also investigating how different stakeholder groups—particularly end users—can be integrated into control decisions. Designing incentive mechanisms is therefore part of the research, as is examining socio-technical aspects, for example in dealing with comfort restrictions or data-protection concerns. The goal is to establish energy management as a central interface between the grid, the market, and users—not only in single-family homes, but also in multi-family buildings and at the neighborhood level, where shared-use concepts, collectively used storage solutions, and cross-sector optimization open up new potential.

Energy system modeling – Digital tools for the energy transition

The increasing complexity of the energy system requires detailed, multidimensional modeling and simulation approaches. In the field of energy system modeling, the team e³ develops tools that enable integrated analysis of the technical, economic, and regulatory aspects of energy systems. The team follows Open Science standards and sets high value on transparency and reproducibility of research results. In addition, the team addresses current issues of research data management and strives to follow the FAIR principles as closely as possible in its work.

A central tool is the eELib – elenia Energy Library. This open modeling library was specifically designed for questions related to prosumer systems. It enables the representation of energy system scenarios at the building, neighborhood, and grid levels, supports the development of operating strategies for energy management systems, and allows detailed analysis of interactions between consumers, producers, storage systems, and the electricity grid.

With the eELib, it is possible not only to simulate physical and technical processes, but also to model economic questions and market responses. The library offers modules for evaluating tariff models, analyzing grid-supportive operating concepts, and identifying possible grid bottlenecks resulting from sector coupling and electrification.

Thanks to its modular architecture and open documentation, the eELib can be flexibly expanded and integrated with existing software environments. It serves as a foundation for co-simulations, optimization studies, and real-world laboratory support—both for academic research and for industrial collaborations and policy consulting.

In addition to the eELib, the team also develops methodological frameworks for scenario analysis, sensitivity assessment, and uncertainty evaluation. These make it possible to systematically explore future developments and develop robust strategies—for example, in dealing with technology uncertainties or regulatory changes.

Energy Economics – Circumstances for a Sustainable Energy System

The transformation of the energy system can only succeed if technological innovations are accompanied by appropriate economic framework conditions. In the field of energy economics, the team e³ analyzes how market mechanisms, regulation, and business models must be designed to ensure efficient, fair, and resilient energy supply.

A central question is how new technologies and actor roles can be integrated into existing market structures. The team examines how variable tariffs, grid-oriented incentive systems, or market-based flexibility products must be structured in order to encourage prosumer-friendly behavior while at the same time ensuring security of supply and grid stability.

In addition, the team focuses on questions of cost allocation, the integration of decentralized actors into system services, and the design of innovative mechanisms and concepts. The effects of current and future regulations on prosumers, aggregators, and grid operators are analyzed, as well as the potential of new business models in multi-party contexts and community energy systems.

A particular research area is dedicated to the interaction between markets and technology: How do economic framework conditions influence the operating behavior of systems? What feedback effects arise on grid expansion, investment decisions, and system costs? Econometric models, simulation-based analyses, and specialized tools are used for this purpose.

International developments—such as market-based procurement of inertia or the design of local energy markets—are also incorporated into the research. The aim is to produce practical recommendations for policymakers, energy providers, and technology suppliers that enable a stable and future-oriented regulatory framework for the energy transition.

Figure 1

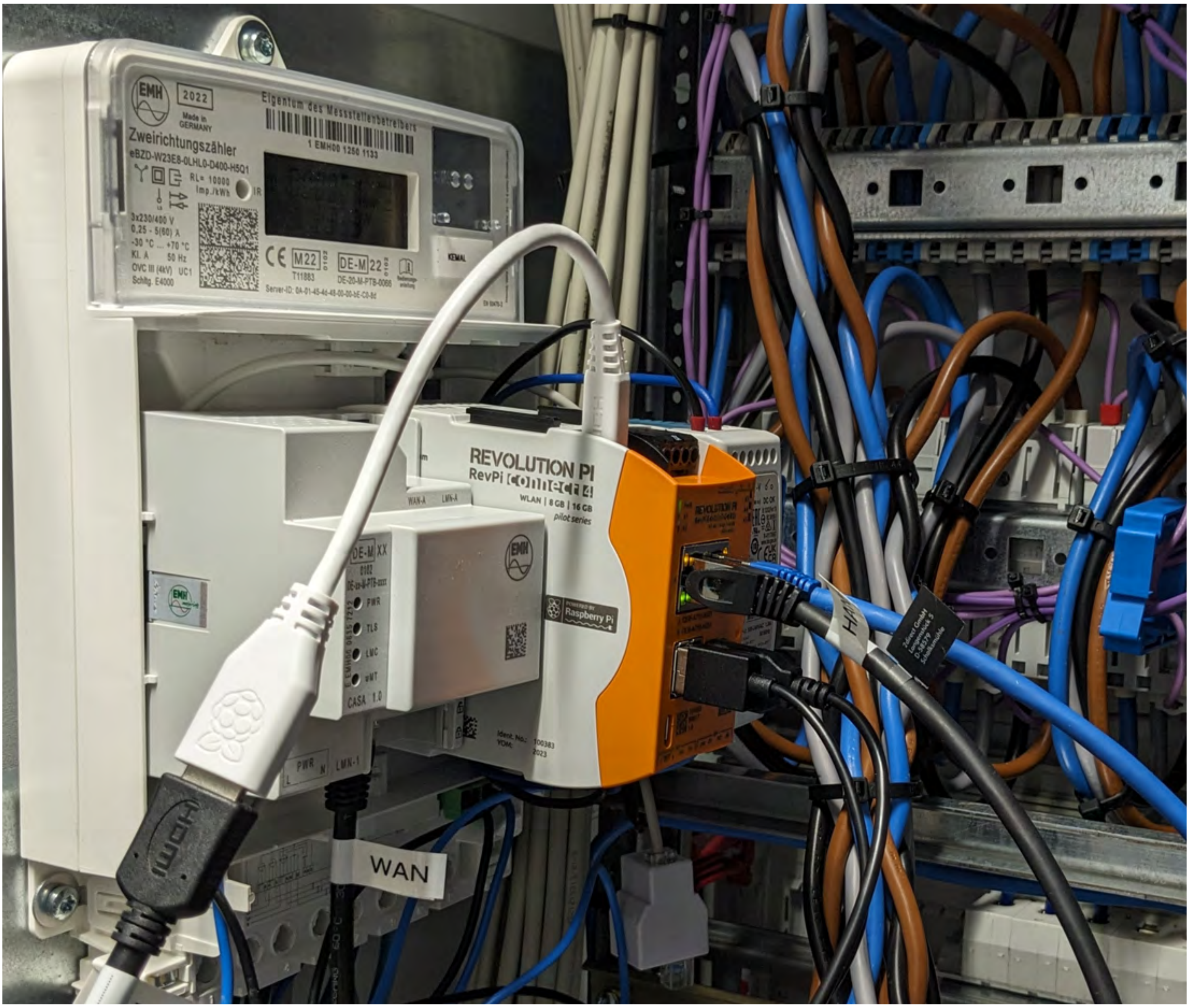

Figure 2: Smart meter with HEMS prototype in laboratory environment.

Holistic, practice-oriented, open – research with system responsibility

The team e³ considers itself as a driver of systemic and forward-looking energy research. Our strength lies in combining engineering excellence, economic system understanding, and societal perspective. We work on solutions that are technologically sound, economically viable, and socially compatible.

Our research approaches are continuously validated and refined in laboratory environments, simulations, and real-world field projects. Close collaboration with industrial partners, municipal utilities, grid operators, and political institutions ensures practical relevance. At the same time, by providing open platforms such as the eELib and publishing results transparently, we promote open, traceable, and collaborative energy research.

The goal of our work is to translate the diverse challenges of the energy transition into concrete solution approaches — from technical system integration and market design to user interaction. In doing so, we actively contribute to transforming our energy system and help achieve sustainable climate goals, security of supply, and social participation.

Team High Voltage, Vacuum and Plasma Technology

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The elenia Institute for High Voltage Technology and Energy Systems has been working intensively for years on the further development of vacuum circuit breakers for use in high-voltage applications.

As one of the leading locations for vacuum circuit breaker research in Germany, we are dedicated to fundamental research through our intensive research activities. Whether during the switching process, or in the open or closed state. The research activities are also evidenced by significant team growth: the team for high-voltage, vacuum, and plasma technology has grown from four to eight scientists and is advancing research at an international level.

Overall, it is clear that the vision of vacuum circuit breakers is the right way forward. The optimization of the vacuum switching principle and intensive investigation of plasma behavior are making a significant contribution to the sustainable transformation of energy technology. This strategic orientation makes it possible to meet the challenges of the energy transition and reduce environmental impact in the long term.

Alternative Insulation Gases for High-Voltage Systems

Sulfur hexafluoride (SF_6) offers excellent electrical properties in energy technology, but is extremely harmful to the climate with a global warming potential (GWP) i.e. a carbon dioxide equivalent of 25,184. In view of rising demand, particularly due to the expansion of the grid for renewable energies, we are researching alternative gases that can replace SF_6 and offer a more environmentally friendly solution to minimize negative climate impacts. This contributes to sustainability in energy technology. Experimental investigations with alternative insulating gases for high-voltage systems aim to find solutions using mixtures of atmospheric gases such as nitrogen, carbon dioxide, oxygen, and argon, or by adding a fluorinated gas. Research at elenia focuses on fluorine-free alternatives with a GWP ≤ 1. To test the suitability of a gas as an alternative insulating gas, the dielectric properties of the test gas are examined, among other things. In particular, the breakdown strength of the different gases is determined by varying different parameters such as different gas pressures, electrode distances, and electrode surfaces. This makes it possible to determine which of the test gases examined is the best alternative for a fluorine-free circuit breaker. In further investigations, the effective ionization coefficient and, from this, the streamer criterion will also be determined. In combination with field calculations and further investigations, a model will be developed to determine the electrical strength of defined arrangements.

Climate-Friendly Switching with Vacuum Circuit Breakers

In addition to alternative gases and technical air, vacuum can also be used as a substitute insulating and switching medium. Vacuum is particularly appealing due to the climate neutrality and maintenance-free nature of vacuum switching devices. Due to these advantages, vacuum switchgear is already predominantly used in medium voltage applications, and vacuum circuit breakers are gradually coming onto the market for high voltage applications. Our research contributes to the development of vacuum circuit breakers by providing a better understanding of individual aspects.

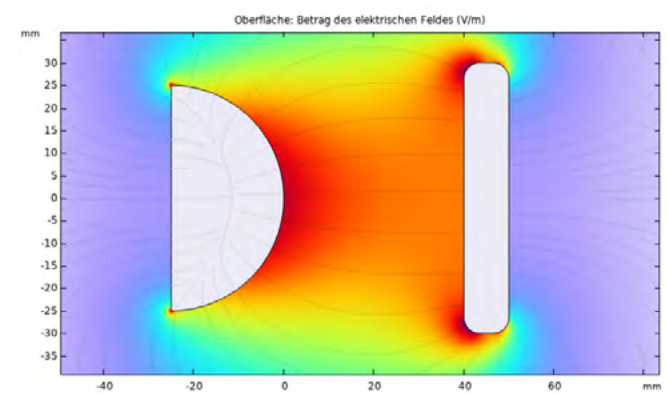

Figure 1: Field simulation of a sphere-plate arrangement

Dielectric

The decreasing electric strength of vacuum over distance makes it difficult to exploit the advantages of vacuum switching technology in the high-voltage range. Therefore, the electric strength of vacuum circuit breakers is an important area of research. In addition to excessive distance enlargement, the series connection of several vacuum switches is used as a possibility for high voltages. Special attention must be paid to voltage distribution, as the voltage distribution across the series connection shifts due to parasitic capacitances. As a result, the voltage across the top vacuum switch is higher than that across the others. Control capacitors are used to keep the voltage distribution in balance despite the parasitic capacitances. At elenia, the use of field controls made of metal shields that capacitively control the electric field is being investigated.

Plasma Parameters

In addition to the dielectric stresses in the open state of the vacuum switch, it is also necessary to control increasing short-circuit currents and transient voltages during switching off. Switching off a switching path is achieved by means of a fixed and a movable contact. When a fault occurs, the movable contact is separated from the fixed contact. During this switching off process, the high thermal stresses caused by the short-circuit current cause the contact surfaces to melt and metal vapor to spread inside the vacuum switch. The conductive metallic particles cause the formation of a plasma column, known as a vacuum arc. Due to the geometric contact design of the switching contact pieces, this arc is guided into a rotational movement by magnetic forces or extended to the entire contact surface, so that the contact pieces are worn evenly.

Arc Analysis

TMF contacts (Transversal Magnetic Field) are widely used in the medium-voltage range. Various research and development approaches are underway to make them suitable for use in higher voltage ranges as well. We are investigating high contact gaps of up to 45 mm and the switching off of two vacuum switches in series. The arc behavior during the entire switching-off process is observed with a high-speed camera and compared with measured electric parameters in order to obtain as much detailed information as possible about the plasma behavior.

Parameters such as arc velocity and number of arc rotations are examined. The movement of the arc can be seen when the contact pieces are pulled apart. The formation and subsequent extinction of the plasma is being researched in order to enable good switch performance even for higher voltage levels.

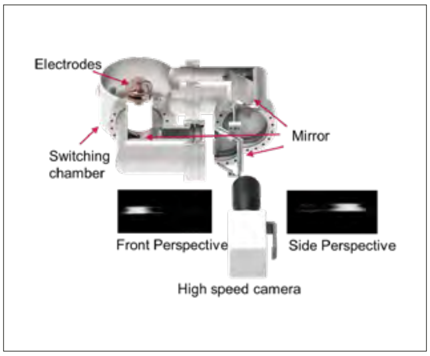

Figure 2: Schematic setup of optical vacuum arc observation with a high-speed camera

Magnetic Field Analysis

AMF contacts (Axial Magnetic Field) play a central role due to their lower erosion compared to TMF contacts. To maximize the service life of switching contacts under high power, heavy load conditions, the magnetic field should be uniform across the contact surface. As a result, the metal vapor is spread uniformly as well.

The axially aligned magnetic field, which pulls the metal vapor arc apart and converts it into a diffuse mist, is of crucial importance here. This even distribution reduces the local thermal load and thus the wear on the contact surfaces.

The figure shows the magnetic field generated by the current. As the distance between the contacts increases, the metal vapor cloud contracts, as can be seen in the illustration by the weakening of the field in the center of the contact gap. The arrows also illustrate the direction of the magnetic field lines.

Information about the field strength can be obtained both from simulations and from experimental measurements. In addition, the movement of the metal vapor cloud itself can provide clues about the field distribution.

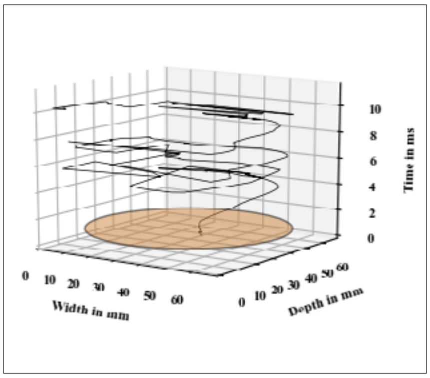

Figure 3: Movement of the vacuum arc during opening of TMF contacts under high current load

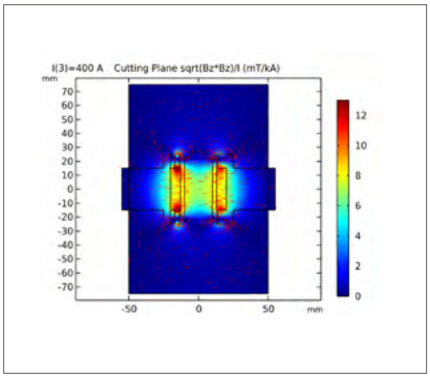

Figure 4: Magnetic field between AMF contacts

Interfacial Contact Resistance

Optimizing the efficiency and reliability of electrical transmission paths, in particular through comprehensive evaluation of the power loss of switch contacts under various conditions, rounds off our research on vacuum switches. A special test setup was developed to systematically analyze the contact resistance and associated surface effects for a range of materials. The contact materials investigated include alloys of copper, chromium, tungsten, molybdenum, and reference materials such as aluminum and brass. This setup simulates realistic mechanical and electrical conditions as found in medium-voltage switchgear.

Insulation Systems for High-Frequency Power Electronics of the Future

The new generation of semiconductors made from silicon carbide and gallium nitride (GaN) is becoming increasingly important in power electronics and is gaining ground in the market. The demand for efficient semiconductors is growing, particularly in the areas of high-voltage electrical systems and electromobility. A key advantage of these technologies is their ability to switch higher frequencies and voltages, resulting in high-frequency high voltage (HFHV). However, the fast switching processes pose new challenges, increasing the load on insulation systems and leading to more frequent failures. This places greater demands on the insulation materials used. In order to investigate the dielectric properties of solid insulating materials under high-frequency high voltage, a wide range of signal shapes, frequencies, and voltages is required. The generation of HFHV is technically challenging because it combines two extremes: high electrical voltage and high frequency. This combination places special demands on the components, materials, and design of the system. This makes the development of a new generator necessary.

In addition, test specimens are essential for reliably analyzing the effects of these stresses. Additive manufacturing can be used to produce both simple and complex test specimens quickly, easily, and cost-effectively. In order to use 3D printing for test specimen construction, the material must first be characterized and examined. The investigations show that the printing parameters have a significant influence on the dielectric properties of additively manufactured materials. One focus of the research was on the use of 3D-printed electrodes made of ESD-PLA to influence the dielectric breakdown voltage of air. It was found that although these electrodes have lower conductivity than conventional metal electrodes, they can still be promising for certain applications. The results illustrate that further optimization of the printing parameters and material properties could make additive manufacturing a cost-effective alternative for specific electrical applications.

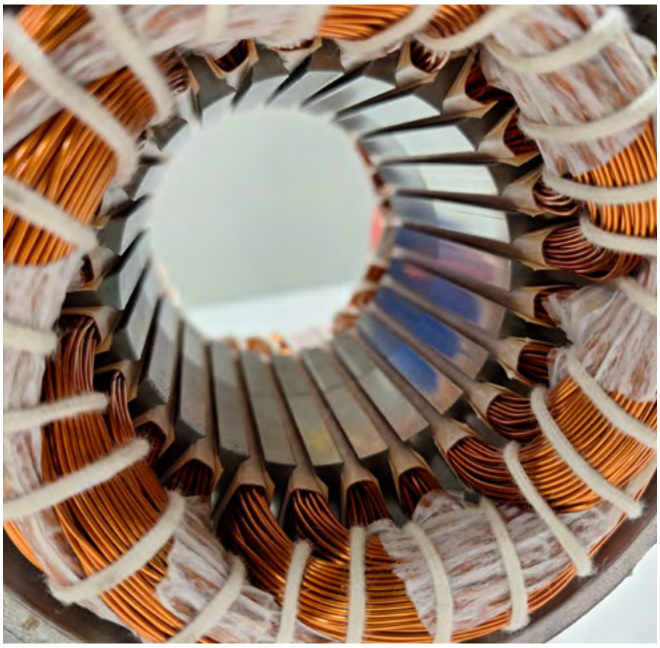

Figure 5: Insulation system in electromobility

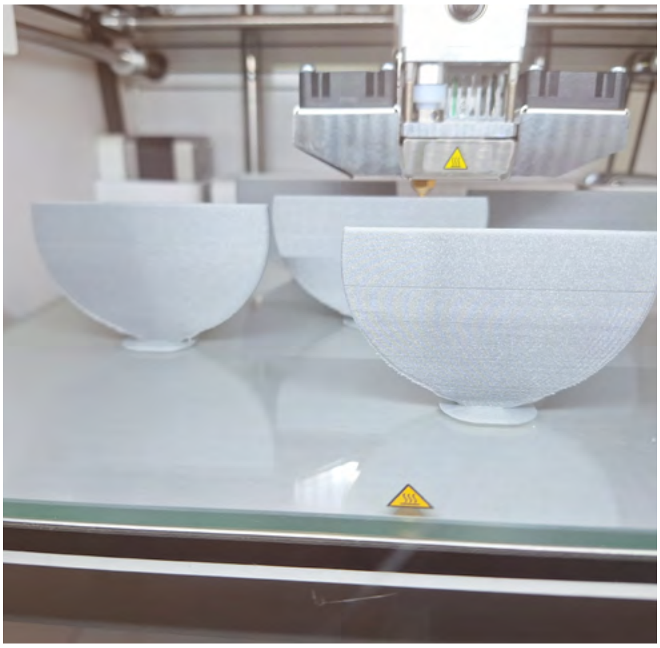

Figure 6: Test specimen production with 3D printing

Team Grid Dynamics and System Stability

Sofie Brammer, Max Gand, Till Garn, Johanna Grobler, Nelly Gorkow,
Stefan Klöpping, Timo Sauer, Frederik Tiedt, Stefanie Walujski,
Björn Oliver Winter.

Achieving a stable power grid in the future. We are developing solutions for tomorrow's grid stability.

The transition to renewable energy and the climate crisis require a fundamental restructuring of our electricity grids. Germany's decision to phase out nuclear and coal-fired power means that in future there will be fewer power stations connected to the grid via synchronous generators and instead more power electronic connected systems such as wind turbines, photovoltaics and battery storage facilities. Until now, some of the system services necessary for stable grid operation have been provided by synchronous generators due to their grid-forming properties. These include balancing energy, instantaneous reserve and voltage maintenance. In the future, renewable energy generation plants are expected to take over these tasks, ideally in their entirety. These generation plants supply direct current, which must be converted into the sinusoidal alternating current required by the grid via an inverter. Today's plants are almost exclusively connected via grid-following inverters, which take the frequency at their grid connection point as a reference and mimic it. In order for plants connected via inverters to be able to provide the system services previously performed by synchronous generators, their control must be adapted to a grid-forming control that does not rely on mimicking an external voltage. Only then can systems react instantly to disturbances and, in future, perform stabilising functions in the energy system, even in relevant transient short-term ranges.

The Team Grid Dynamics and System Stability conducts research into such grid-forming controls and their integration into different voltage levels in the energy grid. The aim is to ensure secure and resilient grid operation in the carbon-neutral energy supply system of the future.

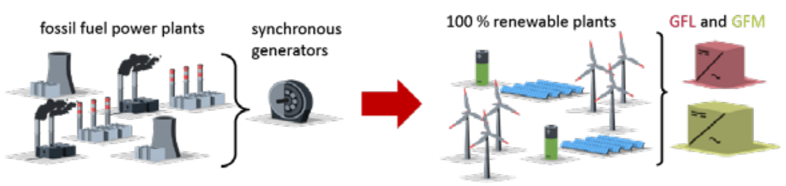

Figure 1: Change in the grid's generator structure from large plants with synchronous generators to smaller plants connected via power electronics.

The methodological approaches used by the team range from the comprehensive grid integration of new components, the development of control models for grid-forming inverters for dynamic time domains, and island grid detection methods to detailed simulations and laboratory tests. Prototype inverters and power hardware-in-the-loop systems are used for this purpose. The main tools used within the team are MATLAB Simulink and Python. The practical parts of the projects are implemented by the team in the grid dynamics laboratory at the elenia Institute. There, for example, demonstrators and prototypes are set up and experiments with grid-forming controls are carried out. In the future, the construction of a new laboratory will lay the foundation for further research and will be continuously expanded with additional high-performance components, such as a highly dynamic laboratory voltage source from Spitzenberger & Spies.

Quantifiable control behaviour of power converters with regard to transient stability and grid fault behaviour

The project *MetroSDL* is developing measurement technology in order to determine key variables for the market-based procurement of instantaneous reserve, such as the start-up time constant and dynamic frequency changes from current and voltage measurements. In addition, existing grid-following current control concepts are being further developed and supplemented by highly dynamic measurement and control methods in order to investigate the potential provision of faster primary control power products as a supplement to instantaneous reserve in control loops. The team is working on methods that effectively record grid parameters such as frequency, phase angle and frequency gradient (RoCoF) and incorporate them into the control system. Another focus is on determining the start-up time constants and the available instantaneous reserve of grid-forming inverters. The concepts and methods developed are extensively validated in the laboratory and form the basis for verification, prequalification and certification procedures.

The *Fuchstal leuchtet* real-world laboratory is investigating whether stable grid operation can be achieved in a decentralised medium-voltage grid powered exclusively by power converters without higher-level communication. The focus is on developing control strategies for grid-forming power converters that are operated with integrated large-scale battery storage systems, thereby enabling potentially self-sufficient grid management. What is special about this is the actual validation of developed measures in a real medium-voltage grid section in southern Germany. To this end, simulations are first used to analyse undesirable interactions and the interplay of the various control systems in order to minimise possible disruptive interactions. Furthermore, the Fuchstal leuchtet project investigates system stability in response to load changes and derives stability-promoting measures from this. Protection techniques and selective shutdown mechanisms, especially for the safe island operation of real grid sections, are evaluated, as are the existing grid parallel operation parameters with regard to future requirements. The aim of the project team is to develop a comprehensive control concept for power converter-based interconnected grids and to evaluate whether safe and stable operation of the medium-voltage grid can be guaranteed.

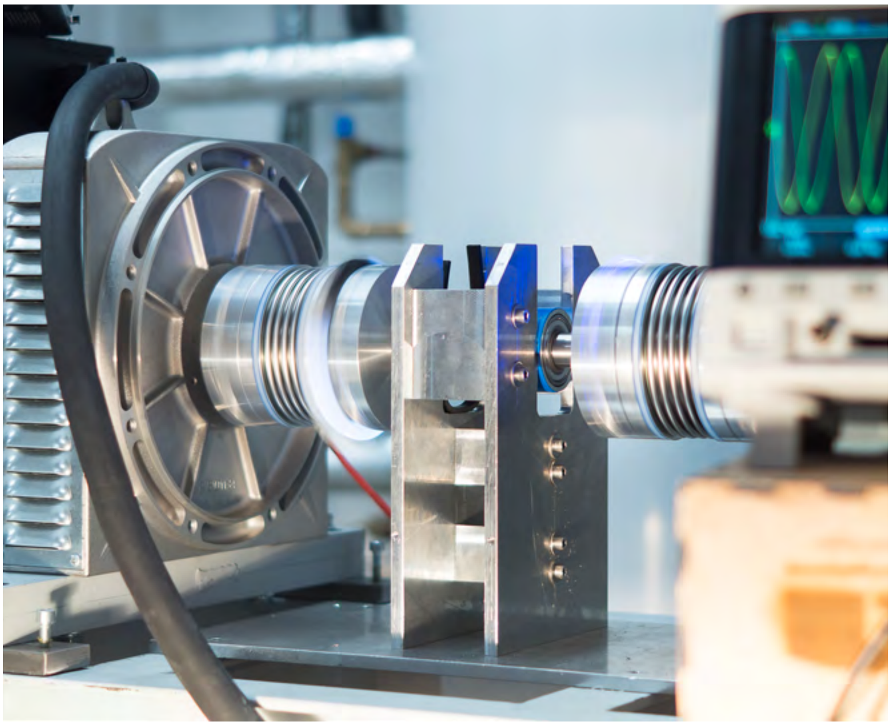

Figure 2: Coupled unit consisting of an asynchronous and synchronous machine with fully configurable converter

Demand assessment and provision of instantaneous reserve and implementation of robust Frequency Control

In order to ensure full system stability in the future, additional generation plants at lower voltage levels, such as low voltage, may also need to contribute to this. Grid-forming inverters could also help to maintain frequency. The overall goal of the NetFlexum project is therefore to contribute to the safe and successful introduction of grid-forming inverters in prosumer households and thus to work on solutions for greater grid serviceability, flexibility and cost-effectiveness of prosumer households. In this project, the team is using grid-forming control to create load collectives in order to identify the

Figure 3: Fully programmable three-phase prototype inverter

loads on both the inverter and the battery storage system. These are validated using a demonstrator in the grid dynamics laboratory. Finally, an economic evaluation of the prosumer household will be carried out to identify the options and limitations resulting from the provision of additional instantaneous reserve capacity.

The *SysStab2030* project is investigating what stable operation of the European interconnected system with up to 100% renewable energies can look like in the future. This project accompanies the system stability roadmap adopted by the German government in 2023. Specifically, SysStab2030 aims to identify system requirements arising from the changes described above. In addition, the potential of various plants will be researched in order to meet these requirements. The Grid Dynamics and System Stability team is focusing primarily on instantaneous reserve. The project consortium consists of several universities as well as the four transmission system operators, which enables immediate and direct exchange between all highly relevant interest groups at the highest level.

Interoperability in the use of grid-forming inverters and the design of a future grid

In order to guarantee safe and efficient operation in the future with high inverter penetration in the low and medium voltage grid, innovative solutions are being developed in the project *Verteilnetz2030+*. The team is focusing on three core areas: Grid protection is being adapted to changed grid characteristics in order to ensure system stability and prevent unwanted partial grid formation. At the same time, converter systems are being retrofitted and parameterised by transferring successful solutions from the transmission grid to the distribution grids in order to ensure stable operating conditions even under extreme load conditions. In addition, reliable solutions are being developed for the unwanted formation of island networks in order to minimise the risk of island networks while highlighting the potential advantages of decentralised network structures. This should contribute to economic efficiency without compromising network security and reliability.

Figure 4: 1 MW AEM- electrolysers

Field trials for the grid-friendly integration of battery storage systems and H_2 storage power plants

On 23 March 2023, construction began on the Braunschweig Hydrogen Terminal, which is being funded by the BMBF with over €20 million. In a joint project involving the Steinbeis Innovation Centre (siz) energieplus and the Technical University of Braunschweig, together with seven research institutes and the building management division, a research laboratory is being built on an area of around 4,700 square metres. This serves as a demonstration plant for a future megawatt -scale energy centre that covers the entire value chain from electricity generation using renewable energies to the production of green hydrogen. In addition to a 1 MW AEM electrolyser, a 1.1 MW/1.1 MWh battery storage system with a grid-forming power converter, a 100 kWp photovoltaic system, a hydrogen filling station, a connection to the local heating network, hydrogen pipelines to neighbouring research facilities and various test benches will be installed. The aim of the project is to bundle research synergies along the hydrogen value chain and to implement activities in the areas of hydrogen production, storage, feed-in, distribution, reconversion into electricity in fuel cells, and grid-friendly integration into the European electricity grid. Key issues here include assessing the dynamic controllability of AEM electrolysers in combination with a grid-forming battery power converter. This relates to potential participation in the primary control power market or the potential ability to provide instantaneous reserve power.

The GFI Pilot research project also aims to pilot grid-forming battery inverters at all voltage levels of the distribution grid and to develop operating strategies for these systems for the provision of instantaneous reserve. The extensive field and simulation studies are intended to make a significant contribution to the introduction of this technology and to system stability. A grid section in Thuringia, where black start capability and islanding have already been successfully tested, is being used for the pilot project. All operating modes (normal operation, islanded operation and grid restoration) are being tested in a real grid. The team is focusing on investigating grid-forming inverters in low-voltage systems, analysing the necessary operational requirements, planning measurement and investigation programmes, and carrying out simulations to evaluate disruptive events and the parallel operation of several systems. Finally, laboratory investigations and field tests will be carried out and the results evaluated in order to derive recommendations for the widespread introduction of grid-forming systems.

Figure 5: Joint team activity: mudflat hiking in Cuxhaven


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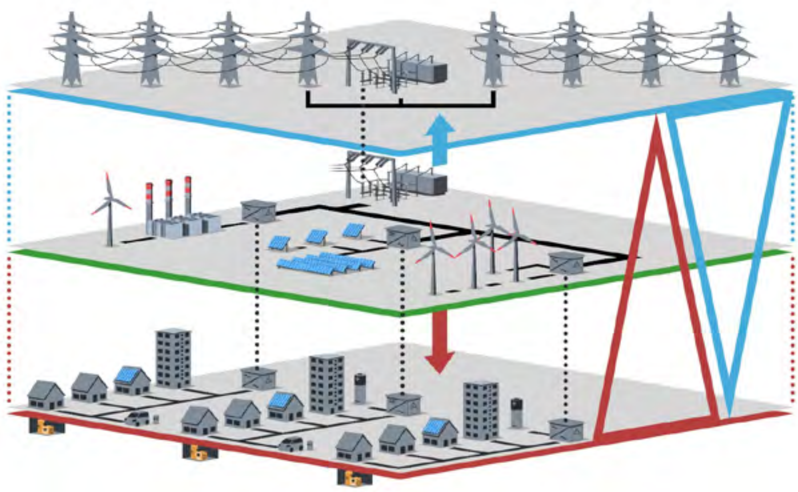
Team Grid Planning and Grid Operation

Lukas Ebbert, Gerald Gebhardt, Nils Gräfer, Robin Herman,
Hartmudt Köppe, Merten Schuster.



Research topics in the Grid Operation and Grid Planning team

Optimization of grid quality, innovative reactive power management, and new approaches to grid planning.

The Grid Operation and Grid Planning team has worked on a total of seven projects with eight employees over the past two years.

LISA4CL

In the LISA4CL project, a fast-charging inductive charging system with a charging capacity of 22 kW, which complies with existing standards, was developed and tested in real-world conditions. elenia's research work was limited to the implementation of grid and system integration for the charging infrastructure. This takes into account generation-oriented and grid-oriented charging concepts in order to increase the share of renewable energies in charging, minimize the grid impact of electric vehicles, and continue to ensure high grid stability. In addition, concepts were developed that can positively influence the voltage quality in the low-voltage grid. The figure shows the individual project components. In addition, practical operating scenarios were analyzed to better understand the interaction between charging infrastructure, energy supply, and vehicles and to derive recommendations for action for the future widespread use of inductive charging systems. The requirements for the use of vehicles in city logistics were also taken into account.

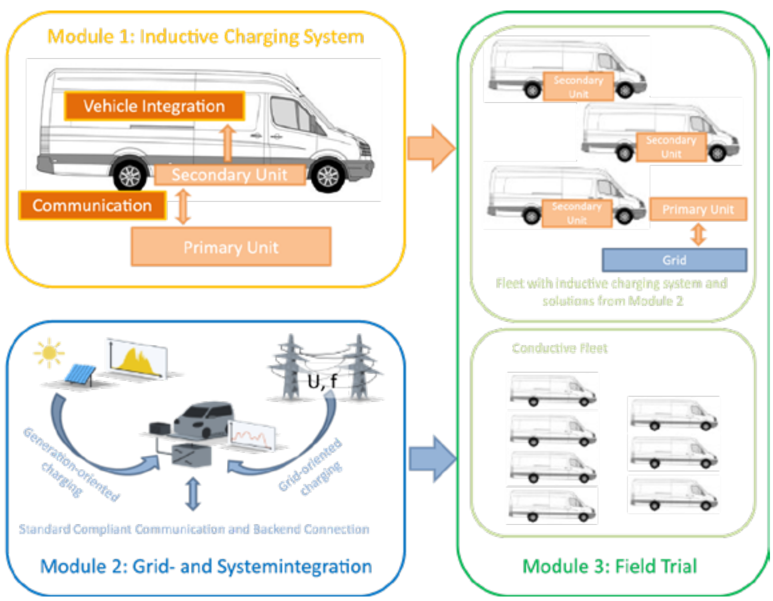


Figure 1: Structure of the different project contents of LISA4CL

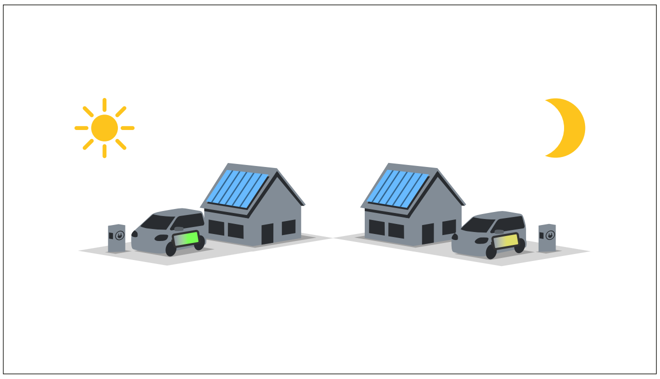


Figure 2: Example illustration of the day-night balance of PV energy

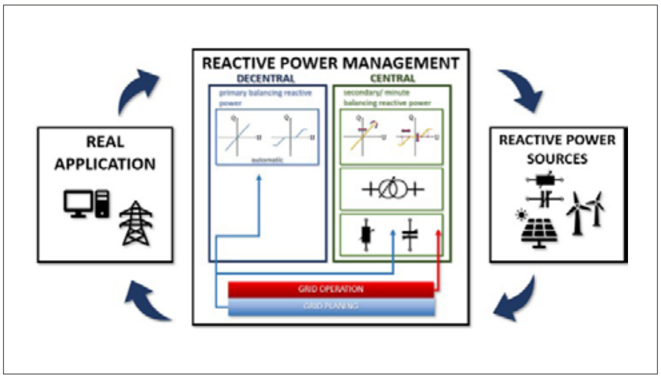


Figure 3: Schematic representation of reactive power management

NetFlexum

The NetFlexum project is investigating how bidirectional charging can contribute to flexibility and improved grid operation. Electric vehicles (EVs) are used not only as consumers but also as energy storage devices to balance peak loads and integrate renewable energies more efficiently. The NetFlexum project focuses on interaction with the grid, taking into account both economic and grid-related aspects of bidirectional charging. Only prosumer households that are primarily connected to low-voltage grids are considered. In addition to balancing PV energy between day and night, variable electricity tariffs and external grid signals are also taken into account to ensure the most efficient, sustainable, and grid-stabilizing use of available resources. Aging effects due to increased use of the infrastructure and the vehicle are also considered.

Q-Real

Reactive power management (RPM) is becoming increasingly important in the context of the energy transition, as longer transmission distances and higher grid utilization increase reactive power demand. At the same time, the supply from conventional synchronous generators is declining, while renewable energy plants (REPs) offer new potential. So far, this potential has not been fully exploited, as technical guidelines restrict their use.

The Q-REAL project (until 2025) focuses on adaptive control methods, improved reactive power forecasting, and a more accurate analysis of losses from RES parks in order to better assess the economic effects. In doing so, both the requirements of the distribution grid and those of the transmission grid are considered holistically. In addition, it is investigating how coordinated control and improved data availability can automate reactive power management and make it more efficient.

PICNIC

The PICNIC project will investigate the practical and technology-neutral design and requirements of efficient power quality control, taking into account decentralized components (charging infrastructure and storage systems) and decentralized smart metering systems, as well as the resulting digital control options. The sub-project at Technical University of Braunschweig will pursue the goal of developing control concepts. In addition, measurements of components will be used to investigate the influence of power quality disturbances on the components. The control systems developed and consolidated within the consortium will be implemented by the Technical University of Braunschweig in home storage systems and charging infrastructure in order to promote a positive influence on power quality through the control systems. Simulations of the mutual influence of the control systems provide insights into the future grid integration of the control systems. Cooperation with partners enables the implementation of control systems in and via smart metering systems (iMSys). An important goal is to conduct field trials with the implemented control algorithms in the iMSys that have been introduced.

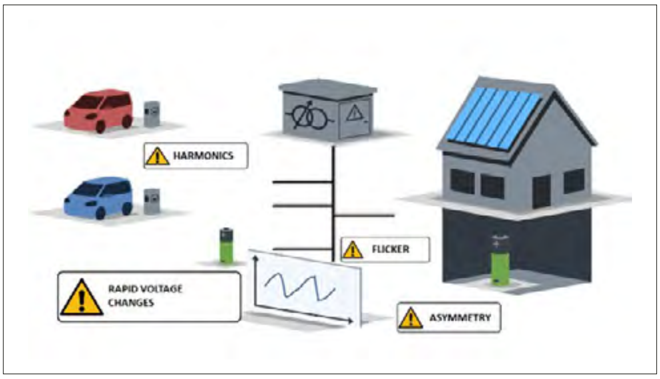


Figure 4: Components and their possible influences on various stress quality characteristics

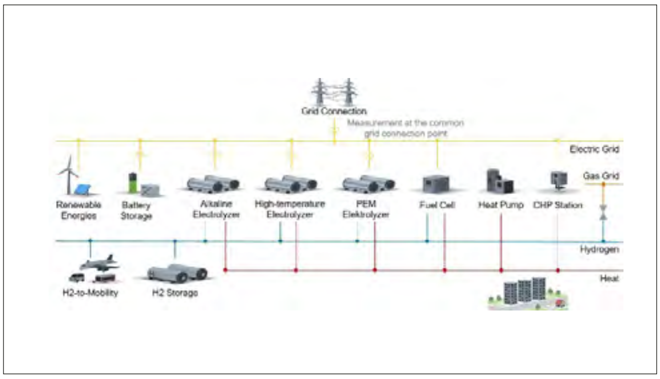


Figure 5: Schematic representation of the hydrogen environment

These field trials will demonstrate the feasibility of the system. elenia develops economic, normative, and technical analyses of the regulations under investigation with the aim of evaluating the best possible control strategies. In particular, the technical implementations of the regulations are compared with each other. Another objective of elenia is to derive recommendations for action with a focus on funding policy recommendations. The results should demonstrate efficient voltage quality regulation, taking into account decentralized components (charging infrastructure and storage systems) and decentralized smart metering systems. Some of the components and quality characteristics considered are shown in Figure 4.

H2-Terminal

The H_2 Terminal Braunschweig, a research project funded with over €20 million, is being established as a hydrogen competence center affiliated with the Technical University of Braunschweig. The project is a joint venture in collaboration with various institutes at the Technical University of Braunschweig, the University of Hamburg, and the Steinbeis Innovation Center energieplus. It comprises a research laboratory with a demonstration plant for the entire green hydrogen value chain, including electrolysis, storage, reconversion to electricity, and grid integration.

A central focus is on the holistic and grid-friendly integration of the various producers and sectors. Figure 5 shows a schematic diagram of the H_2 terminal complex.

SINED

The SiNED project is investigating the integration of prosumer households (with PV systems, battery storage, heat pumps, and electric vehicles) into the power grid to provide system services (SDL) such as voltage maintenance, congestion management, and frequency stabilization.

Due to the increasing decentralization of energy generation, these households can actively contribute to grid stability. The aim is to make optimal use of the flexibility of these systems in order to avoid grid overloads and reduce grid expansion.

The project analyzes regulatory, economic, and technical aspects and develops simulation models to improve the grid-friendly control of prosumer systems. Initial results show a high potential for improving grid stability and reducing the need for balancing power through the coordinated use of household flexibilities.

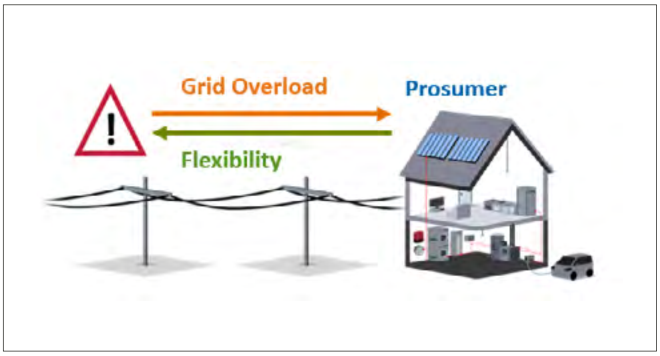


Figure 6: Coordinated communication with the Prosumer household

Connect to Transform

Connect2Transform (C2T) is a research project that promotes the transformation of heating and cooling supply in cities. The focus is on Braunschweig's Bahnstadt district—a 300-hectare area around the main railway station that serves as a real-world laboratory for the energy transition.

Connect2Transform (C2T) is a research project that promotes the transformation of heating and cooling supply in cities. The focus is on Braunschweig's Bahnstadt district—a 300-hectare area around the main railway station that serves as a real-world laboratory for the energy transition.

Intelligent networking of all components and technologies as a holistically efficient transformation approach to achieving climate protection goals

What makes C2T special is its holistic approach: instead of looking at individual technologies in isolation, we are developing a system in which all components, products, and solutions are intelligently networked and contribute to climate neutrality through their combined performance. From large heat pumps and hydrogen electrolysis to seasonal heat storage – everything communicates and works together.

A consortium of scientists, business leaders, and urban developers is working together to realize this vision. Under the leadership of SIZ energieplus, new technical solutions are being developed and tested. The focus is not only on technical aspects, but also on social and economic conditions.

Interdisciplinary cooperation between business, science, administration, politics, and citizens as a sustainable, forward-looking model for success

The C2T project, funded by the Federal Ministry for Economic Affairs and Climate Protection, is part of the German government's 7th Energy Research Program and was approved as part of the "Climate-Neutral Heating and Cooling" funding call. The funding enables the participating partners from science, industry, politics, and urban development, together with the citizens of Braunschweig, to develop innovative solutions for climate-neutral heating and cooling, and is intended to serve as a model: What succeeds in Bahnstadt should later be able to be implemented in other cities.

C2T thus makes an important contribution to achieving climate protection goals in urban areas. Greater efficiency, cost-effectiveness, and quality through standardized planning specifications for public and private building owners.

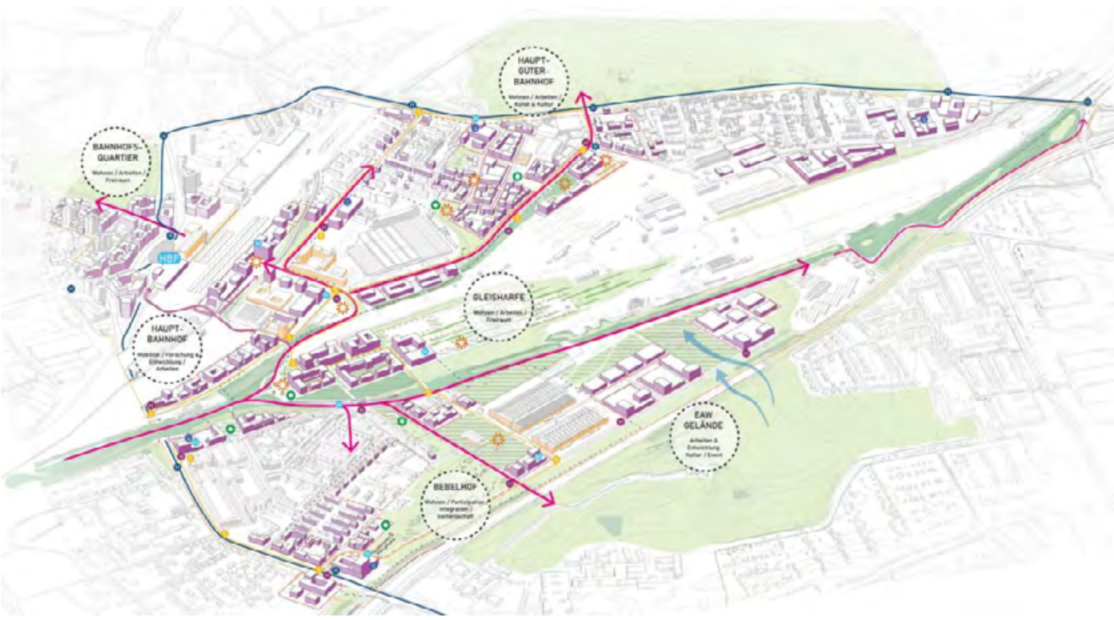
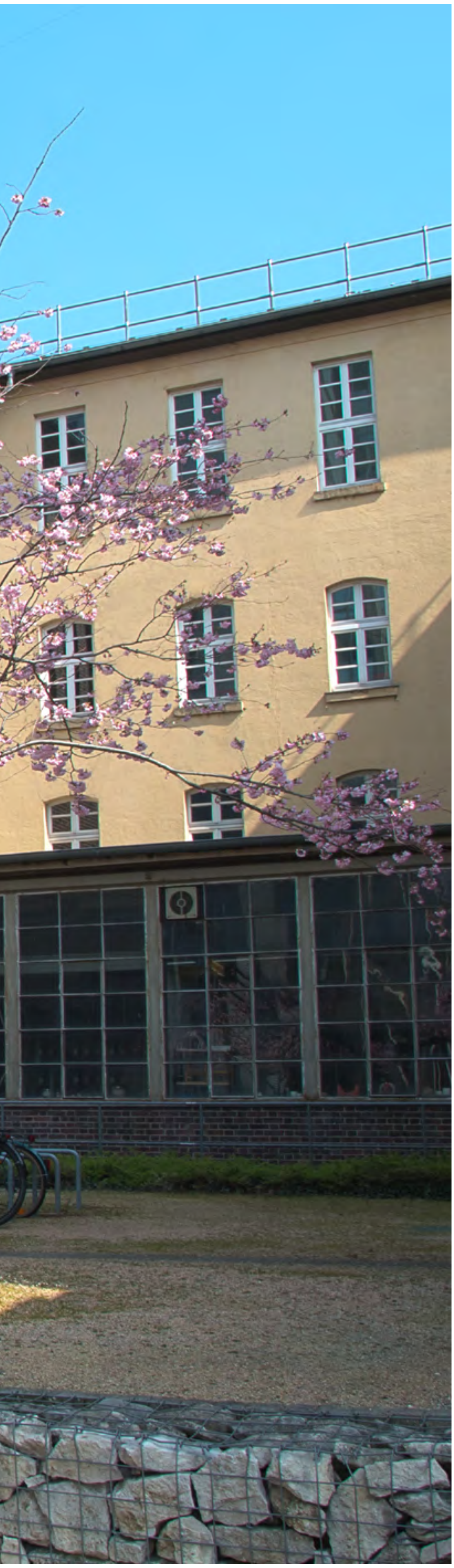
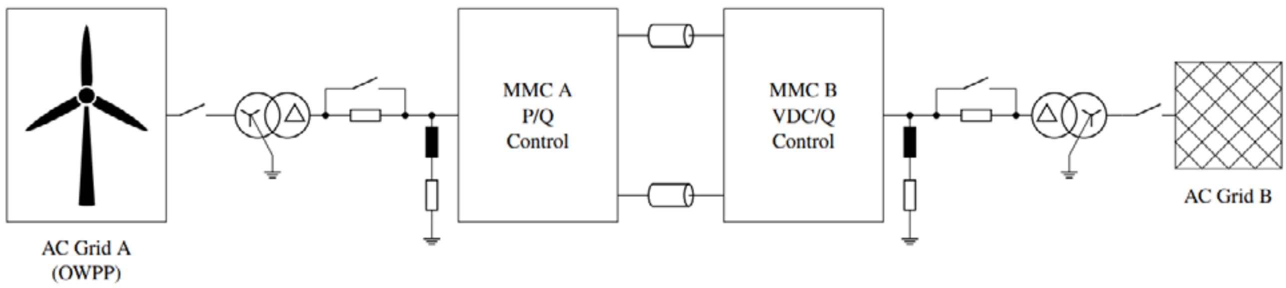


Figure 7: Representation of the railway district under investigation


Prosumer
Elektromobilität
PV-Speichersysteme
eel
eleniaenergylabs
Energiemanagement-Labor
Power-To-Heat
Lademanagement
IKT & Messsysteme
Prüffeld



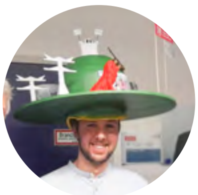
Dissertations



Team DC Systems and Circuit Breakers

Marc René Lotz

Systematic Development of a Laboratory-Scale HVDC System with Power-Hardware-in-the-Loop Simulation Capabilities for the Validation of Control and Protection Principles



Due to advancements in the utilization of HVDC systems, extensive research activities are underway with the aim of increasing the Technology Readiness Level (TRL) of the associated technologies. In the field of control and protection concepts for complex HVDC system configurations and in the analysis of AC/DC system interactions, developments are at a stage that increasingly require demonstrations in laboratory environments. PHiL (Power-Hardware-in-the-Loop) simulations are essential to achieve the necessary complexity of laboratory-scale demonstrators.

It has been found that research activities often lack a holistic description that relates to both the demonstration of laboratory-scale HVDC systems and PHiL simulations of Modular Multilevel Converters (MMCs). Therefore, this work pursued a systematic and holistic development process, resulting not only in a detailed description of the implementation of PHiL-MMC simulations with stability analysis and interface design, but also in the development of a demonstrator representing a laboratory-scale HVDC system that enables the validation of control and protection concepts in a meaningful way. This is a significant contribution to the studies on HVDC systems, which are essential for increasing the TRL.

To promote confidence in the use of PHiL simulations in this field of research, an MMC of the laboratory-scale demonstrator was implemented in the form of a PHiL-MMC simulation, which was also developed in this work. For this purpose, the PHiL testbed was characterized in detail, including a Real-Time Simulator (RTS) and a power amplifier, as well as delays that can occur due to communication interfaces and the timing of model equation calculations. Types of MMC simulation models were evaluated, leading to the implementation of a self-developed Type 4 model on the RTS. With the development of comparable subsystems, the maturity level of PHiL simulations could be analyzed with regard to the feasibility of representing a hardware MMC in the laboratory environment.

Marc René Lotz

AT ELENIA FROM

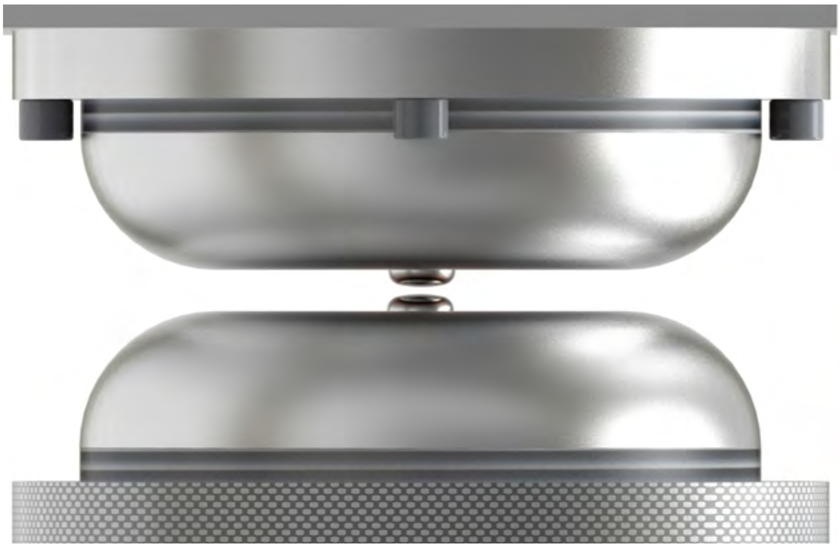
2020 – 2025

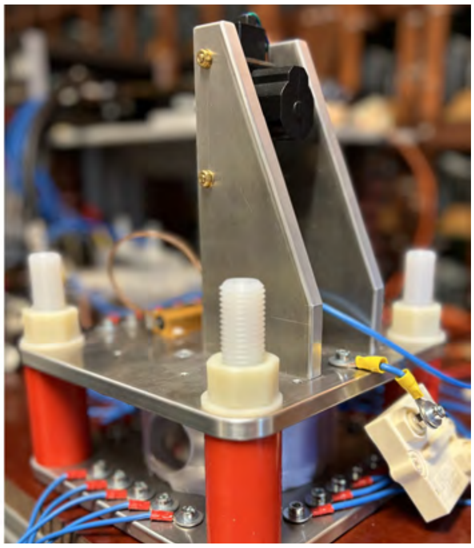
ACTIVITIES AT ELENIA

- SiNED project – Ancillary Services for Reliable Power Grids in Times of Progressive German Energiewende and Digital Transformation
- PROSECCO project – DC Protection, Security, Control, and Optimization
- Power-Hardware-in-the-Loop simulations of laboratory-scale HVDC systems

CURRENTLY EMPLOYED AT

- TenneT TSO GmbH





Team DC Systems and Circuit Breakers

Patrick Vieth

Experimental Research and Modeling of Plasma Recovery in DC Hybrid Switching Devices

A large part of our energy supply is still based on fossil fuels. In order to slow down the resulting climate change, the share of renewable energies is being steadily increased. In addition, energy efficiency is being improved in order to reduce overall energy consumption. A promising approach to increasing efficiency is to convert industrial networks from alternating current (AC) to direct current (DC). DC networks allow for easy integration of renewable energy sources and energy storage systems. In addition, excess energy from production processes can be fed back directly into the grid.

However, suitable switching devices are required for safe and reliable operation. Mechanical switching devices have minimal on-state resistance and galvanic separation in the off state, but are comparatively slow. Semiconductor switching devices are characterized by high switching speeds and arc-free operation, but have comparatively high on-state losses and are sensitive to overvoltages. In order to combine the advantages of both technologies, hybrid switches are now used that combine both switching device topologies. They offer low losses when switched on and high switching speeds. This makes them a crucial component for powerful DC grids of the future.

The aim of this work is to optimize hybrid switching devices in order to increase switching speeds and reduce costs. The focus was on the mechanical part of the hybrid switching device. The study examined how the plasma of the arc generated during switch off process recovers to air. For this purpose, an existing laboratory setup was adapted (see header image) to represent various scenarios within the framework of design of experiments. In addition, a method for measuring the breakdown voltage was developed.

It was found that so-called immediate recovery effects, which are otherwise used in light switches, can also be applied to DC switching devices. In addition, it was shown that the choice of overvoltage protection significantly influences the switch off speed. To explain this, a semi-empirical simulation model based on charge carrier movements was developed. Both the setup and the model can be used in future projects to optimize the switch off process of hybrid switching devices. This can further increase the attractiveness of DC networks in order to contribute to climate protection.

Patrick Vieth

AT ELENIA FROM

2021 – 2025

ACTIVITIES AT ELENIA

- Collaboration and team leadership of the DC Systems and Switchgear Team
- Work on the PEEL, SMS II and UPS projects
- Experimental investigation and modeling of hybrid switchgear

CURRENTLY EMPLOYED AT

- Nexans Deutschland GmbH as Head of the high-voltage Lab

Team Energy Management, Energy System Modelling and Energy Economics

Felix Klabunde

Technisch-wirtschaftliche Analyse der Energieversorgung mobiler Arbeitsmaschinen mit postfossilen Antriebssystemen in der Landwirtschaft

As one of the main players in decentralized energy generation, agriculture already plays an important role in the energy transition. In addition to widespread photovoltaic and wind energy systems, agriculturally operated biomass power plants enable the weather-independent generation of electrical and thermal energy. The operation of agricultural machinery is still dominated by the use of fossil fuels. To reduce fuel consumption, alternative drivetrains can be used in the future, which are supplied in part by local renewable energy and the power grid.

As part of this dissertation, the transition of agricultural machinery from diesel use to alternative drivetrains is being investigated through simulation. The focus lies on the technical and economic investigation of energy supply from renewable energy sources and the power grid. For battery-powered agricultural machinery, a battery swapping concept is being investigated, so that recharging is decoupled from machine operation. The swap batteries enable the direct use of electrical power within the machine and are used interoperably across different machine types. The simulations also show that battery-electric operation is not suitable for all machine types and that heavy fieldwork requires other drive systems. One such drivetrain could be cable operation, in which the agricultural machine is continuously supplied with power. However, this system is not suitable for mobile work (e.g., transport runs). Such work can be performed by agricultural machines with swappable batteries or fuel cells, although in the latter case, direct self-supply via renewable energy is not possible without prior hydrogen production via electrolysis or steam reforming. The grid studies also show that the switch to electric drivetrains generally requires a medium-voltage connection for the agricultural business.

The economic viability of alternatively powered agricultural machinery compared to diesel-powered machinery is achievable only if certain cost components decline and diesel prices rise. Additionally, targeted subsidies and regulation can help accelerate the transition to alternative drivetrains in agriculture.

Felix Klabunde

AT ELENIA FROM

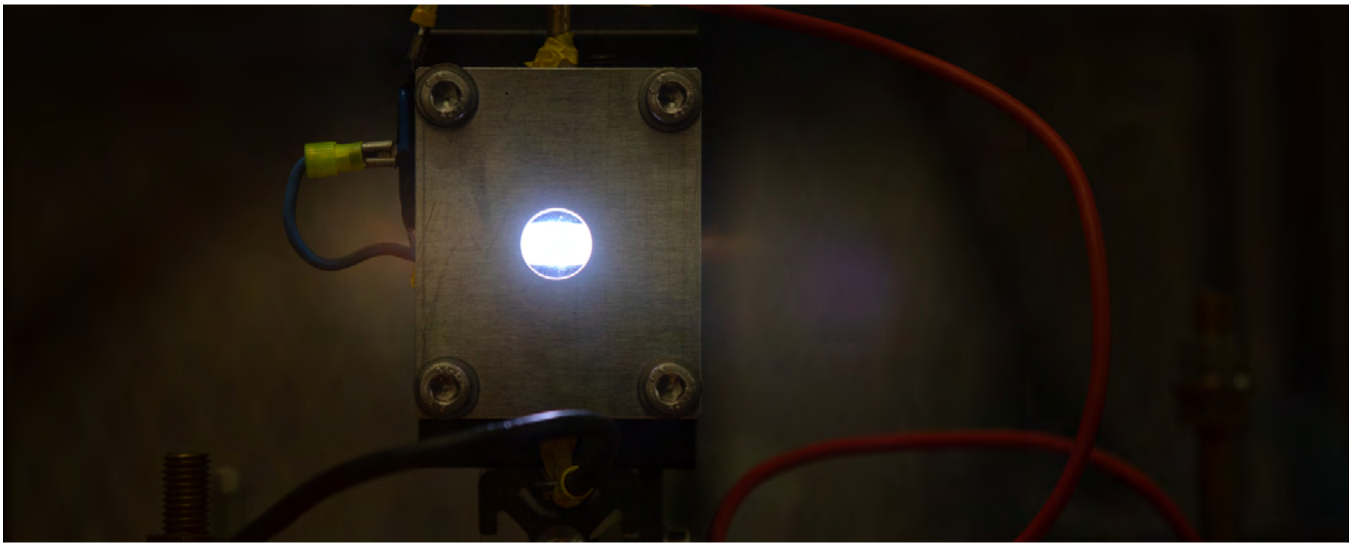
2020–2024

ACTIVITIES AT ELENIA

- Working on the Energy-4-Agri research project
- Working group leader for Energy Systems 2022–2024
- Team leader for Energy Economics and Energy Management 2021–2022

CURRENTLY EMPLOYED AT

- TenneT TSO GmbH in Asset Management as an Asset Strategist



Team High Voltage, Vacuum and Plasma Technology

Enno Peters

Investigation of the transient recovery process of plasma properties in spark gaps after surge current application

In the context of the energy transition, short-circuit power in supply networks is increasing due to a growing number of decentralized generation plants. At the same time, digitalization is advancing, leading to the formation of smart grids that integrate sensitive electronic equipment into the modern low-voltage network of the future.

In the event of a surge-related fault, both high-frequency and mains-frequency overcurrents can occur, accompanied by voltages in the range of several kilovolts. These high interference voltages place stress on all insulation distances in the low-voltage system and cause a high potential for damage in the event of failure.

An internal lightning protection system therefore offers protection against mechanical and thermal damage. In order to achieve a complete lightning protection concept, external and internal lightning protection must be in place, with the so-called type 1 surge arresters having to meet the highest requirements.

The task of a lightning current arrester is to establish a parallel path between the phase and the equipotential bonding bar within a short period of time. Once the energy from the lightning strike has been dissipated, the arrester should ideally return to an insulating state and restore galvanic isolation. This ensures uninterrupted operation even during a fault.

This thesis focuses on the time period after the surge current excitation has subsided. If the switching path does not return to its insulating state quickly enough, a grid follow current driven by the supply network flows as a short circuit, which in the worst-case scenario can lead to the destruction of the connected components.

The aim of the experimental investigation in this work is to develop a comprehensive understanding of the recovery phase and its influence by a varying set of input parameters. Partial models created from experimental data are used to calculate thermodynamic and transport-relevant variables such as plasma temperature and mass density. These are used to extend data-driven black-box models into a hybrid model using physically based parameters. Once the behavior of the plasma properties and their influence by the input parameters is known, this knowledge can be specifically applied to the chamber wall materials and the contact materials. This enables an increase in switching capacity in both the high-current and recovery phases. In particular, the grid follow-current extinguishing capability can be improved, resulting in higher reliability over the entire service life.

Enno Peters

AT ELENIA FROM

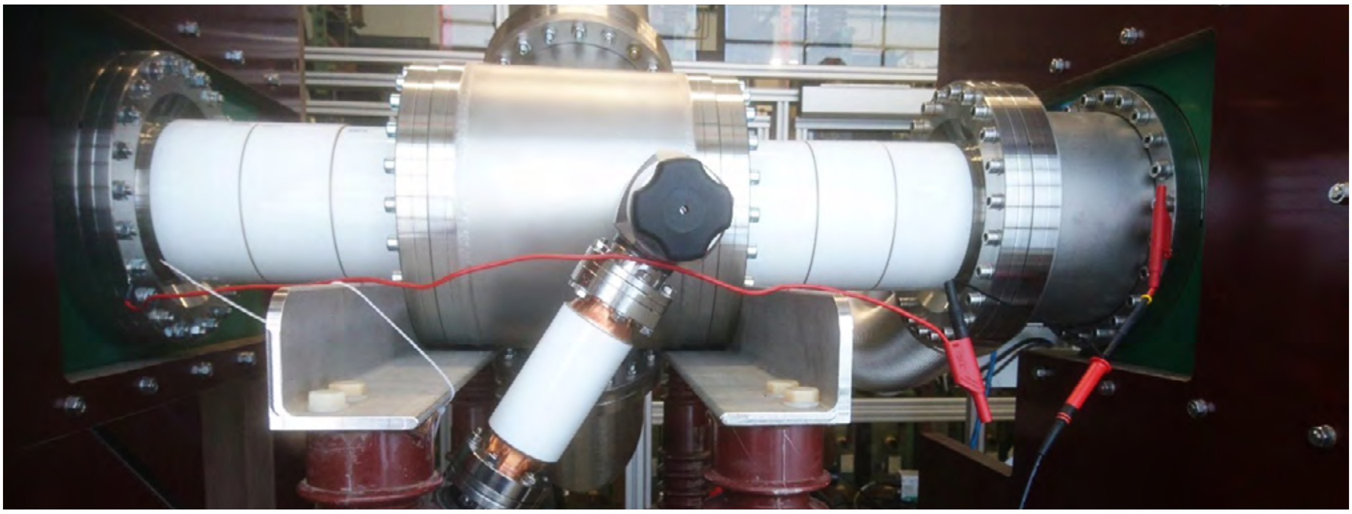
2018–2023

ACTIVITIES AT ELENIA

- Working group leader for energy technologies (2022–2023) & team leader for HVP (2020–2022)
- Working on research projects with industry partners Phoenix Contact GmbH & Co. KG and ABB
- Investigation of the recovery of surge current arresters in the distribution network

CURRENTLY EMPLOYED AT

- Avacon Netz GmbH in high-voltage asset management



Team High Voltage, Vacuum and Plasma Technology

Timo Meyer

Breaking current analysis of test circuit measurements at zero crossing for vacuum interrupters

The vacuum circuit breaker is an alternative to the green house sulphur hexafluoride circuit breaker used in high-voltage networks. In order to replace the sulphur hexafluoride device completely, new vacuum interrupter designs are being investigated. An objective evaluation criterion is needed to assess their successful interruption.

One such criterion is the post-arc current. It provides insight into the residual plasma remaining in the interruption gap after contact separation. If this residual plasma does not dissipate quickly enough or if the rising transient recovery voltage is too high, a restrike or reignition may occur. By measuring the post-arc current, a threshold can be defined above which the interruption gap is likely to fail. A switching operation is deemed successful only if neither restrikes nor reignitions takes place. However, experiments by different researchers have not been comparable, due to disturbances introduced by their test circuits.

This thesis develops a methodology that separates the post-arc current from measurement-circuit-induced interference. That makes analyses more precise and renders the results comparable and traceable for the first time. The results reveal a measurement-error-corrected correlation between the observed post-arc current, short-circuit currents, and complex vacuum-arc behaviour. These findings offer new insights into future applications of vacuum circuit breakers in high-voltage systems. Short-circuit currents up to 15 kARMS were investigated at a standard contact gap of 10 mm.

The proposed methodology successfully isolates the post-arc current from disturbances, greatly enhancing the analysis of current behaviour and paving the way for future measurements at higher voltage levels or in DC systems. In doing so, it opens deeper insights into the dynamics of the after-current and its practical applications.

Timo Meyer

AT ELENIA FROM

2019–2025

ACTIVITIES AT ELENIA

- Team leader HVP (2021–2023)
- Working on a research project with industry partner ABB: “Experimental investigation of single and double interrupters equipped with AMF or TMF contact pieces in a vacuum environment”
- Working on DFG project: “Advanced magneto-optical arc analysis”
- Working on BMWK project: “Green Energy Technology for Medium Voltage Distribution Grids”

CURRENTLY EMPLOYED AT

- Siemens Energy

Team Grid Planning and Grid Operation

Gian-Luca Di Modica

Technical methods for charging electric vehicles to reduce voltage unbalance in low-voltage grids

In recent years, static voltage stability, which deals with the reduction of slow voltage changes, has become a core element of power quality against the background of overvoltages at the low-voltage level due to high PV feed-in, but also with regard to undervoltage due to an increasing number of electric vehicles. In addition to slow voltage changes, there are other voltage quality characteristics such as unbalance and harmonics, which are of central importance for high power quality. A negative influence on these characteristics due to an increasing penetration of electric vehicles and PV systems is also possible. The focus of this work is on the characteristic of voltage unbalance.

In this dissertation, various control methods for charging electric vehicles in order to reduce voltage unbalance in low-voltage grids are investigated, as well as their effects on long-duration voltage variations. The methods constant displacement factor, active power-dependent displacement factor control, voltage-dependent reactive power control and voltage-dependent active power control already defined in the field of distributed generation are considered. In addition to the symmetrical approach for threephase charging, a phase-precise implementation in which each phase is controlled separately is tested for the voltage-dependent methods. The phase-precise approach is also investigated for use in single-phase and two-phase charging. The methods that control the displacement factor are also investigated for three-phase as well as single-phase and two-phase charging. Furthermore, a reactive power control is developed as a function of the phase shifts of the voltages.

The investigations are initially conducted simulatively with a grid model for a rural low-voltage grid and a developed electric vehicle model that implements the methods. In addition, a prototype is built to test the methods in a realistic laboratory environment. The prototype implements the methods and also considers the charging communication between the electric vehicle and the charging point. The results show that the phase-precise voltage-dependent active power control and reactive power control depending on the phase shift are the most effective for reducing voltage unbalance. With regard to static voltage stability, phase-precise voltage-dependent active power control and phase-precise voltage-dependent reactive power control lead to the greatest reduction in voltage changes. The effects of the methods depend on various influencing factors, such as the origin of the voltage unbalance. The suitability of the respective control method has to be checked in the case of application before use.

Gian-Luca Di Modica

AT ELENIA FROM

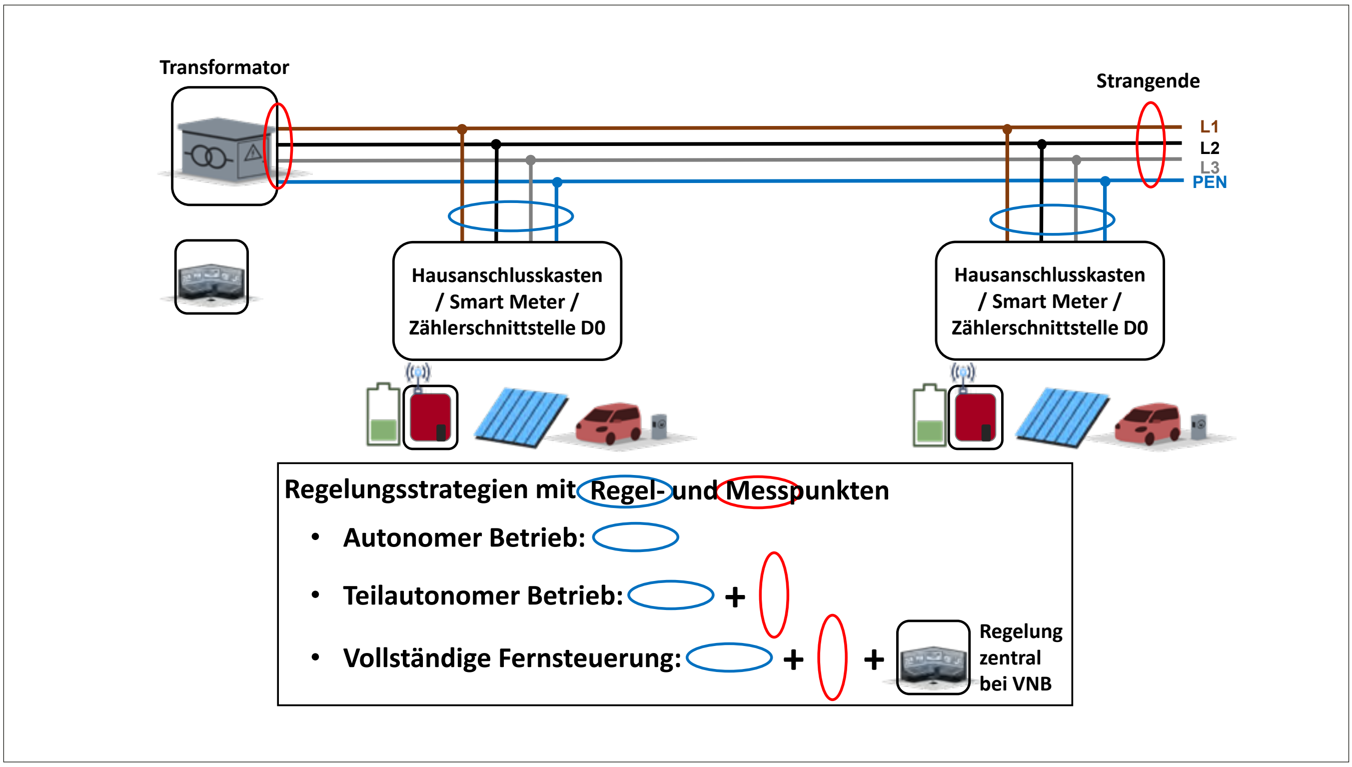
2018 – 2025

ACTIVITIES AT ELENIA

- Collaboration in the focus area Active Distribution Grid and in the team Grid Operation and Grid Planning
- Working on the projects U-Quality und LISA4CL
- Research in the field of grid integration of electric vehicles

CURRENTLY EMPLOYED AT

- Avacon Netz GmbH as an engineer for network planning in high-voltage asset management



Team Grid Planning and Grid Operation

Cornelius Biedermann

Reducing dynamic imbalance in low-voltage grids using battery energy storage systems – economic, normative, and technical considerations and laboratory implementation

The energy transition is leading to increased electrification and a rise in all components — including single-phase ones — such as heat pumps, electric vehicles, and PV systems. The counter-system voltage imbalance occurring in low-voltage grids must not exceed the normatively defined limit of 2%. In addition to permanent imbalance, component behavior leads to dynamic imbalance. This dissertation develops, analyzes, and implements a control system in low-voltage grids with battery energy storage systems (BESS) to reduce dynamic imbalance. The basic knowledge of voltage imbalance, its limit value determination, its causes, and effects are described. Furthermore, the structure of BESS is presented. Studies and our own field measurements on imbalance provide comprehensive, practical insights.

In addition, the influence of voltage stability concepts on asymmetry is examined. Three-phase Q(U) control reduces the voltage asymmetry of the counter-system to a small extent. Single-phase Q(U) control with single-phase voltage measurement is unsuitable for asymmetry control. It has been shown that both active and reactive power settings and three-phase measurement are necessary to ensure the functionality of single-phase imbalance control. Based on these findings and analyzed boundary conditions, imbalance control with BESS is being developed.

The control strategy is based on autonomous operation of a BESS with single-phase connection, which measures voltage and phase angle at the connection point in three phases. The active and reactive power settings are decoupled and control the voltage amplitude and phase angle.

Other requirements, such as the timing requirements for control, are taken into account in the development. The voltage stability function is achieved by reducing asymmetry. The control system is structured around the recording of measured values, the formation of setpoints, and the introduction of voltage stability in two asymmetry reductions. The control system can reduce both the zero-sequence and the negative-sequence voltage asymmetry. The reduction function is performed by a MATLAB function “fminsearch.” To reduce the imbalance, the counter system is prioritized about three to four times more than the zero system voltage imbalance.

Laboratory tests verify the function and test it in defined scenarios. The scenarios consist of unbalanced grid loads, reduced grid voltages, and variations in the number and power of the BESS.

The simulations carried out on small grids provide estimates of the necessary power and energy requirements for control in real low-voltage grids. To improve the counter-system voltage imbalance by more than 0.2% on average, BESS require about one-third of the relative power compared to the unbalanced load. Improvements of about 1.8% were achieved at maximum. Thus, BESS with multiple system services and the proportions for multiple use (multi-use) in the BESS are taken into account for the proportion of imbalance.

The use of BESS requires financial encouragement for their owners. Such financial compensation is being determined. Economic and normative studies provide implementation options for realizing the regulation in existing grid infrastructures.

BESS owners and distribution system operators (DSOs) prioritize different economic aspects. There is no clearly determinable price for the costs of asymmetry influences. Compensation for the expenses incurred by BESS owners is found in the study. The costs for imbalance regulation could be paid by the DSO to the BESS owner as energy compensation. In this case, the energy is purchased by the DSO as loss energy, whereby the DSO incurs costs in the range of voltage maintenance costs from a Q(U) regulation, e.g., of a few euros per year, in the event of high imbalance. The expected costs for the VNB are low in the case of rare dynamic imbalance. This results in an economically affordable solution for imbalance reduction. The compensation energy is determined by a factor of 1.5 of the energy that can be drawn from the grid compared to the energy fed in. Concrete formulations have been developed to adapt relevant standards and guidelines.

The developed control system enables an improvement in dynamic imbalance in low-voltage grids with battery energy storage systems.

Cornelius Biedermann

AT ELENIA FROM

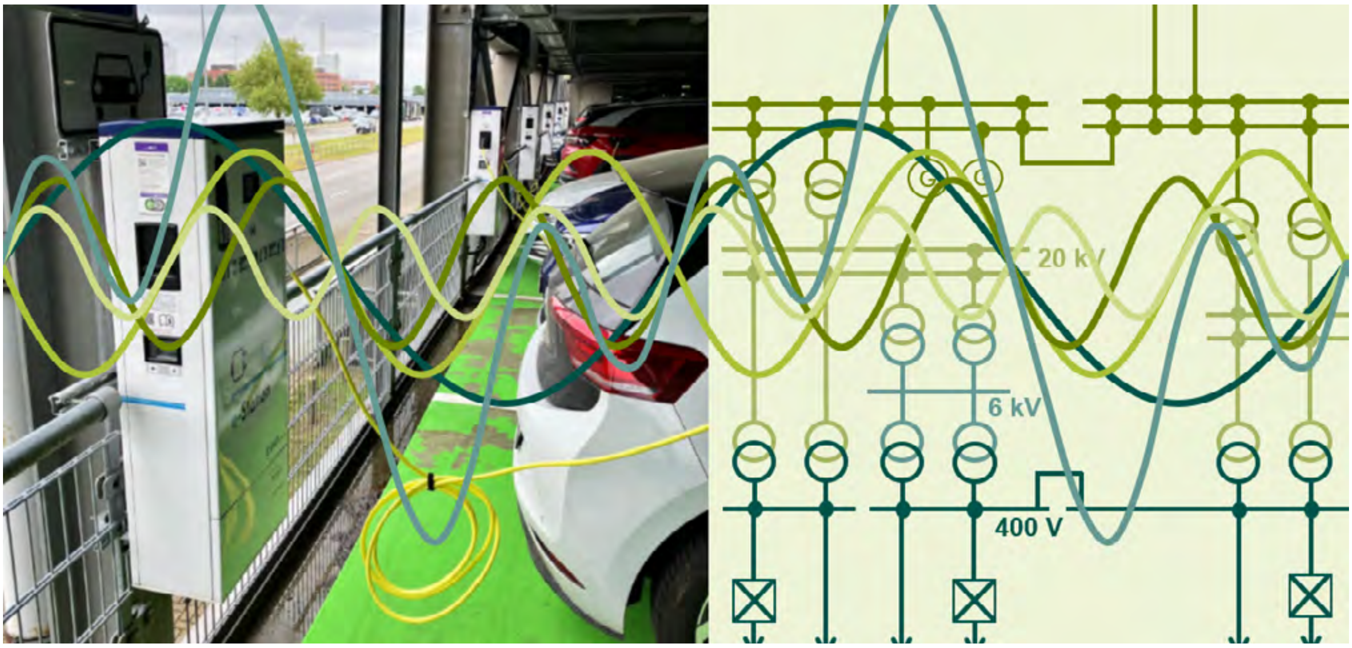
2019–2025

ACTIVITIES AT ELENIA

- Collaboration in the focus area of active distribution grids
- Work on various research projects

CURRENTLY EMPLOYED AT

- TenneT TSO GmbH



Julia Gartner

Production-compatible integration of electric vehicles into the industrial grid with regard to harmonics

Electric vehicles play a key role in reducing CO_2 emissions and ensuring the success of the mobility transition as part of the transport transition. With the increase in electric vehicles, there is a growing need for charging infrastructure, which is best set up at the employer's premises due to long downtimes and thus charging times. Charging electric vehicles generates harmonics. This poses major challenges in terms of increasing harmonic loads, particularly for industrial grids where there is a high density of electric vehicles at certain points, such as in employee parking lots.

This paper discusses the impact of AC charging of electric vehicles in industrial grids and provides recommendations for action for production-compatible grid integration. The investigations are carried out using simulations based on a worst-case scenario and measurements. The primary focus lies on voltage harmonics as effects on the industrial grid.

The simulation results show that the integration of electric vehicles has a negative impact on harmonics, which are typically already elevated in industrial grids without electric vehicles due to the existing topology. In addition, amplifications in the higher harmonic range can be found depending on the electric vehicle model used. Measurements taken in employee parking lots, where electric vehicles constitute the main load, also show an increase in typical voltage harmonics in the industrial grid. However, the proportion of production is not included due to local conditions. Therefore, the angle approach is used to estimate the impact on production. The position of the angle of an harmonic is compared with that from the industrial grid. The fundamental oscillation U1 forms the reference pointer. The focus is on the 5th harmonic order because previous measurements in the industrial grid already show an increase in this order without electric vehicles. Using the angle approach, a slight to moderate amplification can be derived for the 5th voltage harmonic.

The angle approach also serves as the basis for the recommended course of action. The measurements show that a parking lot with electric vehicles has a characteristic progression of the position of the 5th order angle. This knowledge makes it possible to use a connection point in the industrial grid where, in the best case scenario, the angle of the already increased 5th harmonic order is located in the opposite quadrant, thus leading to a reduction in harmonics. In this way, forward-looking planning can ensure production-compatible charging.

Julia Gartner

AT ELENIA FROM

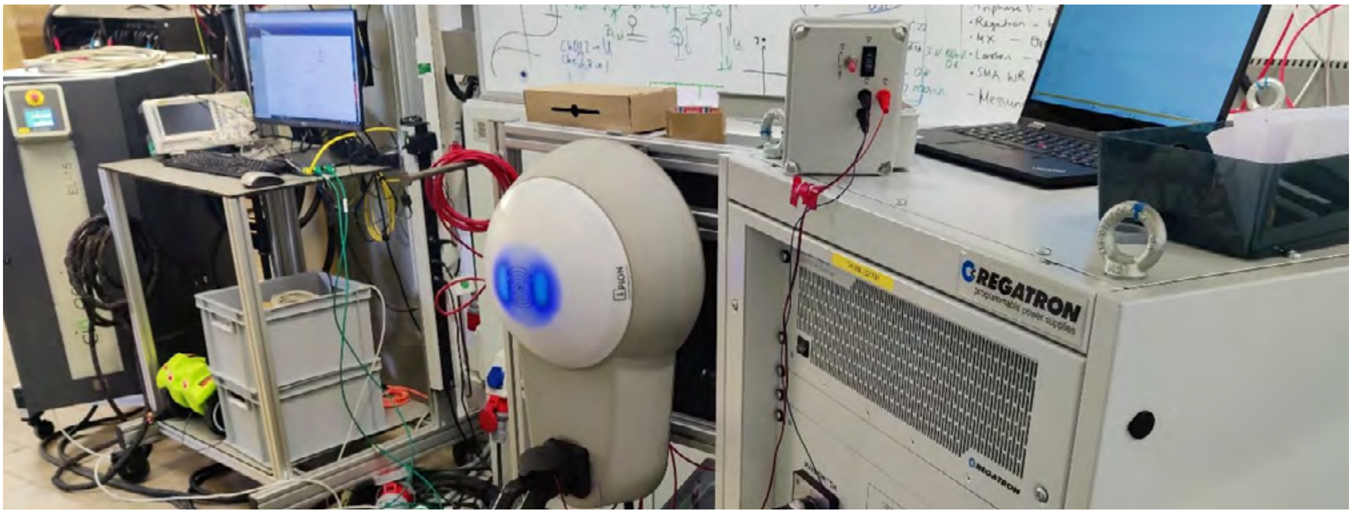
2018 – 2024

ACTIVITIES AT ELENIA

- External doctoral candidate
- Collaboration in the Energy Systems working group and in the Electric Mobility focus area in the Electric Vehicle Charging research group
- Supervision of the Analysis, Simulation, and Planning of Networks course

CURRENTLY EMPLOYED AT

- Volkswagen AG as an electrical planner



Nils Müller

Technical and economic comparison of the response options available to a distribution network operator in relation to electric mobility hotspots

The energy transition represents a key challenge and, at the same time, a major opportunity for the transformation of the energy system in Germany, Europe, and the world. In the electricity sector, it aims to replace fossil fuels with renewable energies, thereby significantly reducing CO_2 emissions. Through sector coupling, this goal is also being transferred to the mobility, heating, and industrial processes sectors through increasing electrification. In Germany, a country with a world-leading automotive industry, this transformation is particularly relevant with regard to electromobility. In 2023, Germany was one of the largest manufacturing countries in the automotive industry, producing over 3.6 million vehicles. This dominance underlines the need to develop innovative solutions for the transportation and energy sectors in order to meet the increasing demands for climate protection and energy efficiency while maintaining security of supply.

The dissertation is dedicated to the analysis and development of solutions that enable distribution system operators to efficiently overcome the challenges posed by the increasing electrification of mobility. The focus is on electric mobility hotspots, which are characterized by a high concentration of electric vehicles and charging infrastructure. Such hotspots can place a considerable strain on existing distribution grids, but at the same time require sustainable and economically viable solutions in order to successfully advance the energy transition.

Technical, economic, and regulatory measures that can be taken by distribution system operators to ensure security of supply while minimizing the costs of grid expansion are systematically examined. Both theoretical approaches and practical solutions are addressed. Key methods include the simulation of controlled charging processes, field tests to analyze incentive mechanisms, and the development of a prototype for universal control of charging processes. These approaches are analyzed and evaluated in terms of their technical feasibility and economic efficiency.

Depending on the grid area, the simulation showed that the capacity for electric vehicles could be tripled with only a slight reduction in customer comfort. During the field test, the implementation of flexible grid fees resulted in a 30% reduction in the maximum grid load during the test period. From an economic perspective, intelligent control offers a significant macroeconomic advantage over traditional grid expansion for various borderline cases of charging infrastructure penetration. In the course of the doctoral thesis, a smart charging cable for universal control of charging processes was also invented and a patent application was filed.

Nils Müller

AT ELENIA FROM

2020–2025

ACTIVITIES AT ELENIA

- External doctoral candidate
- Supervision of the research collaborations as management consultant at Braunschweiger Netz GmbH until October 2023
- Coordination of the research projects U-Quality, Flexess, NetFlexum, Distribution Network 2030+, Metropolis, PICNIC, ENABLE on behalf of Braunschweiger Netz GmbH
- Collaboration in the focus area of grid integration of electromobility

CURRENTLY EMPLOYED AT

- PowerCo SE – Development of Risk Management Energy

Robin Grab

Decentralized reactive power sources for voltage maintenance in high-voltage and extra-high-voltage grids

As part of the transition of the German energy supply system, system services must be provided to a greater extent than before by decentralized generation plants. This also affects static voltage stability. This dissertation examines various properties of decentralized reactive power sources that are important for their suitability for voltage maintenance in high-voltage and extra-high-voltage grids. In particular, it focuses on the properties of self-commutated converters as a key technology for the future provision of active and reactive power.

First, new evaluation criteria for analyzing the reactive power potential of renewable energy systems for reactive power provision at higher voltage levels are presented and applied. Practical experience is also reported and measurement results from real systems are analyzed. Next, the electrical losses of power converters during reactive power delivery are measured, analyzed, and mapped using parameterizable models. The application of the models is also explained and their accuracy evaluated. In a further section, the dynamic properties of reactive power sources during setpoint changes are examined. The consequences of rapid reactive power changes for plant and grid stability are also considered.

The findings of this work can contribute to the development of appropriate guidelines and laws for reactive power provision in the future, in order to ensure cost-effective and secure maintenance of static voltage levels in the future and under the changed conditions of the energy transition.

Robin Grab

AT ELENIA FROM

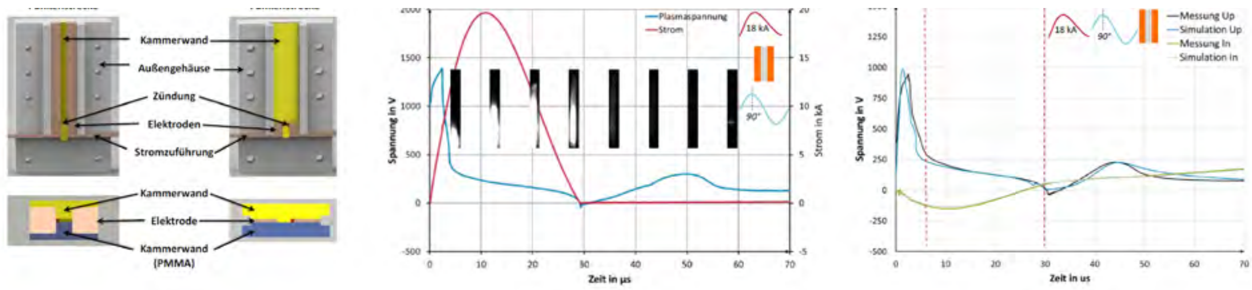
2020 – 2025

ACTIVITIES AT ELENIA

- External doctoral candidate

CURRENTLY EMPLOYED AT

- Fraunhofer Institute for Solar Energy Systems ISE as head of the team “Grid Performance of Decentralised Generators”



Tobias Kopp

Evaluation of the recovery voltage of spark gaps under surge currents and grid stress

To protect people and electrical equipment, spark gaps are used in low-voltage technology as surge arresters. In order to further develop these spark gaps in a targeted manner, it is necessary to know the exact interaction between the spark gaps and the electrical supply network. Therefore, in my work, I have focused on investigating these interactions, in particular the recovery voltage after the discharge of an impulse current.

The results of investigations into the electrical behavior of the test circuit served as a basis for this. With the help of these results, the interaction between the impulse current and the transformer circuit has been discussed. This was followed by a phased description of the electrical behavior of the spark gap in the low-voltage grid. The dependencies of the electrical behavior of the spark gap were presented and discussed for different input variables. These partial results formed the basis for deriving an electrical spark gap model for later implementation in a grid model.

I also investigated the reconsolidation behavior of spark gaps. On the one hand, this made it possible to derive the necessary parameters for the spark gap model, and on the other hand, the investigations provided direct information about the electrical behavior of the spark gap in the low-voltage grid. This will allow the methodology presented here to be further developed in later work and used to analyze plasma properties.

Using the results of the electrical behavior of the test circuit, the spark gap, and the derived spark gap model, a simulation model was developed with which sensitivity analyses for different input variables were performed. The characteristic curve fields determined in this way were used to describe the electrical behavior of the overall system.

Tobias Kopp

AT ELENIA FROM

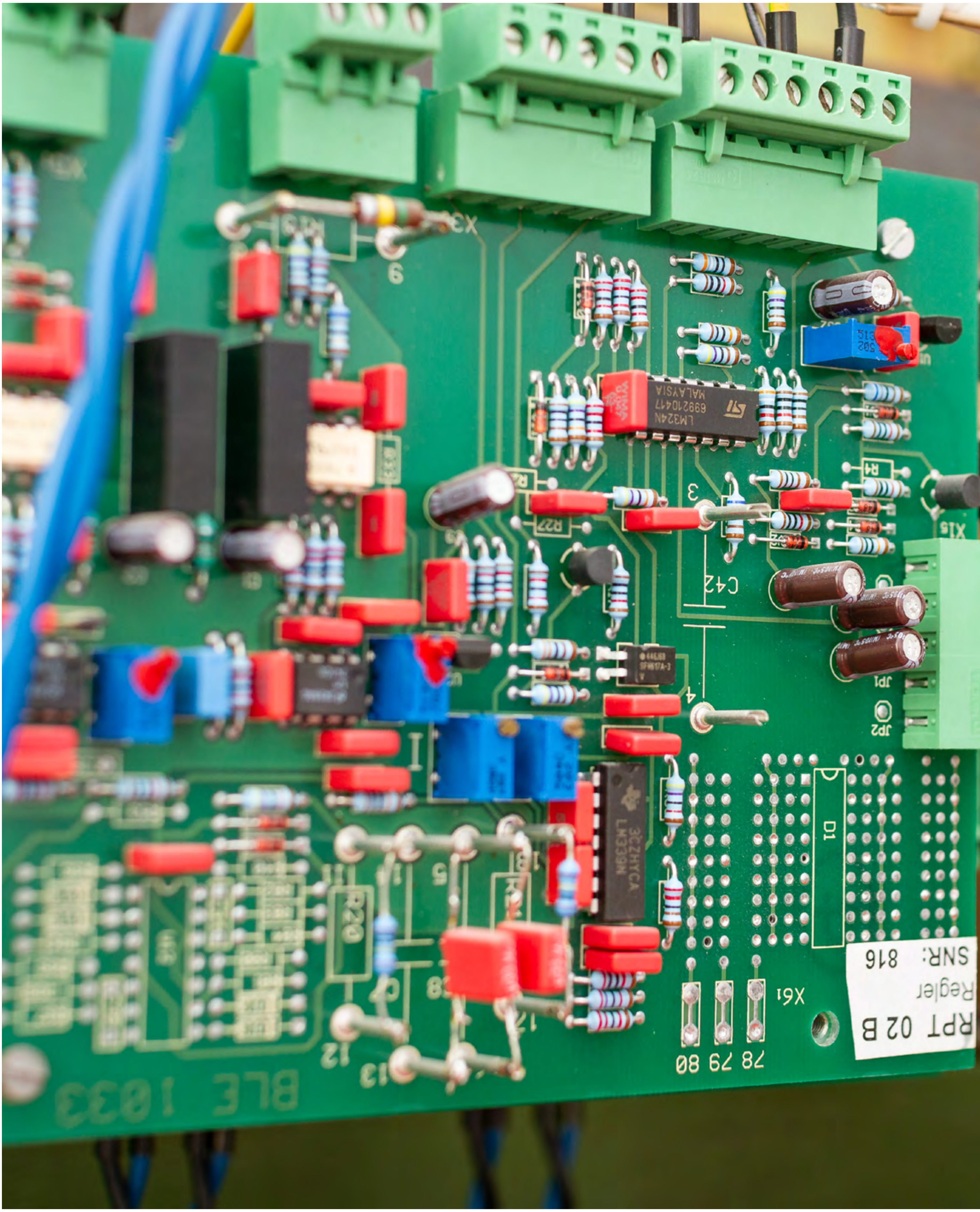
2013–2025

ACTIVITIES AT ELENIA

- External doctoral candidate
- Administrative: Working group leader, focus area leader, PMO, application development, coordination of research projects
- Research: optical plasma analysis, low-voltage switchgear, surge arresters, vacuum switches, electrification of aviation, high-performance test field
- Teaching: transmission grid technologies, plasma technology

CURRENTLY EMPLOYED AT

- enercity, Project Manager for Substations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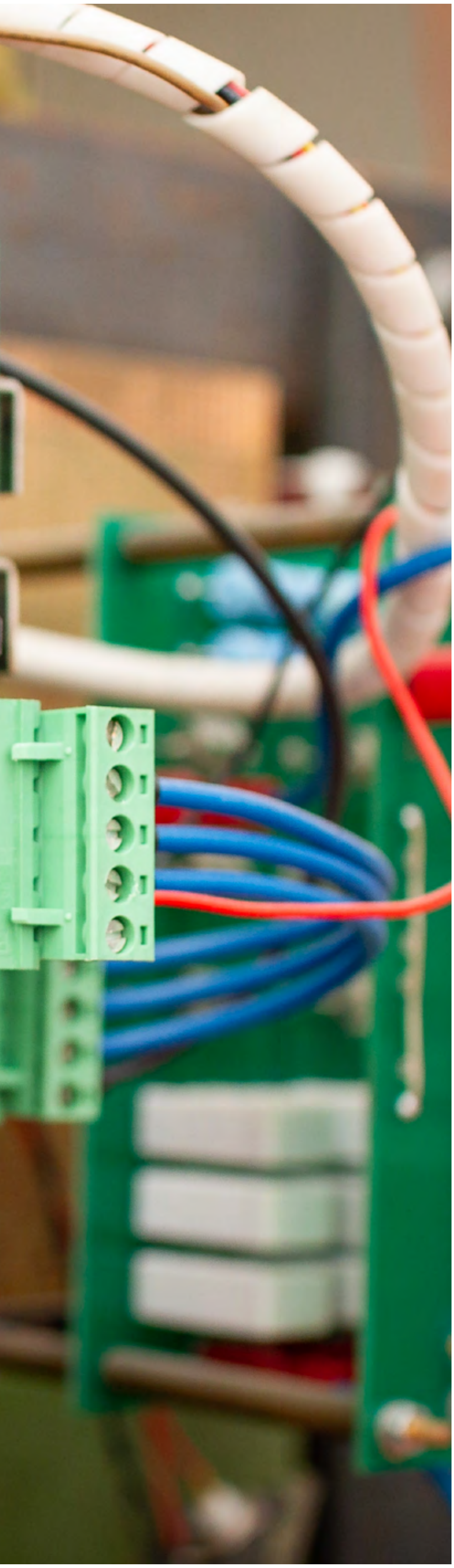
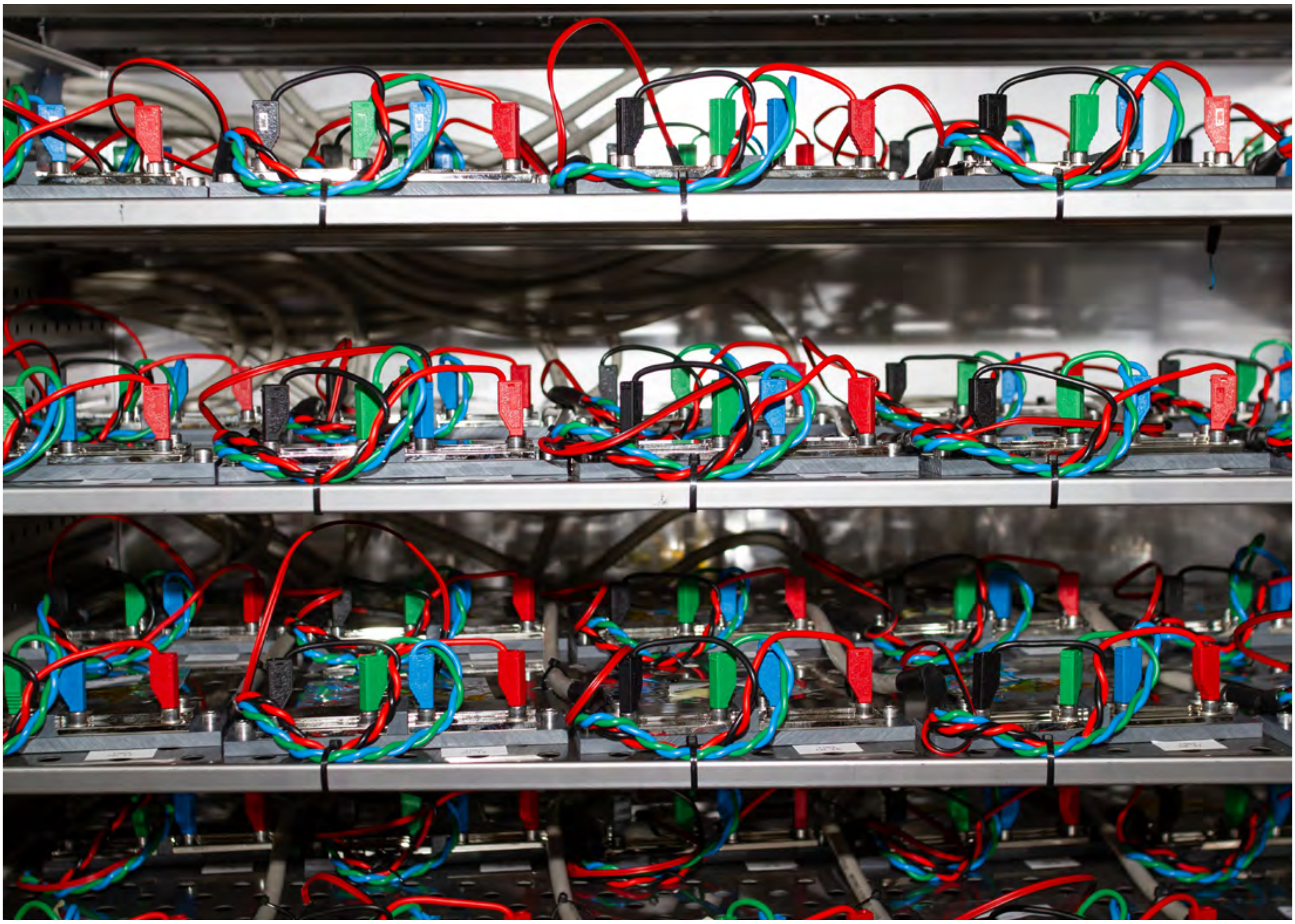


Labs and Workshops


BINDER
VersaSTAT 3

Battery Testing Laboratories



CONTACT

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TASKS AND SERVICES

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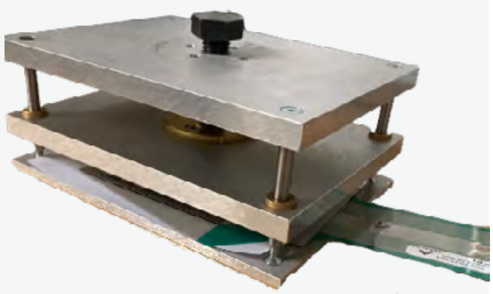


Battery Testing Laboratories at elenia

Testing and inspection at cell, module, and system level

The ongoing development of battery technology is largely driven by the growing global demand for electrical energy storage systems for mobile and stationary applications. As a result of this development, battery technology is increasingly becoming the focus of current research projects. Lithium-ion batteries and next-generation batteries play a central role in this context, as their high energy and power density, high efficiency, and long-term stability make them a key technology for future energy storage solutions. Despite these advantages, there is still potential for research to meet requirements in terms of safety, service life, charging speed, and resource efficiency.

The elenia Institute for High Voltage Technology and Energy Systems has a comprehensive testing infrastructure at several locations, which is geared toward different research priorities:

Battery Testing Lab (BatLab) – elenia, basement

Electrochemical investigations are carried out at BatLab using special three-electrode measuring cells. In addition to an anode and cathode, these cells have an additional lithium reference electrode, which enables separate electrochemical characterization of the individual electrodes. Since early 2020, production has been carried out under inert conditions in a glovebox with an argon atmosphere. Current research focuses on the model-based design of fast charging strategies for different cell material systems.

Battery LabFactory Braunschweig (BLB)

These laboratories primarily investigate large-format lithium-ion cells without reference electrodes. The cells tested originate from the pilot line at Battery LabFactory Braunschweig (BLB) as well as from industrial cooperation partners and commercial suppliers. Current research focuses include the influence of formation on cell performance, model-based fast formation strategies, electrochemical characterization and diagnostics, temperature modeling, and applications of the methods to novel cell chemistries, such as sodium-ion or solid-state batteries.

Physikalische Bundesanstalt Braunschweig (PTB)

At PTB, the focus is on investigating the module and system level. Research activities deal with the diagnostics of battery modules, particularly with regard to their suitability for second-life applications. In addition, electrical and thermal safety tests are carried out at the cell and module level to analyze behavior under extreme conditions.

Test infrastructure and safety equipment

Battery testers from various manufacturers, such as Ametek, BaSyTeC, Digatron, EL-Cell GmbH, Gamry Instruments, and Biologic, are available in the laboratories for carrying out the various tests. Temperature test chambers are used to ensure that constant environmental conditions are maintained. In addition, all test benches are equipped with comprehensive safety devices. These include F90 storage cabinets, automatic cabinet extinguishing systems (Wagner), exhaust air systems, and multi-stage emergency filter systems (Stöbich technology), enabling the laboratories to perform tests up to and including EUCAR Hazard Level 5.

Methods for electrochemical characterization

Defined current and voltage profiles are used for detailed analysis of the electrical properties of lithium-ion cells. Capacity tests at constant current provide information about the achievable capacity of the cells. These are supplemented by current rate, internal resistance, and impedance measurements to analyze cell performance.

Cyclic stress tests involving repeated charging, discharging, and resting phases are performed to investigate the effects of aging. These tests record the loss of capacity and the increase in internal resistance over the service life. This allows conclusions to be drawn about the cyclic aging of different cell chemistries and operating strategies.

Since 2021, these investigations have been supplemented by post-mortem analyses. In these analyses, cells are opened under protective gas and examined microscopically to identify structural and chemical changes, in particular lithium plating on the anode side, as a result of aging. Methods such as differential voltage analysis (DVA) and electrochemical impedance spectroscopy (EIS) are used to determine the causes of observed degradation processes.

In addition to cyclic aging, calendar aging is also investigated. For this purpose, cells are stored in safety cabinets under defined conditions over extended periods of time. Changes in electrical properties and self-discharge are recorded and evaluated in order to quantify the influence of calendar aging.

Modeling and Simulation

In addition to the classic test procedures, special internal resistance tests are carried out to determine parameters for electrical equivalent circuit models. These models enable a simulation-based description of the electrical behavior of battery cells. Furthermore, electrothermal models are developed to map the behavior of the cells under different operating conditions.

GLOVEBOX FROM FA. M. BRAUN

Workplace under argon protective atmosphere

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

KEYENCE DIGITAL MICROSCOPE VHX7000

Optical examinations of electrode materials

- 20× –2500× magnification 3D measurement software

TEMPERATURE TEST CHAMBERS

Controlling a defined and consistent test environment

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

TEMPERATURE TEST CHAMBERS FROM FA. WEISS AND VÖTSCH

- Test volume 600 l and 34 l
  - -40 °C bis 180 °C and -20 °C up to 80 °C
  - Includes cabinet extinguishing system, exhaust air, and accident filter

GAMRY REFERENCE 3000 AND 5000

Optical examinations of electrode materials

- Impedance measurements
- Measurement range 10 µHz to 1 MHz
- Maximum excitation 3 A
- Maximum cell voltage 15 V

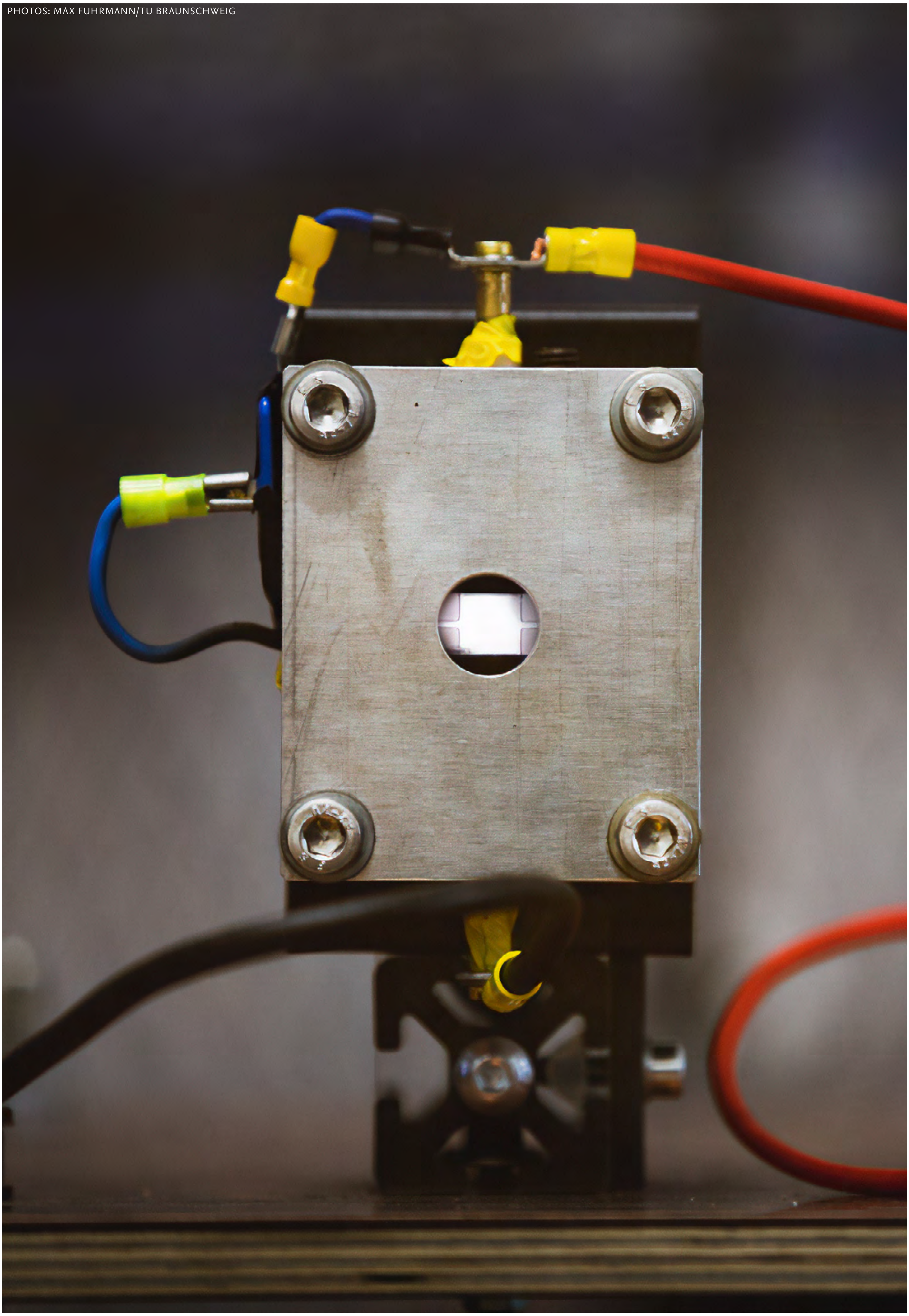
3-ELECTRODE CELL TESTER FROM EL-CELL

- Test system for three-electrode measuring cells
- 40 channels ± 0,1 A, 0–6 V, EIS
- 46 PAT-cells
  - Including 4 PAT-Cell Force and 2 PAT-Cell Press

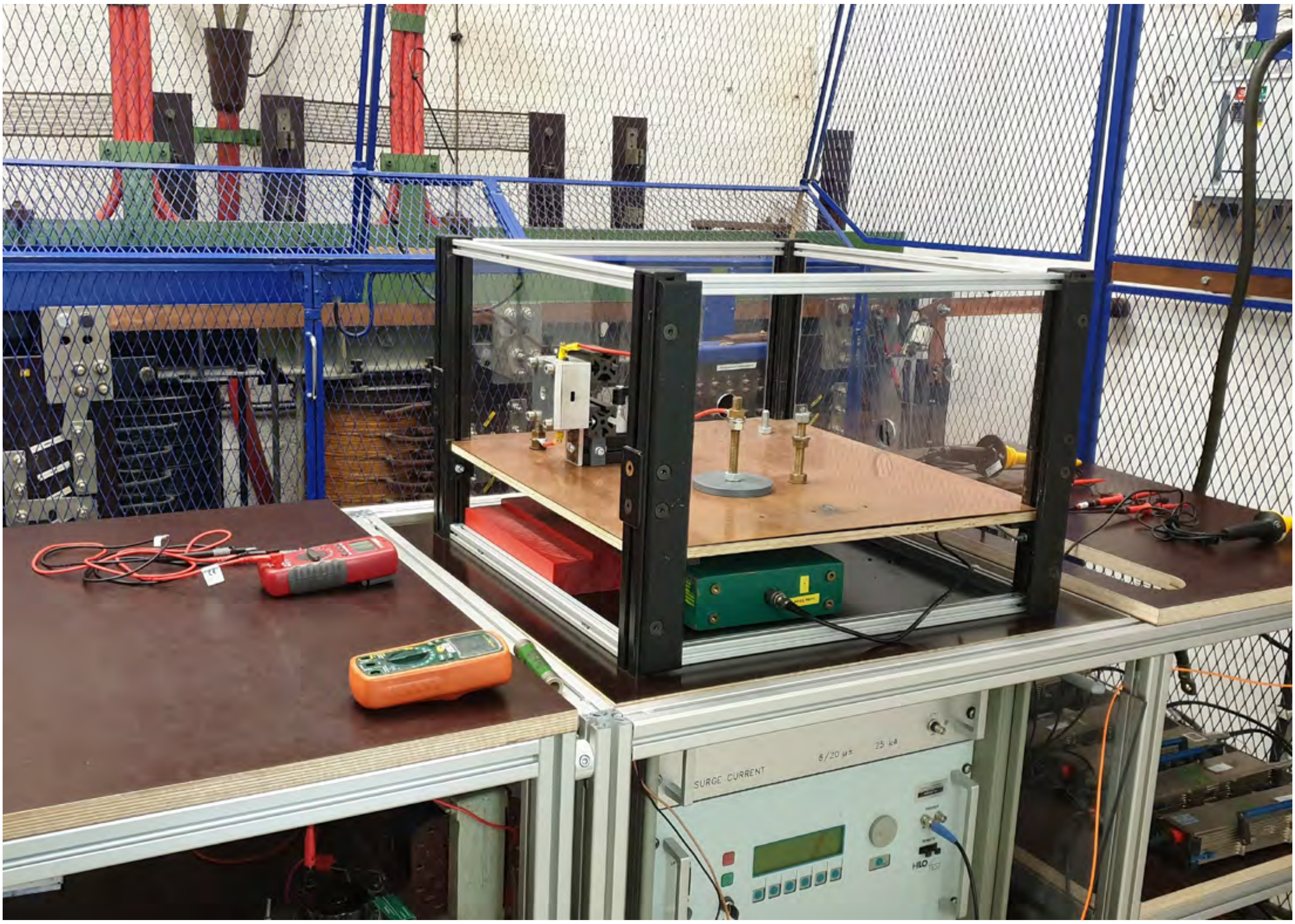
OPTICAL EXAMINATIONS OF ELECTRODE MATERIALS

Test bench for cell tests

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


PHOTOS: MAX FUHRMANN/TU BRAUNSCHWEIG

Lightning protection laboratory



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www.tu-braunschweig.de/en/elenia/research/laboratories/lightning-protection-laboratory

TASKS AND SERVICES

- Measurements on the low-voltage grid with voltages from 50 V to 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)
- Various mains synchronization angles, triggering of the surge current to 1° Accuracy
- Measurement of transient plasma properties (pressure, temperature and conductivity)

Lightning protection laboratory

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

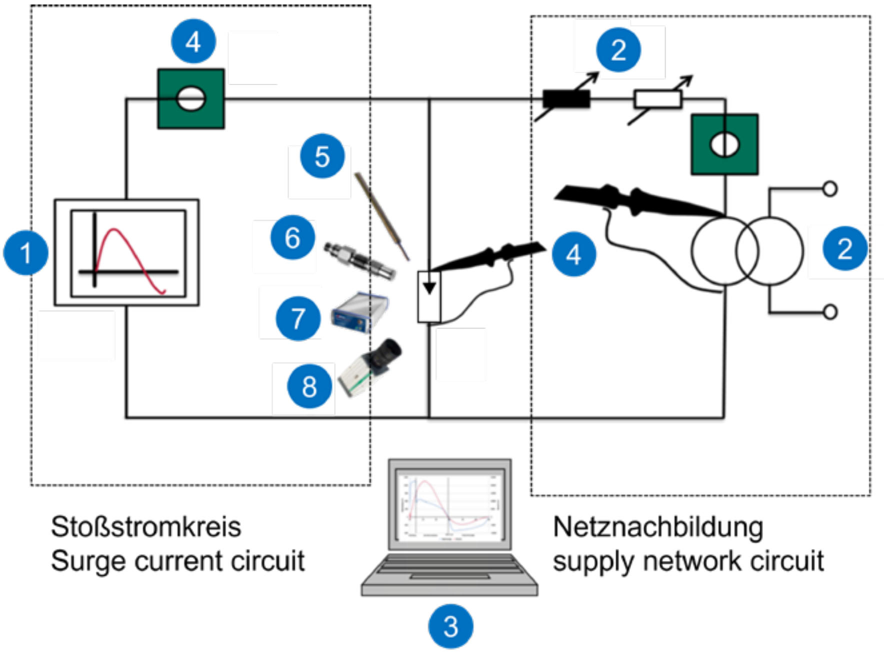
Surge protectors (Type 1) are used as a primary protective mechanism to ensure the uninterrupted operation of electrical and electronic devices. They limit the occurrence of surges resulting from lightning strikes or switching operations in the grid. In surge protectors based on spark gap technology, exceeding a characteristic overvoltage leads to the formation of plasma between two electrodes. This plasma creates a momentary short circuit to the grounding system, establishing a low-impedance potential equalization and enabling the safe dissipation of high energies.

Due to the short circuit to the grounding system, interactions occur with the connected power supply network, allowing a network-induced short-circuit current to flow through the plasma path (so-called network follow-up current). This network follow-up current should extinguish as quickly as possible after the successful discharge process, so that the upstream fuses or circuit breakers do not need to actuate. Various impulse voltage and impulse current generators are available at elenia for the investigation of surge protectors. Particularly noteworthy is the “lightning protection laboratory”. In addition to an impulse current, a low-voltage supply can be connected in parallel. The low-voltage network is connected to the medium-voltage network at the 6 kV level via three power transformers. This enables the investigation of both the impulse current and the network follow-up current.

Figure 1 shows the simplified schematic diagram of the laboratory. In addition, a special test circuit for investigating re-solidification has been set up. This test circuit is based on a capacitor-based current source connected to the surge protector via a high-impedance resistor. This allows a measuring current in the range of 100 mA to flow through the still heated residual plasma path immediately after the current zero crossing in the spark gap. This enables the analysis of the plasma properties specifically after the high-current phase.

The impulse current is generated using an impulse current generator (1). 8/20 μs impulses with up to 25 kA, but also 10/350 μs impulses with up to 600 A, can be generated. The grid feed is realized via three parallel-connected 130 kVA transformers (2). Resistance and inductance banks are available for adjusting the ohmic-inductive ratio of the grid emulation (2). In these very rapid plasma processes, stable and time-discrete measurement technology is necessary. For this purpose, measurement probes with a sampling rate of 100 MS/s are available. The measurement probes are optically isolated connected to the measurement system via optical fibers (3). Additionally, additional sensors are available, such as Pearson probes, high-voltage probes (4), potential probes (5), pressure sensors (6), spectrometers (7), and a high-speed camera (8). The current research goal is to investigate the transition from highly conductive plasma to the insulating state after the impulse current load.

Using the measurement technology described in Figure 1, these experimental investigations take place. Precision mounts are available in the laboratory for these investigations, which facilitate the optical alignment of the camera to the combustion chamber of the model spark gaps. The research enables the modeling of spark gap arresters and thus a targeted development of surge protection..



OVERVIEW OF THE EXPERIMENTAL FIELD FOR DETERMINING THE PLASMA PROCESSES

1) Surge current generator EMC 2004
2) Low-voltage network up to 750 VAC with adjustable network impedance
3) Connection of measuring system to PC
4) Voltage and current measurement
5) Conductivity via potential probes
6) Pressure measurement
7) Spectroscopy
8) High-speed camera

HIGH-SPEED CAMERA NOVA S6 FROM BY PHOTRON

High-speed camera for analysing plasma distribution

- Resolution up to 1024×1024 pixels
- Black and white recordings
- Maximum frame rate of 800 kfps
- Minimum exposure time of 200 ns
- External triggering possible

SURGE CURRENT GENERATOR EMC 2004

Surge current generator for generating partial lightning currents

- Max. Charging voltage of 10 kV
- Max. Energy 1500 Ws
- Various waveforms possible
- Max. Surge current of 25 kA
- External control possibleMax. Ladespannung von 10 kV


AC
DC
Engineering GmbH
RÜCKLAUF
DC
ES Engineering GmbH
RÜCKLAUF
DC
DC

DC grid laboratory

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TASKS AND SERVICES

- Investigation of dynamic state changes in the grid
- Development and testing of DC protection systems
- Investigation of the switching characteristics of commercially available DC switching devices
- Investigation of DC grid topologies
- Characterization of various operating and fault scenarios in variable grid structures

DC grid laboratory

Investigation of DC networks spanning multiple voltage levels with variable source and load characteristics

The ongoing energy transition in Germany and technical advances in the field of modern power electronics mean that DC technology is becoming increasingly important in industry, energy transmission, and electromobility. And for good reason: energy transmission and distribution offer a wide range of application advantages, such as efficiency gains, material savings, and the possibility of easily integrating renewable energies and storage systems. On the other hand, it also brings new challenges and questions. These must be answered in order to ensure safe use. The DC demonstration grid laboratory at elenia enables the investigation of a wide range of grid topologies thanks to its flexible, quickly adaptable design and a wide spectrum of different source and load characteristics. The laboratory has two voltage levels in the low-voltage range (0–380 V and 1 kV) and one medium-voltage level (± 1.5 kV DC).

Structure, components, and subject of investigation

The demonstration grid laboratory offers a wide range of tests for investigating DC grid topologies. The planned overall setup, including the performance data for all voltage levels and a detailed description of the laboratory components, can be found on the next page. Work is currently underway in the demonstration grid laboratory on general grid characterization and modeling for DC grids. A large test range is achieved through a wide range of variable load impedances and active source and load components. In addition, a DC protection system is being developed and investigated in various fault scenarios. In addition to current and voltage, the time constant, grid topology, and internal control of selected sources and loads can also be adjusted. Another advantage is the ease with which additional equipment can be integrated into the existing setup. The measurements taken are recorded using state-of-the-art measurement technology. This allows the network states during dynamic load changes and switching operations, as well as the response of the protection system, to be analyzed with precision.

Protection technology

The laboratory has a central, modular protection concept for identifying, localizing, and classifying faults in the DC network. The protection system concept is based on continuous monitoring of the system status using current sensors installed at various points in the network. The sensor data is collected in a central protection unit, where an FPGA controller calculates further derived variables from the measured values. The measured and calculated variables are used for decision-making by the protection algorithm. Depending on the dynamic change in the status of the demonstration network, the protection unit makes different assessments of the current status and, if necessary, forwards instructions in the form of switching commands to the switching devices in order to carry out fault clearing as selectively as possible.

LVDC SWITCH CABINET WITH LVDC AFE & DC BUSBAR

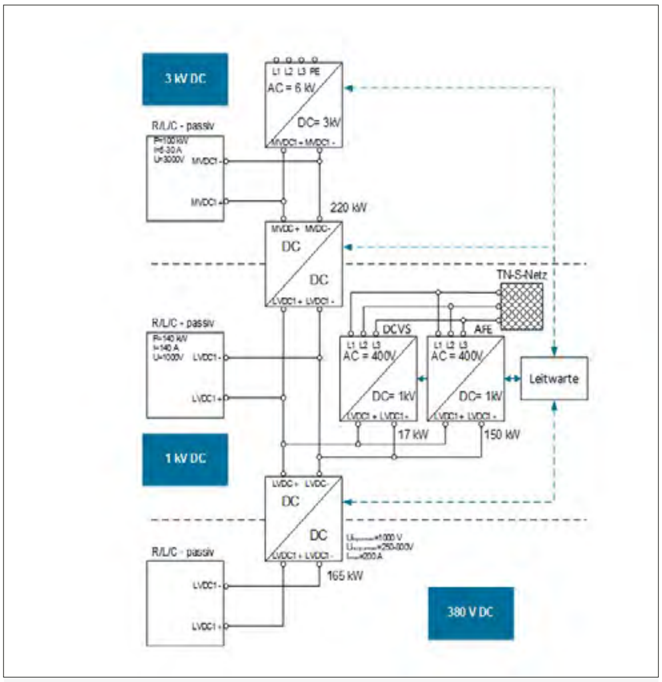
Connection and protection of low-voltage components

- Connection of low-power consumers and a plug-in system for topology formation via circuit breakers
- DC circuit breakers protect DC voltage converters for the subordinate, variable LVDC voltage level
- LVDC AFE can be used as a sink in regenerative mode
- Integration of a braking resistor

LVDC BREAKER CABINETS WITH PASSIVE LOADS & CONTROLLED VOLTAGE SOURCES

Simple setup of variable network topologies via a PV plug-in system

- Replication of a wide range of DC vehicle electrical systems, industrial, and distribution network structures
- Network characterization and modeling of DC networks using statistical experimental design
- Development, investigation, and optimization of novel DC protection systems with a focus on switchgear coordination in the event of electrical faults



OVERALL NETWORK OVERVIEW AS A BLOCK DIAGRAM

Structure and core functions

- Three grid levels (3 kV, 1 kV, and < 1 kV variable)
- MVDC-side connection of the test field directly to the 6 kV AC medium-voltage grid of the Technical University of Braunschweig
- LVDC-side connection via AC low-voltage grid
- Two active front ends (AFE): one each in the MVDC and LVDC levels
- Coupling of the voltage levels via DC/DC converters
- Bidirectional power transfer between voltage levels
- Additional supply of the LVDC levels via controlled voltage sources (DCVS)
- The combination of equipment allows a wide variety of applications to be simulated
- Control and monitoring of all laboratory components via central control room
- Variable test duration and parameters adjustable via digital sequence control

CONTROL CARD OF THE MVDC CONTROL CABINET

Central monitoring and control of laboratory components

- Connection of control cabinets to control room via CAN / CAN FD
- Manual and automated control of protection technology
- Setting of relevant control parameters
- Transmission of measured values for monitoring and recording to control room and elenia server

MEDIUM-VOLTAGE CONNECTION

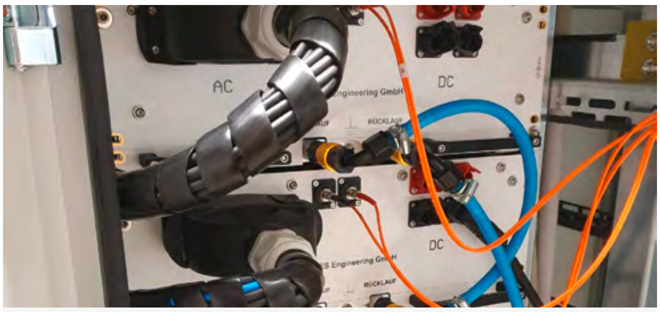
Medium-voltage output with protection technology

- Connection: 6 kV AC – medium-voltage grid of the Technical University of Braunschweig
- Fuse protection for medium-voltage transformers: 63 A
- Fuse protection for laboratory output: 31.5 A
- Additional fuse protection via two VD4 vacuum circuit breakers directly in the laboratory and at the output to the laboratories

MEDIUM-VOLTAGE TRANSFORMER

Supplying the AFE power modules from the medium-voltage grid

- Rated power: 220 kVA
- Primary side: 6 kV AC
- Secondary side: 4 windings at 375 V AC
- Connection type: Dyn5



MVDC AFE POWER MODULES

Filtering and rectification of AC voltage

- Input voltage per module: 375 V AC
- Output voltage per module: 750 V DC
- Integrated EMC filters and chokes
- Symmetrical connection of modules: ± 1.5 kV DC
- Nominal power per module: 50 kW
- Total power: 200 kW

High-performance DC test field

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TASKS AND SERVICES

- Development and optimisation of DC switches.
- Investigation of switching properties of commercially available DC switchgear.
- Investigation and development of hybrid switchgear.
- Insulation coordination and investigation of switching processes at low air pressure.

PERFORMANCE DATA

- Power: up to 18 MW
- Nominal voltage: up to 12 kV
- Testing current: up to 30 kV
- Supply from the 6 kV universal or 20 kV public grid

High-performance DC test field

Laboratory for the research and development of DC switchgear for a successful energy transition

In addition to the expansion of renewable energies, one component of the energy transition is the reduction of consumption. Especially in industrial applications, the advantages of direct current networks over classic alternating current networks become clear. Efficiency increases as a result of a changeover, also because direct current grids can absorb energy generated in the process. The trend here is towards ever higher voltage levels. As a result, the demands on the switchgear, which have to guide and interrupt the operational currents, are increasing. In order to develop and test these switchgears, suitable test equipment is essential.

These must be able to provide the required currents and voltages. For this reason, the new high-performance DC test field was built in the institute‘s high-voltage hall during the Universal Power Switch project. It impresses with its performance data and can provide a wide range of test voltages at low ripple and high currents. The maximum DC voltage is 12 kV and the maximum current provided is 30 kA. However, this cannot be accessed at all voltage levels, but is limited by the connected grid at 18 MW. Essentially, the primary equipment consists of the medium-voltage switchgear, the two test transformers and the rectifier including circuit breakers.

Medium-voltage switchgear

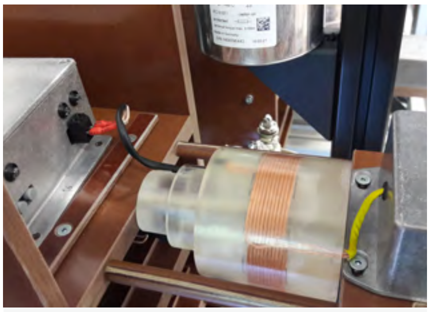
The power supply of the high-performance DC test field is ensured by an in-house switchgear. This has two different feed-in options. On the one hand, the university‘s 6 kV network can be accessed without prior registration. However, the connected load is much lower than with the 20 kV connection, which is also available. However, the release by the network operator is only granted after prior registration. Then the maximum power of 18 MW can be extracted. The system is protected by a short-circuit current limiter (IS limiter), also in order to minimize possible grid feedback.

Test Transformers

The medium-voltage switchgear feeds into two test transformers. Both secondary sides are connected in Y-connection and have two separate windings per phase. These have a large number of taps, which can be connected almost arbitrarily by means of quick adjustment. As a result, a variety of voltages can be set. On the primary side, one transformer is connected in Y and the other in delta. This achieves a phase rotation of 30°, which allows the use of a B12 rectifier.

Rectifier

The two transformers provide a six-phase system for the rectifier. In each case, one transformer feeds one of the two B6 bridges connected in series. The upstream circuit breakers act as a safety switch and disconnect the rectifier from the mains after each test run. The entire test sequence is ensured by a programmable digital sequence control.



HIGH FREQUENCY TRANSFORMER TO SUPPLY THE THYRISTOR DRIVERS

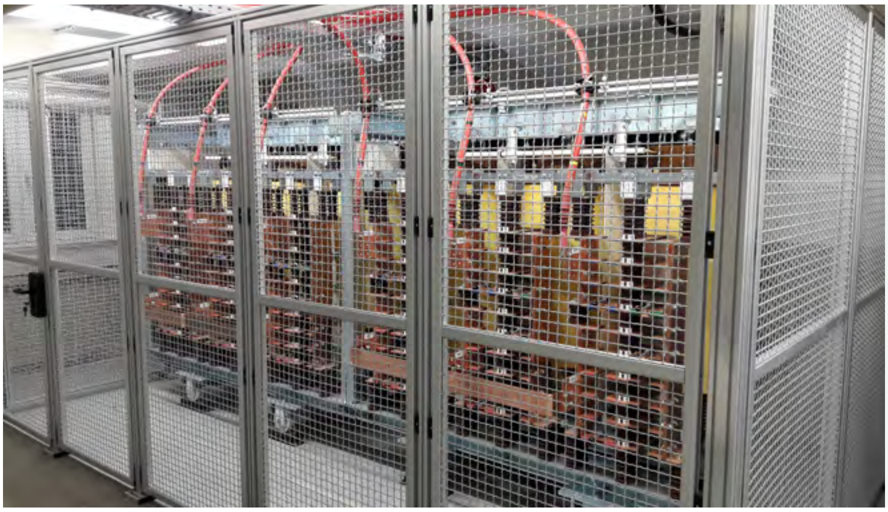
- Supply of thyristor drivers

B12 RECTIFIER INCLUDING UPSTREAM CIRCUIT BREAKER

- Max. current 30 kA
- Max. 12 kV

SWITCHGEAR

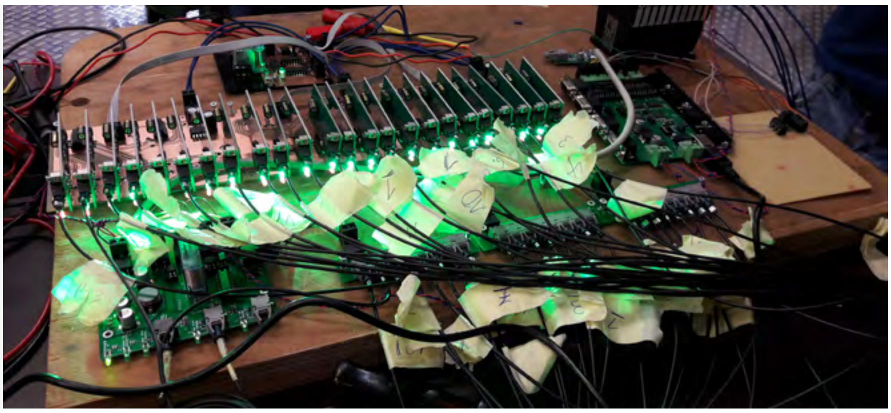
- Substation for connection to the 6 kV university network or 20 kV network of the municipal grid operator



TEST TRANSFORMERS WITH TAPS AND QUICK ADJUSTMENT FOR SETTING THE DC VOLTAGE

- Power 1155 kVA
- Short-term power 11258 kVA
- Groups Diii(y) & Yiii(y)
- Year of construction 2021
- Total weight per transformer approx. 6800 kg

CONTROL DURING INITIAL COMMISSIONING



High Voltage Laboratory

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APPLICATIONS AND SERVICES

- High voltage measurements (flashover/discharge) with AC, lightning impulse and DC voltage on model structures or prototypes in accordance with IEC 60060-1
- Partial discharge measurements and interpretation on low-, medium- and high-voltage models and components, if necessary in accordance with IEC 60270
- Dielectric material tests such as dissipation factor, relative permittivity and volume resistances at variable frequencies and temperatures
- Various high-speed cameras are available for the visualization of discharges

High Voltage Laboratory

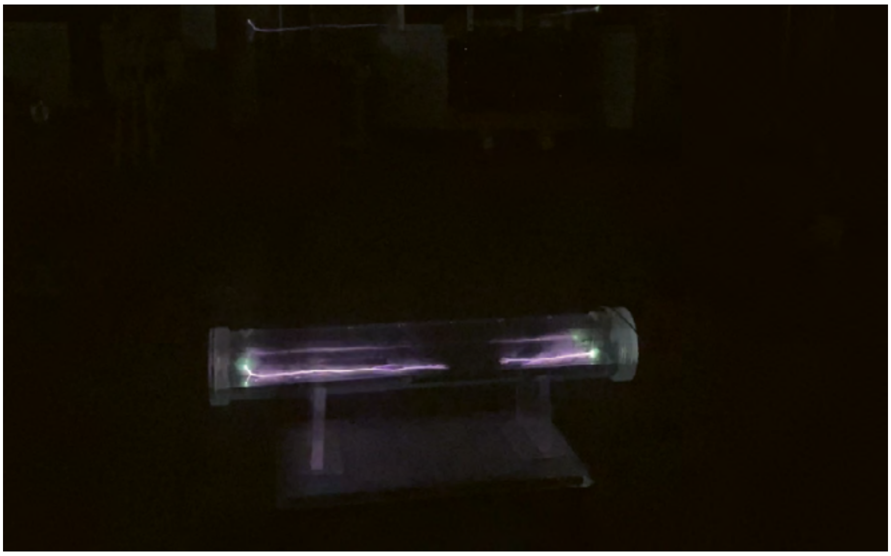
The investigation of the insulation properties of power system components requires high voltages.

The institute's high-voltage laboratory offers many testing options. The large test field contains two systems for high-voltage generation of AC and impulse voltage, the modular construction system for setting up various generation and measurement circuits and the electrically shielded partial discharge measurement cabin. The large test field offers the classic high-voltage tests for examining electrical strength, including the use of the Greinacher cascade, which generates a DC voltage from an AC voltage on the input side, so that three voltage forms can be generated in the large test field. This allows, for example, high-voltage insulators, switchgear or complex insulation systems to be tested for their electrical strength under different conditions. The voltage amplitudes that can be achieved are up to 800 kV for AC and DC voltage and up to 2 MV for lightning impulse voltage. In addition, a wide range of circuits in the voltage range up to around 300 kV can be constructed using the modular system that is further available. In addition to generation equipment, appropriate measuring devices and voltage dividers are also required. Here, too, there is a suitable divider for every voltage type and level, be it the damped capacitive (Zaengl) divider suitable for up to 2 MV, various capacitive dividers up to 400 kV, resistive dividers up to 200 kV or installed in the Greinacher cascade up to 800 kV. The voltages can be transmitted potential-free via measuring satellites of transient recorders, thus ensuring the safety of the experimenters.

In addition to generation and measurement, the right experimental vessel is also required for correct investigations. Countless setups are already available and new ones can be manufactured in the institute's workshop. These include a cryostat for investigations up to $\hat{U}$ = 200 kV at temperatures of -190 °C in liquid and gaseous nitrogen with options for visual observation of the discharge via high-speed cameras and sight glasses, as well as irradiation of the set-up. Alternatively, investigations can also be carried out in a vacuum test vessel with up to 700 kV at 10^{-6} mbar. Current investigations in this test vessel are used for the optical observation of breakdowns during tests with lightning impulse voltages. In the partial discharge measurement cabin, which is protected with mains filters against mains-side interference and electrically shielded, a partial discharge measurement 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 PD cabin. It can be assumed that high-frequency interference will become more relevant in the future, particularly due to the use of power electronics.

In order to inspire enthusiasm for high-voltage technology at an early stage, a number of show experiments were set up. As part of lectures or the Future Day, guessing the musical pieces, which were impressively reproduced by the music Tesla, or experiencing electrostatic charging, which makes hair stand on end, on the tape generator were well received.

Music-Tesla-Coil



Sliding discharge across the surface of water

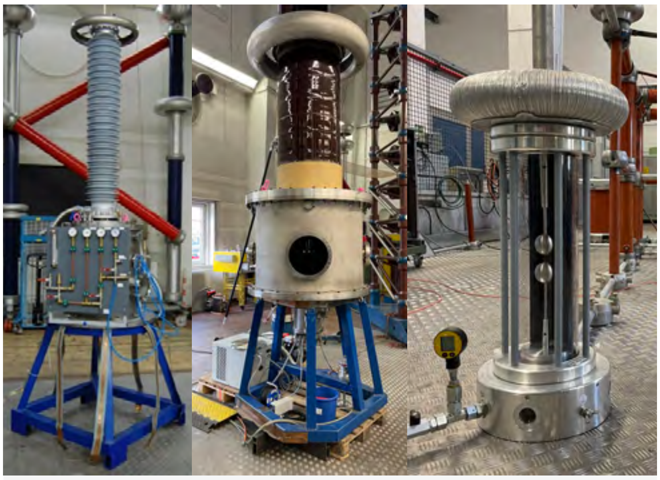
MARX-GENERATOR

Impulse voltage generator

- Surge voltage generator for switching and lightning impulse voltages with 400 kV / 50 kJ (up to 2 MV possible)
- Load capacity and resistors adjustable for standardized 1.2/50 pulses
- Damped capacitive divider up to 2 MV

AC VOLTAGE TRANSFORMER

- 50 Hz AC voltage transformer up to 400 kV / 400 kVA (up to 800 kV possible)
- Compressed gas capacitor for voltage measurement



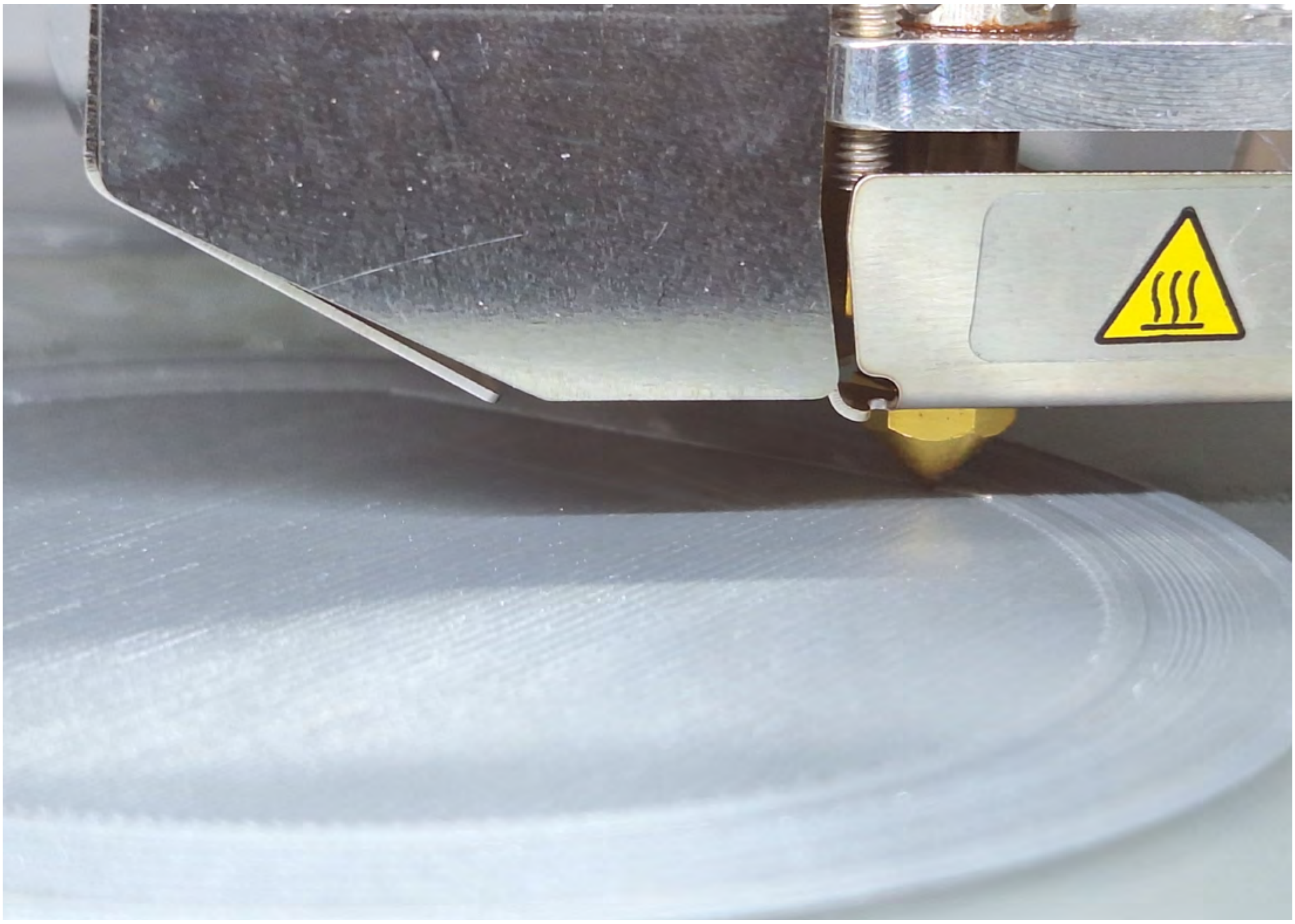
TEST VESSELS

- Cryostat up to -190 °C and approx. 200 kV up to 3 bar absolute pressure
- Vacuum test vessel up to 700 kV at 10^{-6} mbar with sight glasses
- Pressure test vessel up to 12 bar absolute and 150 kV

HIGH-VOLTAGE MODULAR SYSTEM

- 50 Hz AC voltage transformer up to 200 kV
- Various modular components consisting of capacitors, resistors and diodes

Insulation Materials Labor



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TASKS AND SERVICES

- Dielectric material testing
- Long-term behaviour of insulating materials
- Modelling and simulation
- Test specimen production
- Partial discharge measurements and interpretation on models and components

Insulation Materials Labor

Modern insulation diagnostics for electromobility and high voltage

In elenia insulation materials laboratory, insulation materials for use in electromobility and high-voltage applications are systematically tested, analyzed and further developed. The ever-increasing demands placed on modern insulating materials, particularly in electric drives and energy transmission systems, make it necessary to establish new, innovative concepts and diagnostic methods in addition to proven testing procedures in order to ensure precise evaluation and reliable service life estimation.

A key research topic is the integration of new generations of semiconductors based on silicon carbide (SiC) and gallium nitride (GaN). These materials, which are characterized by high switching speeds and outstanding energy efficiency, set new standards, but at the same time pose considerable challenges for existing insulation systems. In particular, the partial discharge phenomena caused by fast voltage edges require adapted measurement technology and interdisciplinary cooperation between research, development and application.

In order to meet these requirements, the insulation materials laboratory was recently expanded to include its first high-frequency high-voltage generator (HFHV). The generator, which has now been put into operation, enables tests to be carried out at 20 kHz and voltages of up to 7 kV. At the same time, the electrically shielded TE measurement cabin is being structurally redesigned so that insulation systems for larger electrical applications, such as electric motors, can also be tested in future. This is the first step in the comprehensive expansion of the laboratory. Another HFHV generator is currently being designed for tests at 40 Hz and up to 10 kV.

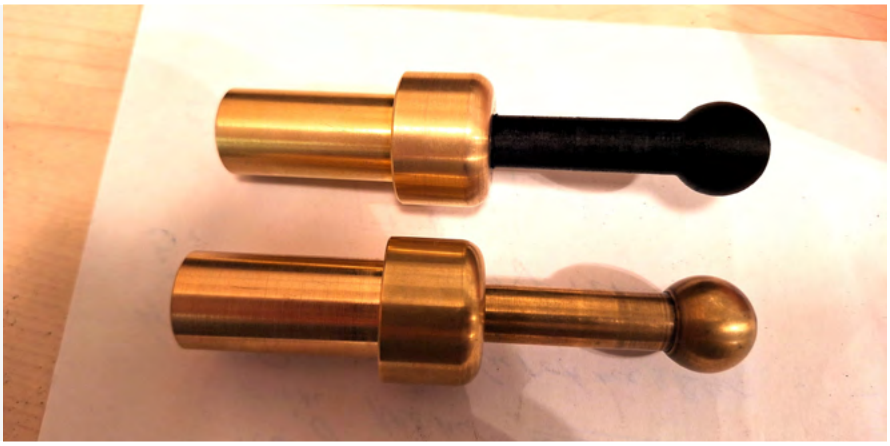
With the integration of additive manufacturing processes, 3D printers based on fused filament fabrication (FFF) and stereolithography (SLA), complex, functionally optimized test specimens can be manufactured cost-effectively and flexibly. A specially equipped workstation enables a continuous workflow from CAD design to additive manufacturing to electrical testing, ageing and optimization in one location. This allows tailor-made solutions to be implemented for specific issues in insulation technology.

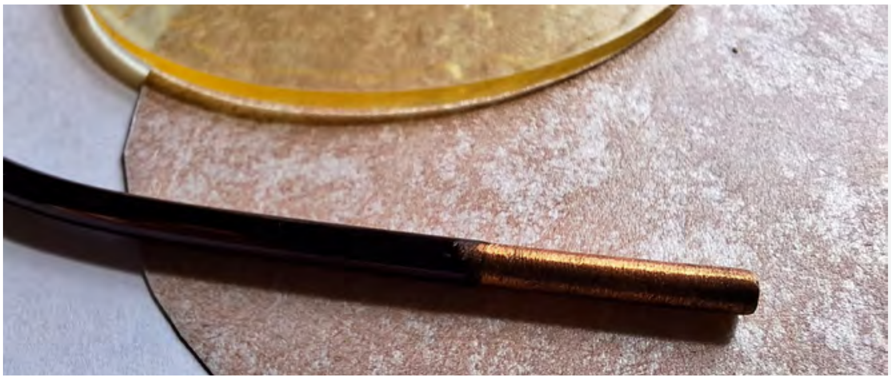
With these targeted improvements in infrastructure, technology and methodology, elenia is strengthening its position in the field of insulating material research. The laboratory is thus contributing to quality assurance, increased efficiency and reliability of modern electrical energy systems, while at the same time promoting training and the development of young talent in a forward-looking field of research.

Metallised plastic samples for improved measurement accuracy through vapour-deposited electrodes

Additive manufacturing of electrodes using conductive plastics

- ESD-PLA as a conductive 3D-printed thermoplastic
- Sphere electrode as a replacement for brass





Basic components of the insulation system of an electric motor

- Encapsulation material
- Insulating paper
- Enamelled wire

Visualisation of the fill level of test specimens

- Enables optimised test specimens
- Use of materials only in critical areas


REMOTE
OP1263
ENABLE
DISABLE
START
STOP
L1
L2
L3
SW1 AC
DISCONNECT
SW2 DC
DISCONNECT
CHASSIS INDEX
7 0
USER 1
USER 2
PWR ON
MASTER/SLAVE
TX RX
SYNCHRO
JTAG
PROG
CFG OK
RX
TX
SFP Modules
OPAL-RT
TECHNOLOGIES
OP4510
RCP/HIL FPGA-BASED REAL-TIME SIMULATOR
OPAL-RT
TECHNOLOGIES
STATUS
FAULT
OP1210
10 FB/HB SUB-MODULES
MODULAR MULTILEVEL CONVERTER
MMC TEST BENCH
OPAL-RT
TECHNOLOGIES
OP1210
10 FB/HB SUB-MODULES
OPAL-RT
TECHNOLOGIES

HVDC-PHiL Testbench

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TASKS AND SERVICES

- Validation of meshed DC systems with real-time simulation concepts (HiL, PHiL, RCP)
- Operating, control, and protection concepts for MMC-based DC systems
- Modeling and simulation

HVDC-PHiL Testbench

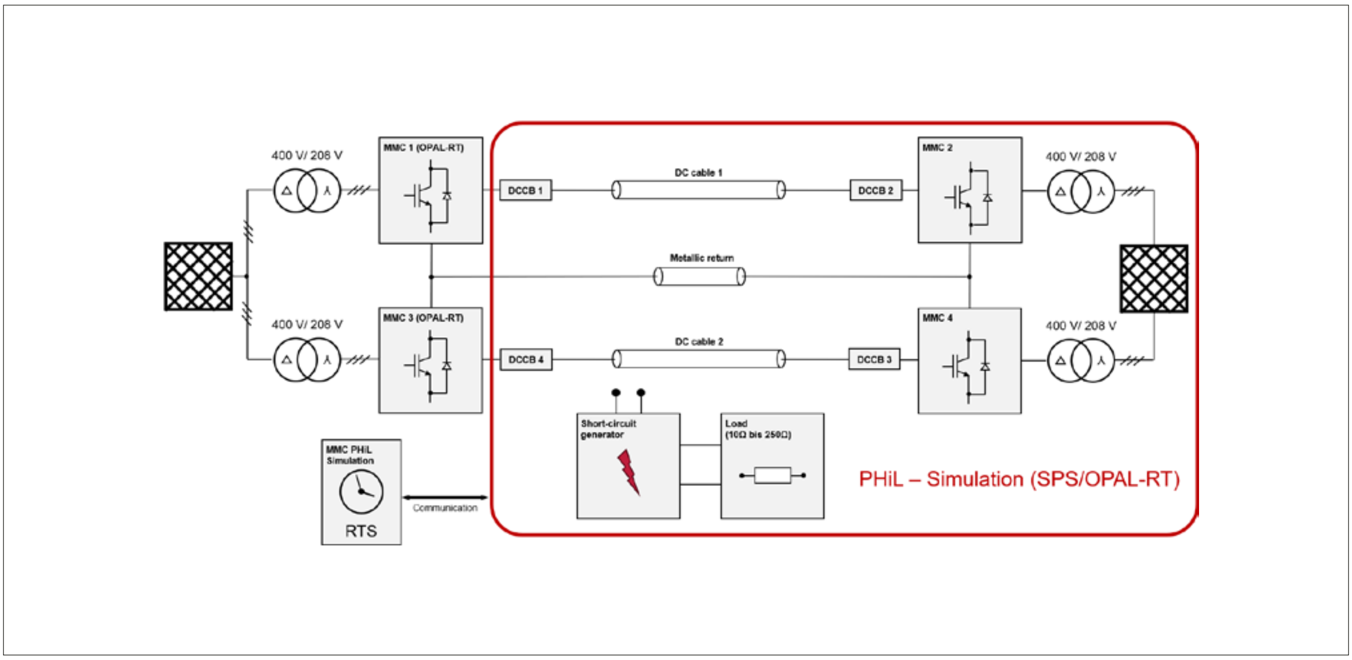
MMC-based DC system for validating operating, control, and protection concepts with PHiL simulations

In the context of the energy transition, low-loss high-voltage direct current (HVDC) transmission systems are becoming increasingly important for transmitting large amounts of power over long distances. However, the validation of meshed DC grids in the field of HVDC remains a major challenge, particularly due to the complexity of such systems.

There is a great need for proof of concept based on laboratory-scale prototypes. This is precisely the focus of the cooperation laboratory, which elenia has set up together with the Institute for Electrical Systems and Automation Technology (IfEA) at Ostfalia University of Applied Sciences. This enables the validation of operating, control, and protection concepts in a real environment. These prototype implementations form the interface between simulation and large-scale implementation. Experiments can be carried out safely in the laboratory under defined conditions. The results obtained in this way significantly support the validity of pure simulations and thus make an important contribution to increasing the Technology Readiness Level (TRL).

Due to the complexity of the DC systems under consideration, not all system elements can be replicated in the laboratory. However, with the help of power hardware-in-the-loop (PHiL), some elements can be outsourced to real-time simulations in order to still be able to map a complete system. This means that not all mapped hardware components need to be physically present, and additional flexibility can be created at the same time. The collaborative laboratory at the IfEA in Wolfenbüttel has a suitable laboratory infrastructure and focuses on the validation of DC systems with laboratory-scale prototypes, the control and performance of modular multilevel converters (MMC), and PHiL concepts and applications. The real-time simulators and power amplifiers used there, as well as real, scaled MMCs, are essential components of the laboratory equipment. The laboratory prototype interacts with the elements within the real-time simulation and vice versa, with the power amplifier forming the interface. The validation process and the development of PHiL experiments can be tested in the laboratory with real-time simulations of MMCs and DC systems.

The focus of current and future work is on analyzing the interactions between AC and DC systems as well as the protection and control concepts of MMC and DC networks. The laboratory setup is currently being expanded on the hardware side with an additional, similarly scaled MMC and another power amplifier to create a bipolar point-to-point connection in order to better replicate real systems. The expanded use of PHiL also allows cable replicas to be simulated more accurately, bringing their behavior closer and closer to that of a real long cable. The flexible hardware setup in combination with real-time simulation will also make it possible in the future to simulate hybrid AC/DC networks with multi-terminal systems.



Planned schematic layout of the HVDC system in the collaborative laboratory

MODULAR MULTILEVEL CONVERTER (MMC)

RCP platform for validation of operating, control, and protection concepts

- OPAL-RT OP1200
- 400 V DC, 6 kW
- 11 Level
- 5 kHz PWM-Frequency

REAL-TIME SIMULATOR

Real-time simulation of AC/DC systems and MMCs

- OPAL-RT OP5707XG
- Analog/Digital IO
- Communication protocols like IEC61850
- Interface to power amplifiers for PHiL

Source: OPAL-RT Technologies

LINEAR POWER AMPLIFIER

Flexible amplifier with high bandwidth

- Spitzenberger und Spies APS15000
- 15 kW, 570 V DC
- > 52 V/µs climbing speed
- Interface to real-time simulator for PHiL

LABORATORY SETUP

CAD-Model

- Real time simulator
- 2 linear power amplifiers
- Switchpanel, DC-cable-models, DC-Switches
- 2 Modular Multilevel Converters (MMC)
- 2 Transformers
- Variable load
- AC-grid simulator

Source: Chroma ATE Inc.

AC GRID SIMULATOR

Flexible AC source

- 15 kVA, 350 V
- DC and 30 Hz to 100 Hz
- Phases can be controlled independently of each other

LINEAR POWER AMPLIFIER

Amplifier with full 4Q operation

- Triphase PM15
- 15 kW, 650 V DC
- 16 kHz PWM-Frequency
- Interface to real-time simulator for PHiL


V
A
DURCHFLUSS
ABB
VORPUMPE
HEIZUNG
NETZ

Synthetic Test Circuit

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TASKS AND SERVICES

- Performance testing
  - Testing of power circuit breakers up to rated voltage U_N=72.5 kV
  - Single-phase short-circuit testing
- Contact geometry analysis
  - Investigation of novel contact geometries
- Thermographic inspection
  - Investigation of surface temperatures for different materials

Synthetic Test Circuit

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

The institute's synthetic test facility is used to research vacuum circuit breakers for application at high-voltage levels. For this purpose, short-circuit conditions — representing the maximum stresses on circuit Breakers are reproduced synthetically in the test facility. To establish vacuum circuit breakers at high-voltage levels, various contact geometries are investigated, including options with two vacuum interrupters connected in series and variable contact stroke. A special vacuum vessel was developed to enable variable contact stroke.

Interruption tests are performed on this vacuum breaker. First, the breaker is subjected to a high short-circuit current. While current is flowing, the breaker is opened, producing a metal vapor arc. After the arc extinguishes, the breaker is subjected to a damped voltage oscillation, also referred to as the transient recovery voltage (TRV).

During switching operations in the power system, faults can occur that lead to short-circuit currents and TRVs. A high-current capacitor bank is used to generate the short-circuit current. It is charged to a maximum voltage of 3 kV, producing a half-sine current wave with a maximum current of 63 kA (RMS) at a frequency of 35 Hz or 50 Hz.

The high-voltage capacitor bank generates the TRV, which is applied via a triggered spark gap shortly before current zero. The capacitor bank can be charged up to 150 kV; for safety reasons, however, it is typically charged only up to 90 kV. This results in a TRV peak value of 140 kV.

The other components of the high-voltage circuit are modular, allowing different voltage rise times and frequencies to be realized. The TRV frequency ranges from 5 to 40 kHz. This range covers the frequencies typically encountered in medium- and high-voltage systems during fault conditions and partly exceeds them to simulate increased stress on the breaker.
During the tests, the resulting metal vapor arc is observed through a viewing window with a high-speed camera. This enables characterization of the arc and verification of various modeling concepts. With a contact geometry such as the transverse magnetic field (TMF) contact, the arc rotates at very high speeds — up to 1000 m/s — across the contact surfaces, leading to distinct phenomena. These rapid processes are captured in detail thanks to the camera's high resolution (1024 × 1024) and a maximum frame rate of 800 kfps.

To test new contact geometries as well as customized shielding and control arrangements for vacuum applications, temperatures up to 1200 °C are generated in a split-tube furnace under vacuum. Ceramics with diameters up to 200 mm can be brazed in this furnace.

HIGH-CURRENT (LEFT) / HIGH-VOLTAGE (RIGHT) CAPACITOR BANK

Single-phase synthetic testing of circuit breakers

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

CARBOLITE GERO TS1

Free-standing split tube furnace for vacuum brazing of test setups and contact pieces

- Usable diameter 200 mm
- Temperature up to 1200 °C
- Temperature gradients freely programmable

VACUUM TEST CIRCUIT BREAKER

Enables investigation of plasma phenomena between switching contacts

- Special vacuum vessel
- Vacuum pump ($p < 10^{-7}$ mbar)
- Variable contact stroke up to 2 × 40 mm
- Series connection of two circuit breakers possible

NOVA S6 VON PHOTRON

A high-speed camera is available for the visual investigation of arcs

- Resolution up to 1024 × 1024 pixels
- Monochrome imaging
- Maximum frame rate: 800 kfps
- Exposure time down to 200 ns


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elenia charging park

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TASKS AND SERVICES

- Testing concepts for grid and system integration of electric vehicles
- Investigation of grid-friendly charging strategies
- Research into generation-oriented and grid-oriented charging
- Solutions for increasing the absorption capacity of EVs in the low-voltage grid
- Charging management for electric vehicle fleets

Charging park at the Mühlenpfordthaus

Real-world testing of concepts and strategies for the successful integration of electric vehicles into the grid

The elenia charging park on the idyllic banks of the Oker river, right next to the Mühlenpfordthaus, not only offers six charging spaces for the growing number of electric vehicles in Braunschweig, but also a wide variety of different charging stations and wall boxes. The charging infrastructure there offers four permanently installed charging stations for internal use. However, most of the other charging equipment is mounted on mobile item racks and can be moved around as needed. This allows a large number of different test setups to be implemented in elenia's Network Dynamics Laboratory (NDL) and Energy Management Laboratory (EML). The data obtained from the charging processes of the institute's internal infrastructure can be stored online in a specially created backend for further evaluation and thus be put to profitable use in ongoing projects at the institute, such as MELANI or NetFlexum. Furthermore, the permanently installed charging stations are now also monitored by an SMA energy meter. This allows them to be integrated into an energy management system, where, for example, generation-oriented charging strategies can be investigated. The whole thing is rounded off by linking the charging park with the EML and the NDL. The latter enables the influence of charging processes on specific network topologies and network usage cases to be investigated. Furthermore, innovative network-friendly functions, such as Q(U) control integrated into the charging station, can be analyzed and tested. Overall, the charging infrastructure and laboratory equipment are continuously being developed and improved in order to respond to changes and innovations in the growing electric mobility market.

Interoperability of charging equipment and EVs

Another focus is on communication between the vehicle and the charging station. This is essential for the smooth running of the charging process and thus also for the acceptance of electric mobility in general. In the LISA4CL project, an inductive charging system for outputs of up to 22 kW is being developed in collaboration with partners. One of elenia's tasks is to develop and test standard-compliant communication between the primary and secondary sides of the inductive transformer. During the charging process, parameters such as the charging power or the state of charge (SoC) of the battery are exchanged. In order to implement grid-friendly functions such as bidirectional charging of EVs, this communication must be read out and then intervened in. This is done using so-called developer boards for the vehicle and infrastructure sides, which are used in industry for communication development and are provided to us by our project partners. These can read the communication in CAN format and thus make it available for further programming. This means that, for example, in the event of a local voltage drop in the grid, a signal can be transmitted to nearby charging vehicles so that power from their batteries is fed back into the grid. This allows the voltage at the corresponding grid node to be raised again and damage to equipment or consumers to be prevented.

Developer boards also have another practical application in charging station simulations set up for laboratory testing (see photos). These simulations can be used to simulate AC and DC charging processes with different charging stations in the laboratory. The AC charging simulation replicates the communication that takes place in the EV. The vehicle battery can be simulated by an AC load. In addition, it is also possible to use a bidirectional rectifier and a battery emulator to record the DC parameters of the AC charging process and simulate the behavior of different battery types and sizes.

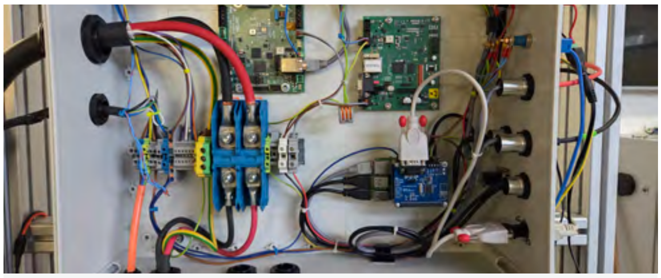
AC charging simulation

The charging park is rounded off by a specially constructed AC charging station for the electric mobility laboratory offered at the institute (see hardware photo). This is operated by a programmable logic controller (PLC) and can thus simulate various charging situations on the institute's own eGolf. In order to also be able to examine DC charging processes during the internship, a bidirectional DC charging station has also been installed. This is equipped with a developer board and can thus simulate DC charging processes using scripts developed specifically in the Python programming language and DC sources controllable via CAN bus. This allows students to gain a comprehensive insight into the charging processes and examine the communication between the vehicle and the charging station. This provides practical insights into the basics of electromobility and attempts to illustrate the challenges of grid and system integration of EVs to students.

CHARGING PARK MÜHLENPFORDTHAUS

EVs can be charged here at 6 charging parking spaces

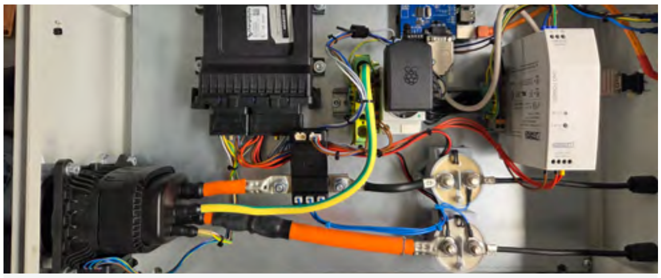
- 3 Charging stations with 6 charging points
- Max. 22 kW three-phase AC charging (32 A)
- Max. 20 kW DC charging (via CCS and CHAdeMO connectors)



BIDIRECTIONAL DC-CHARGING STATION

Based on open source software

- Max. 20 kW DC charging
- One charging point



Vehicle replica for DC charging

- Max. 20 kW DC charging
- Bidirecitonal Charging possible
- Can be operated in conjunction with a battery emulator

PION WAVE

Mobile three-phase wallbox for laboratory testing

- Max. 22 kW three-phase AC charging (32 A)
- One charging point
- Innovative design with exposed aggregate concrete look

SMA EV CHARGER BUSINESS

Mobile three-phase wallbox for laboratory testing

- Max. 22 kW three-phase AC charging (32 A)
- Two charging point
- For industrial use

LABORATORY CHARGING STATION FOR THE E-MOBILITY LABORATORY

Three-phase, PLC-controlled AC charging station

- Max. 22 kW three-phase AC charging (32 A)
- Insight into the safety and control components
- Bidirectional charging possible


SMA
SMA

Energy management laboratory

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TASKS AND SERVICES

- Testing of control methods and communication protocols
- Combined tests with hardware devices, simulation models and control systems with a modular control environment (HiL)
- Energy and power measurements
- Control and evaluation tools for storage efficiency measurements
- Compatibility testing for the technical evaluation of the operation of battery storage systems with battery inverters
- Validation of operating strategies for energy management systems at building level

Energy management laboratory

Research, innovation and practical experience for a sustainable energy future

The energy management laboratory offers ample space for investigating innovative energy management concepts for all-electric households and prosumer demonstrators. Research focuses on prosumer behaviour in the context of electromobility, the coupling of the heating and electricity sectors, load and storage management, and newly developed metering and measurement concepts and communication concepts related to smart meter infrastructure. Numerous devices are available for this purpose, such as various AC loads, DC sources, a charging infrastructure with charging terminals from different manufacturers, and a heat pump test bench consisting of an air-water heat pump, a climate chamber, and a heating circuit. With the help of a large number of mobile measurement setups, various energy-related variables can be recorded, stored, and evaluated. The power and data coupling of the energy management laboratory with the grid dynamics laboratory also offers the option of cross-laboratory measurements. This enables the processing of innovative projects and emerging research questions in the field of holistic laboratory-based research, such as the effects of a smart building on grid stability.

Since the laboratory opened at the end of 2018, prosumer demonstrators have been implemented in the NetProsum2030, Campus: blueMAP and flexess projects. Work on the MELANI, KEMAL and SiNED projects continued until 2025. The PICNIC project is currently working on testing voltage quality improvement regulations.

In the MELANI research project, measurement methods and meter concepts for the multiple use of PV home storage systems were developed. The laboratory environment of the energy management laboratory was used to evaluate a model of the developed concept. The operating strategies for energy management systems at building level created for MELANI were also validated in the laboratory.

Energy management systems were also investigated in the KEMAL (customer-oriented energy management with autonomous load control) research project. However, the focus here was on the usable potential in combination with a smart meter gateway. The project addressed the further development and testing of existing standards relating to the smart meter gateway and took a holistic view of the smart metering system. The focus here was on the development of a home energy management system that ensured the standard-compliant connection of fully flexible prosumers to the smart metering system.

The SiNED project investigated how temporary overvoltages caused by asymmetrical loads in distribution grids with many converter-based generation systems affect protection systems. It assessed the extent to which legal requirements limit the permissible asymmetry and thus also the level of overvoltages.

In the PICNIC project, voltage quality improvement controls are being implemented and tested on decentralised individual components such as PV inverters and DC charging stations. In addition, the project is investigating how these controls can be combined with prosumer-oriented home energy management strategies aimed at optimising active power flows.

In addition to the research area, teaching also benefits in the form of numerous student projects that can be carried out in the laboratories and the additional laboratory experiments offered in parallel to the lectures. Here, students can collect practical experience in the laboratory in experiments on topics such as energy management or heat pumps and consolidate their theoretical knowledge through hands-on practical work.

The laboratory also conducts compatibility tests for the technical evaluation of the operation of various battery storage systems in conjunction with battery inverters. In addition, the extensive equipment in the energy management laboratory enables the processing of service projects in the context of efficiency measurements of PV storage systems in accordance with efficiency guidelines, thus expanding the institute's range of services.

MOBILE CHARGING STATION IN THE LABORATORY

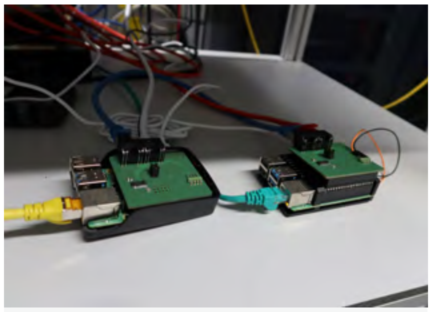
SMA EV CHARGER BUSINESS: Charging electric vehicles

- Charging with up to 2 x 22 kW per charger (230 VAC / 400 VAC, max. 32 A)
- Fully integrated electromobility solution, also for charging with solar power
- RFID and OCPP interface
- Protection against overload of the grid connection point

ENERGY STORAGE FOR COMMERCIAL, INDUSTRIAL OR MULTI-FAMILY BUILDINGS

TESVOLT TS HV 70

- Lithium storage (NMC)
- Continuous charge/discharge rate: 1C
- 8,000 full cycles (10-year warranty)
- Safest cell technology
- High-voltage system



POWERFUL SINGLE-BOARD COMPUTERS

Raspberry Pi 4 Model B

- 8 GB RAM, SSD card as permanent storage
- Use in the MELANI project to test the developed energy management system
- Development of CAN interface in cooperation with the Physikalisch Technische Bundesanstalt (PTB): Reading of various energy meters possible with 1-second resolution → Measured values are processed for efficient power flow control in the energy management system

ELECTRIC MOBILITY AT THE ELENIA INSTITUTE

e-Golf „emilia"

- In use since 2014 in the Braunschweig joint project 'emil'
- Research in the areas of inductive charging and grid connection
- Charging using the institute's own infrastructure
- Range of approx. 140 km without charging stops

COMPATIBILITY TEST FOR THE TECHNICAL EVALUATION OF BATTERY STORAGE OPERATION BASED ON PREDEFINED SPECIFICATIONS

Goals of the tests:

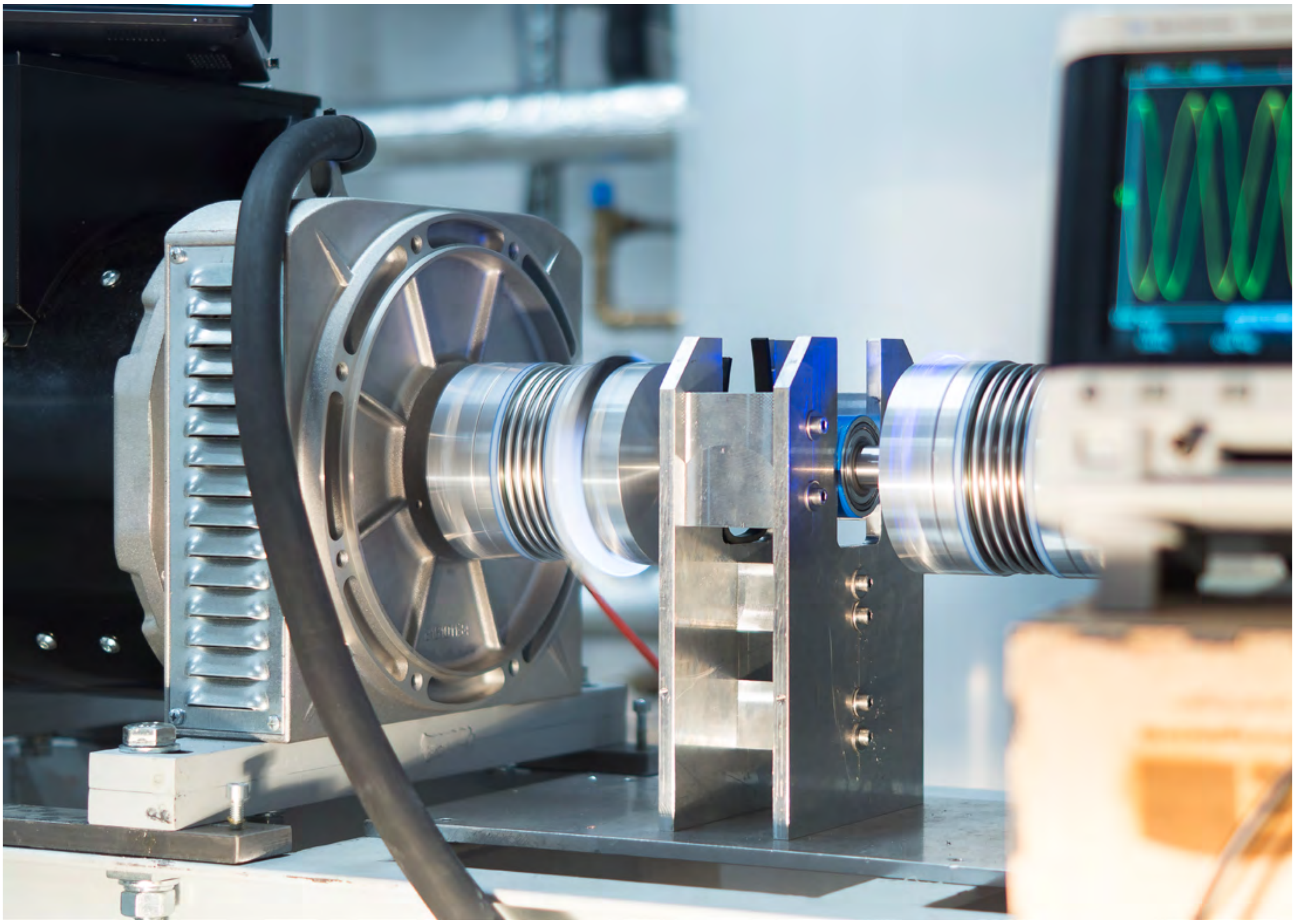
- Determine the compatibility of battery storage systems with battery inverters
- Analyse off-grid and grid-connected system behaviour under various operating scenarios (normal operation, overload and overcharge conditions)
- Confirm safety measures during initial commissioning and safety shutdowns in the event of faults
- Check correct communication between battery storage and inverter
- Inrush current test and DC ripple analysis

METERING CABINET

- Use in the MELANI and KEMAL research projects to model a building network
- Connection of various electronic loads and DC sources possible
- Recording of energy-related measurement variables through integrated power measurement


CAUTION
Risk of Electrical Shock
Inverter_2
Inverter_1
CAUTION
Risk of Electrical Shock

Grid Dynamics Laboratory



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RESEARCH TOPICS

- Development and testing of innovative control concepts for power converters to provide system-supporting properties for the interconnected power grid
- Behaviour and stability of grid-forming voltage-controlled inverters (GFMs) in island grid as well as grid-parallel operation
- Behaviour of components and power converter coupled systems during frequency and voltage changes in dynamic time ranges
- Provision of both conventional and fast primary control power
- Overcurrent limitation and short-circuit behaviour of decentralised generation systems
- Anti-islanding detection and resonant circuit tests up to 33 kVA in accordance with DIN EN 62116
- Effects of variable voltages on controls such as Q(V) and P(V)
- Power converter prototyping at hardware and software level

Grid Dynamics Laboratory

Grid stability in times of converter-dominated grids – Milliseconds matter

Research objectives of the Grid Dynamics Laboratory

The Grid Dynamics Laboratory (NDL) conducts research into current challenges relating to the integration of renewable energies into the low-voltage grid. The focus is on highly dynamic, transient processes in the time range from milliseconds to a few seconds. The experiments concentrate on the transition from classic, generator-based large power plants to decentralised, power converter-based systems, which are increasingly being used in decentralised feed-in from renewable energies. The isolated test environment makes it possible to analyse the behaviour of generation plants – with a particular focus on power electronic characteristics, communication structures and control algorithms – under highly volatile grid conditions. The aim is to thoroughly evaluate critical grid situations, novel power converter controls and potential interactions between conventional and novel plants as a basis for future grid concepts.

Laboratory equipment and simulation methodology

The laboratory uses fully configurable AC and DC voltage sources, adaptable grid simulations, loads, commercially available inverters and configurable full-range converter prototypes. This infrastructure is complemented by two powerful, integrated OPAL 5705 real-time simulators, which enable hybrid test setups combining simulation and hardware in real time. In the resulting power hardware-in-the-loop (PHIL) system, analogue measured variables such as voltage and current are fed into the simulator, calculated taking various simulation parameters into account, and fed back as control variables. With simulation step sizes of less than 50 µs, the simulator can flexibly map components such as networks with different inertia, arbitrary network topologies, and innovative power converter controls, so that even critical fault cases in live elements can be simulated and physically replicated in the laboratory. This approach provides easy access to quickly adaptable test scenarios and helps to ensure personal safety and equipment protection – an advantage over purely hardware-based setups.

Research example: Investigation into grid support and islanding detection

Last year, a laboratory study commissioned by VDE|FNN was successfully completed. The aim of this study was to investigate the possible effects of grid security-based primary control, a highly dynamic frequency support method currently also being discussed for TAR4105, on the islanding detection of inverters in low-voltage systems. After embedding commercially available inverters in low-voltage island network test benches designed for this purpose, millisecond-precise adaptation of the inverter behaviour to the new primary control in the event of frequency jumps, and subsequent extensive test series in which the test devices had to withstand over 2,700 islanding events, the fundamental compatibility of island network detection and fast grid support in the test devices was demonstrated. The results of the study are published by the FNN on the following website: https://t1p.de/FNN-IDV.

New network dynamics laboratory and expanded testing capacities

With the continuous expansion of laboratory capacities through a highly dynamic linear amplifier from Spitzenberger & Spieß and the increase in electrical power capacity, which now allows for devices in the 100 kW power class to be tested, space requirements are also increasing. For this reason, a new grid dynamics laboratory is being set up in room 026 at Schleinitzstraße 23. In addition to the linear amplifier, the new NDL will house a full converter and two cabinets for automated grid replication in its basic configuration. Other devices, such as prototype power converters, can be temporarily integrated into the test setup. In order to be able to realise complex test setups, it will be possible to connect devices in this room to devices in the other laboratory rooms of elenia Energy Labs via coupling cables. In order to dissipate the increased thermal loads, the new NDL has been equipped with air conditioning units with a capacity of 25 kW.

Summary and outlook for further work

The combination of flexible laboratory sources, various power converters and precise grid and plant simulation via integrated real-time simulators makes it possible to examine future operating scenarios in the low-voltage grid in a realistic manner. By simulating critical grid situations, interactions between power converter-based generation systems and conventional generators can be identified at an early stage and control methods adapted. For example, the investigations carried out as part of the VDE|FNN study show that even under highly dynamic grid conditions, it is possible to control inverters sufficiently quickly and precisely. With the expanded testing capacities in the newly designed grid dynamics laboratory, the supply grid will be even more flexibly prepared for the requirements of the energy transition in the future. The systematic testing and verification of scenarios thus makes an important contribution to optimising grid stability in a future decentralised and highly dynamic energy infrastructure.

GRID SIMULATORS AMETEK MX-45 AND REGATRON TC.ACS.30

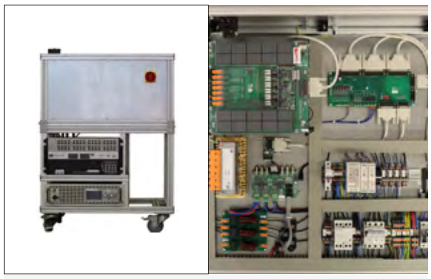
Fully regeneration-capable grid simulators for simulating various grid conditions with variable grid parameters:

- 45 and 30 kVA connected load
- Voltages up to 305 V_{RMS} and 80 VDC
- Currents up to 50 A_{RMS}
- Frequency range 16–1000 Hz
- 4-wire connection (asymmetrical loads possible)
- Integrated measurement system
- Analogue interfaces for precise control of individual phases in amplifier mode
- Operation as RLC load
- Edge rise times of up to 4 V/µs for investigating transient events

OPAL 5707 REAL-TIME-SIMULATOR (2x)

Real-time simulators with high computing power for power hardware-in-the-loop applications and zero-delay laboratory control:

- Analogue/Digital inputs and outputs, as well as fibre optics for connecting a wide variety of laboratory components
- Communication interfaces via protocols such as MODBUS, EtherNet, EtherCAT, CAN, TimeStamp, GOOSE, etc.
- FPGA technology for fast command processing
- Working in the MATLAB/Simulink development environment
- Real-time capable simulations of hardware and electrical networks with simulation step sizes below 50 µs



PROTOTYPE INVERTER SETUP. LEFT: ENCLOSURE; RIGHT: VIEW OF B6 BRIDGE, FILTER AND SIGNAL DISTRIBUTION

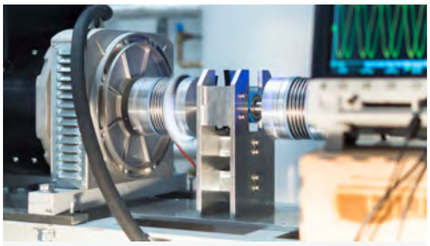
Specially designed and developed laboratory inverter as an open hardware and software evaluation platform with prospective simulation of volatile primary energy source behaviour.

- B6 bridge topology
- DC link voltage U_{DC} = 750–800 V
- Switching frequency f_{sw} = 20 kHZ
- Controller cycle T_R = 50 µs
- Decoupled active/reactive current control
- In the Future: Implementation of grid-forming VCI control and dynamic control of the primary energy side in real time

TRIPHASE – PROGRAMMABLE CONVERTERS

Programmable full converters for implementing and examining in-house control models:

- Two full converters, each with a rated output of 15 kVA
- 1 × 3-wire connection, coupled DC and converter, can be used as a battery simulator
- 1 × 4-wire connection, unbalanced operation, zero system impression
- Control and parameterisation via MATLAB/Simulink



30 KW COUPLED MACHINE SET (ASYNCHRONOUS MACHINE AND SYNCHRONOUS MACHINE)

Machine set consisting of asynchronous and synchronous machines with configurable converter:

- 30 kW connected load at 1500 rpm nominal speed and 150 Nm nominal torque
- Synchronisation unit for connecting external sources to the machine set
- Generator and motor operation possible
- Control via ETHERNET-compatible PLC

CABINET 1 OF THE AUTOMATED GRID REPLICA

Customisable grid replica for simulating low-voltage lines and grid nodes:

- Modular design consisting of 4 cabinets
- Maximum current rating of 125 A
- Simulation of approx. 1500 m NAYY 4 × 150 mm²
- Impedance automatically switchable under load
- Measuring points before and after the impedance in each cabinet
- Various outputs at the exit of each cabinet for simulating network nodes


F11
F12
F13
F16
Q9
Q11

Mechanical & Electrical Workshop

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Mechanical Workshop

The mechanical workshop supports the scientific staff and students in the manufacture of components and equipment for teaching, study, thesis work and research projects. Working closely with staff and students, technical solutions are developed and tested for feasibility using the available machines. In addition to lathes and CNC milling machines, several 3D printers (FDM/SLA) are available for additive manufacturing.

Figure 1: Copper switching contacts

Figure 2: HVDC offshore platform

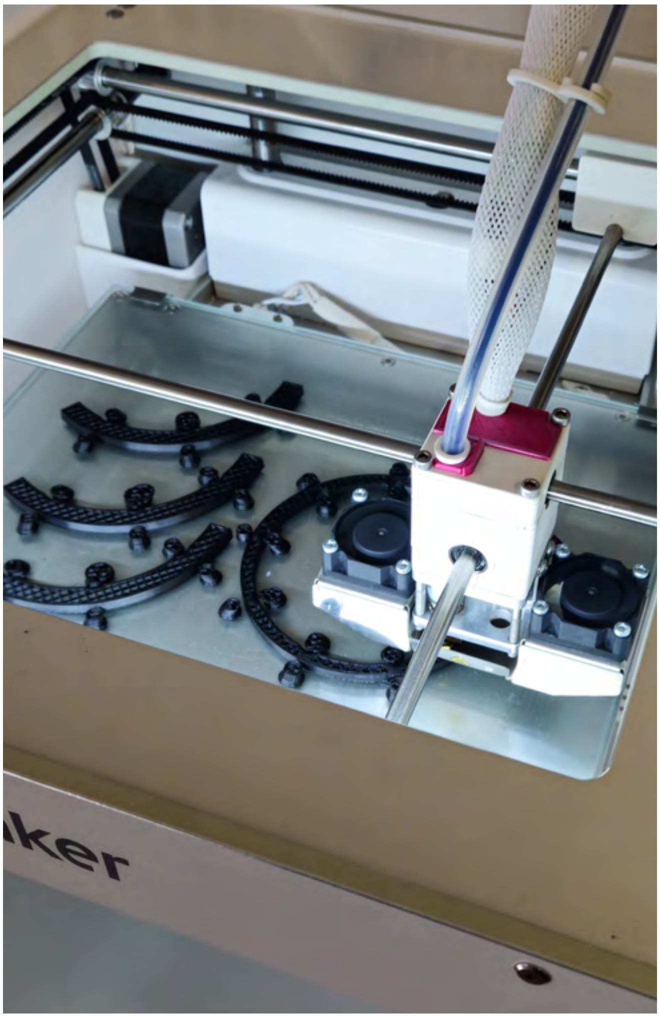

Figure 3: 3D-Print

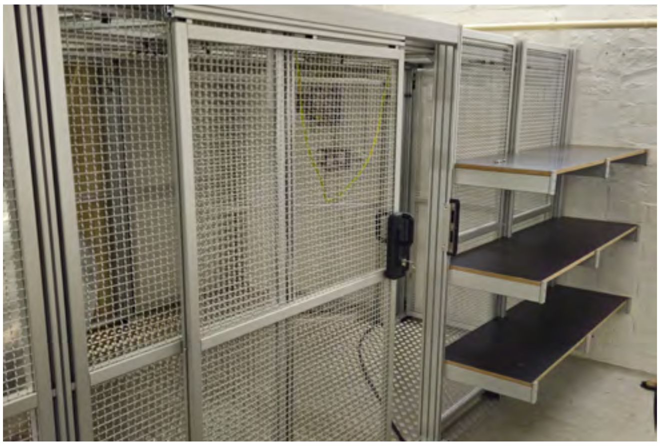

Figure 4: laboratory enclosure

Figure 5: Switch chamber with extraction for material testing

Figure 6: Prosumer house

Figure 7: High-voltage connection of an 800 kV transformer

Electrical Workshop

Laboratory Distribution NDL R026

The power distribution constructed for the future Grid Dynamics Laboratory (Netzdynamiklabor, NDL) is designed for a total rated current of 250 A. Twelve outputs can be separately switched on and off via twelve pushbuttons in the door of the distribution. These outputs are connected to terminal blocks for the connection of the respective loads, as well as two patch panels where additional small distributors can be flexibly connected. The twelve outputs are each switched via a safety contactor with self-holding. They are protected with circuit breakers, residual current devices (RCDs), and NH fuse switch-disconnectors 63 A/160 A to ensure functionality and fast reconnection in case of a fault, especially with high current draw over a longer period. A Smart Energy Meter is also installed, which measures the total consumption via the supply line using current transformers.

During assembly, care was taken to ensure that the arrangement and assignment of the components to one another are symmetrical and easily traceable. For instance, the first visible switch corresponds to the first visible terminal and also the first visible contactor. This makes it quick and easy to potentially replace components and trace the entire system.

Laboratory Coupling NDL

The coupling cabinet has five switches, which are also installed in the distribution cabinet door. Four of these switches operate contactors with rated currents of 3 × 63 A and 1 × 150 A respectively. The cabinet serves only as a coupling and does not have its own mains connection. It thus connects the equipment in the future NDL with another piece of equipment or a fixed connection in a different laboratory. The plan is that the power source can be located both in the NDL and in another laboratory. The connections in the NDL are pluggable via couplings. The outgoing lines to the other laboratory are fixed connections that are wired directly to the contactors. Additionally, the fifth switch can operate twelve relays, each with two normally open contacts, which are connected in parallel and protected with miniature fuses. This makes it possible to switch not only loads but also control signals. Care was taken to ensure that the wiring paths are short and that connecting devices or replacing components is quick and easy.

Automation of an Adjustable Transformer

For numerous experimental setups in the Institute's high-voltage testing area, an adjustable transformer is used. This allows for the stepless adjustment of the mains voltage in the range of 0 V to 230 V for the primary-side supply of the high-voltage transformers. The voltage setting was previously done manually using a handwheel on the transformer to position the tap changer.

Figure 1: laboratory distribution without contact protection

Figure 2: phase distribution via busbar system

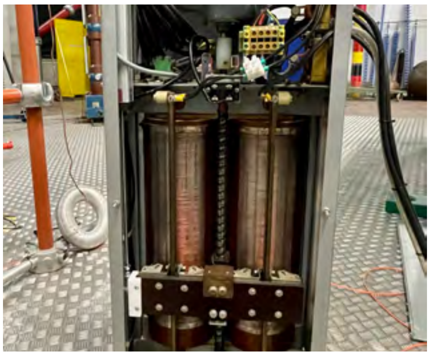

Figure 3: Positioning transformer with absolute value encoder

Figure 4: Inside of a Control Cabinet

Figure 5: conventional user interface

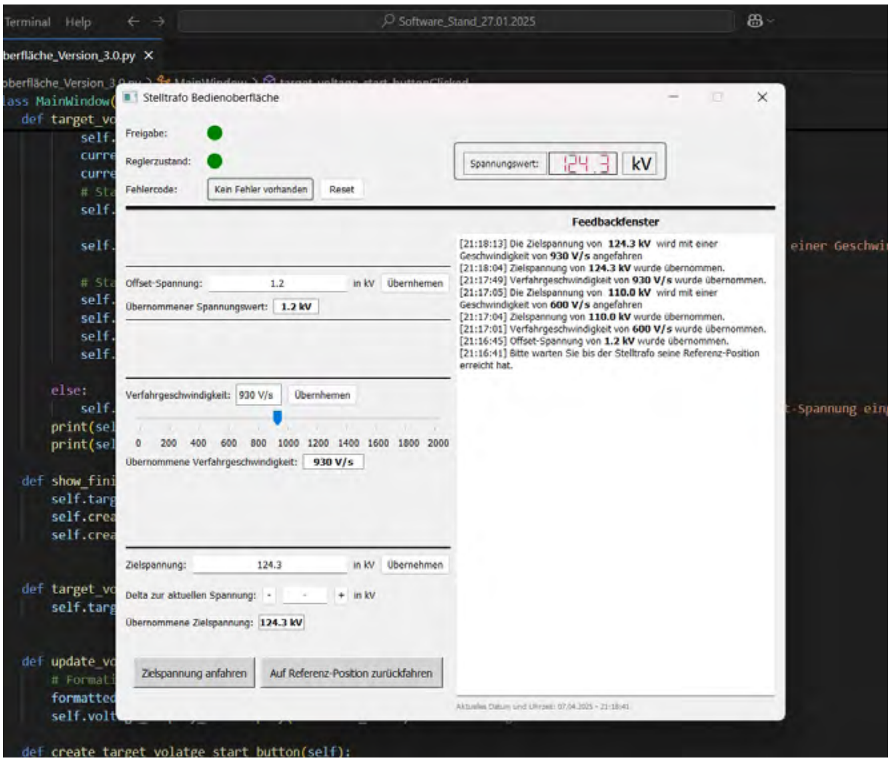

Figure 6: Graphical user interface

In the future, control will be carried out via Ethernet with a digital motor control and a specially developed graphical user interface (GUI). Many parameters are possible, such as setting the stepless travel speed of the tap changer or precisely moving to specific voltage values at defined speeds, as well as setting specific start and stop values.

This simplifies the process of setting voltages for measurements and additionally provides the option of running certain voltage profiles and steps. All voltage profiles can be adjusted to

requirements at any time. For example, the ability to repeatedly run the same profiles for series tests ensures precise reproducibility without major test deviations.

A conventional user interface was also implemented using buttons, allowing operation of the most important functions even without a computer. The control system is integrated into the safety circuit of the high-voltage laboratory. All existing door contact switches, interlocks, and emergency stop buttons, as well as signaling devices, are included. However, the control system also has its own safety relay, which can be easily implemented into other existing safety circuits.

The interface for the intuitive operation of the variable transformer was developed with the Qt framework. Communication with the dryve D1 drive is via an Ethernet connection using TCP/IP and the Modbus-TCP protocol. The control of the regulator is achieved by sending and receiving Modbus telegrams. The entered values are converted into a target position and travel speed and automatically approached. A particular challenge in the implementation was developing a complex and precise universally applicable control system that allows for the control of different adjustable transformers, some of which are older models from the Institute's inventory.

During the development phase, smaller, unforeseeable problems repeatedly arose, or new requirements were posed, necessitating creative and flexible solutions. In the future, the control system is intended to provide a solid foundation for the automation and simplification of test procedures.


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it-administration

TASKS AND SERVICES

- Procurement, maintenance, and servicing of servers and clients
- Provision of workstations and software
- License procurement and management
- Support and training for employees and students (service desk)
- Analysis and definition of IT systems in accordance with the GDPR
- Continuous monitoring and maintenance of institute and research networks
- Setup and maintenance of special project-related IT systems
- Administration of institute and project websites
- IT system hardening in all network segments

IT department at elenia

elenia-IT: Successes and perspectives

Standardization and switch to Windows 11 in the CIP pool

This year, we carried out a series of projects in elenia's IT department to optimize the IT infrastructure. One of these projects focused on the CIP pool for our students and teachers. Here, our focus was on converting and standardizing the computer offering, as well as upgrading from Windows 10 to the new Windows 11 operating system.

In order to create a modern and efficient working environment, older computer models were replaced with more up-to-date ones. Users benefit in particular from larger hard drives, more RAM, and more powerful processors.

Connection of the elenia workstation in the H2 terminal via VPN

The elenia is involved in the H2 Terminal. With its completion, the planning, creation, and configuration of our own virtual private network (VPN) began in order to securely connect our workstation to the new research site.

The purpose was to ensure a stable and secure connection between our internal IT infrastructure and the workstation at our partner's site. By implementing the VPN, we were able to optimize communication between the locations. It also ensures that all data is transmitted in encrypted form and that the integrity of the systems is maintained.

The key tasks included the careful selection of suitable VPN technology, the planning of the network architecture, and the configuration of security mechanisms such as firewalls and access controls. It was particularly important to adapt the solution to the specific requirements of the partner site and the users. In addition, high availability and performance had to be guaranteed.

The successful implementation of the VPN has not only significantly simplified collaboration with the partner location H2 Terminal, but also created the basis for a future-proof, scalable network structure that can be used in further projects.

Creation and planning of the network infrastructure for the new NDL

Another project to improve the digital infrastructure is still in the development phase. It involves planning and setting up a new network infrastructure for the new Network Dynamics Laboratory (NDL). In addition to installing switches, patch panels, and data sockets, the project also includes configuring the network. This will ensure a robust and powerful network connection in the new Network Dynamics Laboratory. As part of this changeover, a new internal network is being set up.

This connects the individual laboratories to each other so that the devices can be monitored regardless of their location. Our careful work on this project demonstrates our commitment to making optimal use of innovative technologies and continuously improving the institute's digital infrastructure.

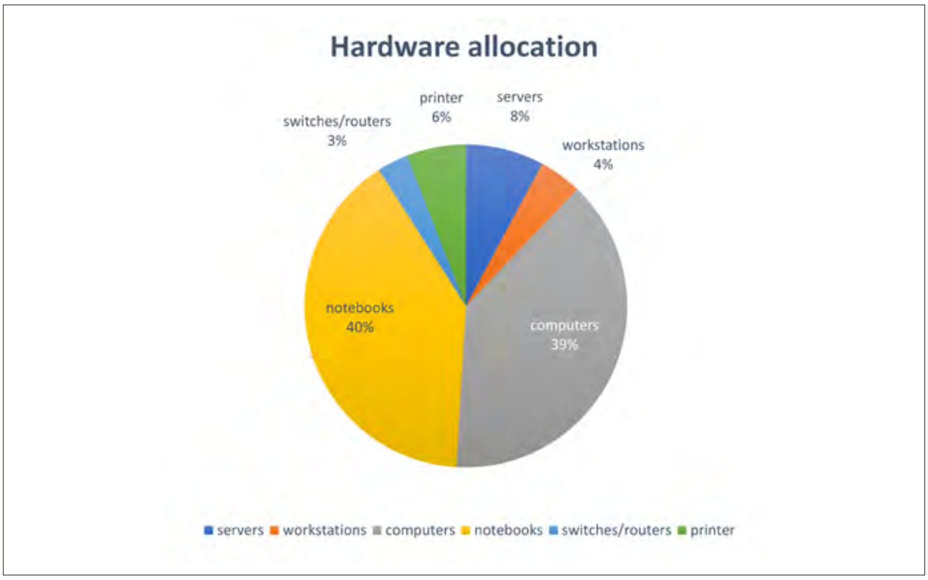
Pool solution - Additional IT services

Last year, we expanded our IT services to include the Institute for High Frequency Technology (IHF). The institute comprises four professorships and two locations, which makes managing the IT landscape considerably more complex.

This is a significant expansion. It is based on the pool solution concept that we introduced several years ago. This model involves pooling staff in specialist departments. The synergies created in this way are intended to provide all institutes with optimal IT services.

Our first task was to address the urgent need for action in the institute's IT department. When we took over, we discovered that crucial system changes had not been made. Despite these challenges, we focused on gradually improving the situation and providing the institutes with a robust and secure IT environment.

As part of these efforts, we plan to introduce new security guidelines. In addition, we are currently developing a new network concept to improve the IT working environment and make it more transparent. In view of the increasing threat of cybercrime and data breaches, it is essential that our institutes' IT infrastructures are operated in accordance with the highest security standards. This is an ongoing process in which we work closely with the institute. Only in this way can we understand individual needs and deliver the required service.



HARDWARE DISTRIBUTION IN 2025 (DATA COLLECTED ON: APRIL 11, 2025)

- 33 server systems (physical and virtual, Windows und Linux)
- 163 computers
- 168 notebooks
- 18 high-performance workstations
- 25 Printers
- 13 routers and switches

Our work at three institutes and the MEES chair is a clear example of how the pool solution model can be successfully implemented. This benefits the institutes within Faculty 5. It demonstrates that we provide IT services efficiently, securely, and to a high standard of quality.

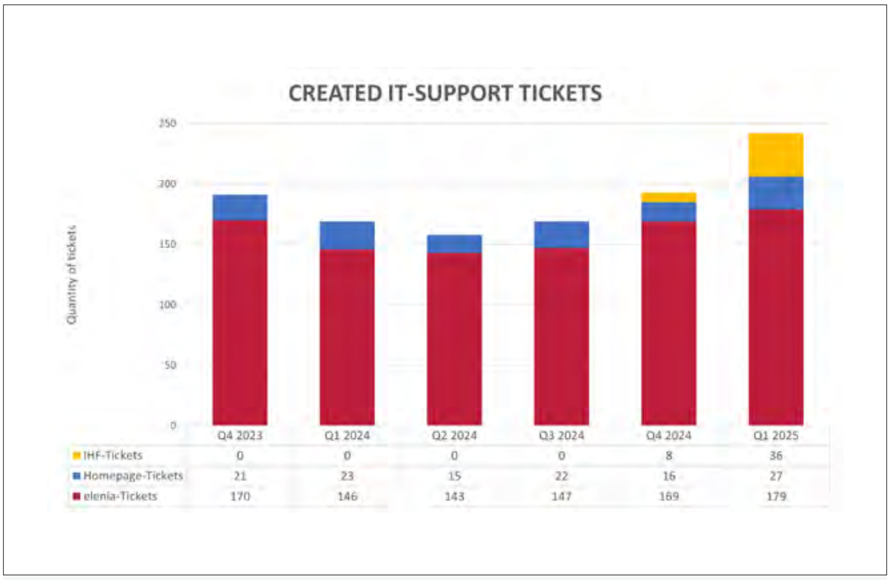
Hardening and implementation of new security policies

A particularly important aspect of our work is the continuous hardening of our IT systems and the implementation of the guidelines issued by the university's Chief Information Security Officer (CISO).

In accordance with the university CISO's guidelines, regular checks are carried out on all institute networks to identify potential vulnerabilities. These checks serve as a starting point for the hardening measures to be implemented in order to make our networks more resistant to cyber-attacks.

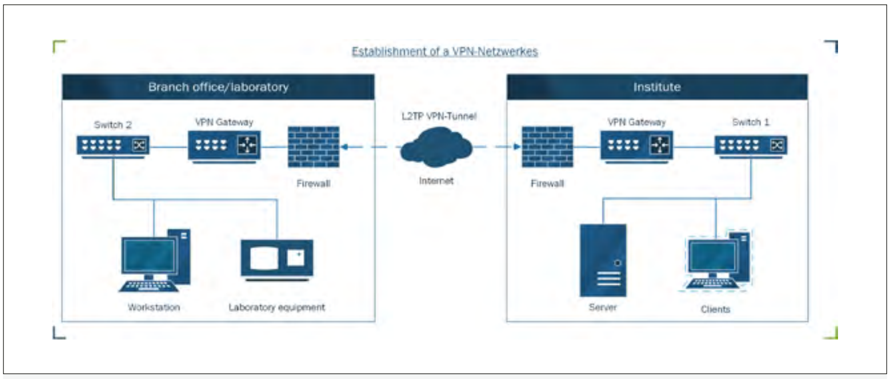
The CISO's other responsibilities include monitoring compliance with security regulations and standards. This includes, among other things, data protection regulations and the proper handling of sensitive information. We have integrated these responsibilities into our work.

Our work in the area of IT security is ongoing. We are convinced that by strictly implementing the CISO guidelines, we can improve the security of our institutional networks and create a safer digital environment for our employees and students.



CREATED IT-SUPPORT TICKETS

- Period: October 1, 2023 – March 31, 2025



SETTING UP A VPN-NETWORK

- Insight: Example of a VPN connection for external laboratory facilities


Werner-von-Siemens Centre
Experience Centre

Education

Courses

Courses: Working Group Energy Technologies

Course	Contents	Lecturer
Electrical Power Systems II	Operating principles of electrical power installations, Basic configurations of switching and transformer substations, Operating principles of switching devices, Design and equivalent circuit representation of overhead transmission lines, Operating principles of earthing systems, Configuration of selective protection schemes in power networks	Dr.-Ing. Dirk Bösche
Structure and Function of Storage Systems	Charging infrastructure, Storage characteristics, System design, Storage technologies, Double-layer capacitor, Energy storage in the form of hydrogen, Structure and operating principles of lithium-ion battery storage systems, Battery aging and diagnostics, Recycling	Dr.-Ing. Frank Lienesch
Numerical Calculation Methods	Solution of symmetric definite systems of equations, Numerical solution of first-order systems of differential equations, Numerical solution of second-order partial differential equations, Finite difference methods, Application of simulation software	Prof. Dr.-Ing. Michael Kurrat
High-Voltage Direct Current Transmission Technology	Introduction to HVDC transmission systems, Operation of LCC and VSC based HVDC systems, Main components of HVDC converter stations, Interaction between AC and DC systems, Basic principles of modeling, analysis and control of dynamic systems	Dr.-Ing. Nasser Hemdan
High Voltage Test- and Measurement Systems	Fundamental knowledge of High-Voltage and High-Current tests, Fundamental analysis of High-Voltage and High-Current test and measurement circuits, Quality assessment, Evaluation and documentation of test performance for High-Voltage components	Prof. Dr.-Ing. Michael Kurrat
Computational Methods for Electrical Engineering B	Nonlinear equations, Sequences and series, Extrema, Integral calculus, Fundamental theorem of calculus, Taylor series, Fourier series, Partial derivatives, Curves and surfaces, Vector fields, Transformation, Integral theorems	Prof. Dr.-Ing. Michael Kurrat
High-Voltage Technology 1	High-voltage networks, Overvoltages, Insulation systems, Gas discharges, Insulating materials, High-voltage direct current (HVDC) transmission	Dr.-Ing. Michael Hilbert
Electric Power Systems Engineering	Fundamental knowledge of power systems, Formulate research problems, Select adequate abstraction level, Use scientific theories and model concepts, Analyze social, economic and cultural consequences, Apply Systems Engineering for system design	Prof. Dr.-Ing. Michael Kurrat; Dr.-Ing. Melanie Hoffmann

Course	Contents	Lecturer
Design and Calculation of direct Current Systems	Calculation and design of DC networks, Operation of DC networks, Fault detection and location, Plant engineering, components for power generation, Distribution and storage, Industrial networks, Island grids, Onboard power systems	Prof. Dr.-Ing. Michael Kurrat; Prof. Dr.-Ing. Michael Terörde
Computational Methods for Electrical Engineering A	Equations and inequalities, Real and complex numbers, Vector spaces, Norm, Basis, Linear maps and matrices, Systems of linear equations, Projection, Determinants, Eigenvalues, Eigenvectors, Ordinary differential equations	Prof. Dr.-Ing. Michael Kurrat
Transmission Grid Technologies	Fundamentals of transmission networks: components, operating modes, challenges; Calculation of transmission networks: overhead lines, cables, synchronous generators, transformers; Fundamental technologies of high-voltage direct current transmission	Prof. Dr.-Ing. Michael Kurrat; Dr.-Ing. Christian Schulz

Courses: Working Group Energy Systems

Course	Contents	Lecturer
Fundamentals of Electrical Power Engineering I: High-Voltage Engineering and Power Transmission	Introduction to the fundamentals of electric power transmission and distribution, Basic principles and analysis of three-phase systems, Transformers and synchronous generators	Prof. Dr.-Ing. Bernd Engel; Prof. Dr.-Ing. Markus Henke; Prof. Dr.-Ing. Regine Mallwitz
Sustainable Energy Systems	Large-scale power plants, Solar technology, Offshore wind farms, Hydropower, Geothermal energy, Biomass, Hydrogen, Energy distribution, Systems engineering, Industry 4.0, DC industry, Grid integration of renewable energies, E-mobility, Battery storage, Sector coupling	Prof. Dr.-Ing. Bernd Engel; Prof. Dr.-Ing. Michael Kurrat
Distribution Grid Technologies	Role of distribution grids in the energy supply, Grid structures, Operating equipment (cables, overhead lines, transformers, switchgear), Protection concepts, Ancillary services, Grid charges, Future developments in the distribution grid (Smart + X)	Dr.-Ing. Johannes Schmiesing
Electrical Bus and Railroad Technology	Introduction to railway vehicle technology, National and international railway power supply systems, Drives for electric trains, Braking systems, Auxiliary power systems, Signaling and safety systems, Future developments, Contactless power transfer, Eelectric bus systems	Prof. Dr.-Ing. Bernd Engel
Renewable Energy Engineering	Fundamentals of the structure of the German and European power supply system and its components (overhead lines, cables, and transformers), Technical fundamentals of grid operation by network operators and their handling of system services	Prof. Dr.-Ing. Bernd Engel
Electrical Power Systems and Networks	Introduction to electric power supply, electrical equipment such as synchronous machines, power flow analysis and symmetrical as well as asymmetrical short-circuit calculations, stability, neutral point treatment and protective measures	Prof. Dr.-Ing. Bernd Engel

Course	Contents	Lecturer
Electrical Equipment of Rail Vehicles	Electric traction, Brakes, Auxiliary power systems, Signaling and safety systems, Control technology on rail vehicles, Passenger information and multimedia, Vehicles in service, Future developments	Prof. Dr.-Ing. Bernd Engel
Energy Economics and Market Integration of Renewable Energies	Introduction to market roles and stakeholders in the energy sector, Fundamentals of energy trading (markets, grids), Mechanisms for the integration of renewable energy into electricity markets	Prof. Dr.-Ing. Bernd Engel
System Engineering in Photovoltaics	Systems engineering perspective of photovoltaic generation plants: Plant configurations, Inverter topologies, Technical operation of grid-following inverters, Challenges in the grid integration of PV systems, Analysis of islanded power systems	Prof. Dr.-Ing. Bernd Engel
Innovative Energy Systems	Development of energy supply and climate targets, Innovations in conventional power plants, Renewable energy sources, Power-to-X, Sector coupling (transport, heat, gas), Storage systems, Use of hydrogen, Islanded grids, Prosumer households	Prof. Dr.-Ing. Bernd Engel
Electrical Power System Control	Introduction to grid control, Transmission of electrical energy, Dynamic behavior as well as frequency and voltage control of synchronous generators in power plants, Higher-level control of power grids, Control of DC systems, Converter technology, Grid-following and grid-forming converter controls	Dr.-Ing. Stefan Laudahn
Fundamentals of Electrical Power Engineering for Transportation and Environmental Engineering	Fundamentals of electric power supply, Complex AC calculations and their application in three-phase systems and network equipment, Topics in electrical safety	Prof. Dr.-Ing. Michael Terörde Prof. Dr.-Ing. Bernd Engel Prof. Dr.-Ing. Markus Henke

Seminars: For Students

Seminar	Contents	Lecturer
Advanced Seminar in Innovative Energy Systems	Lecture series and presentation training on energy technology and energy economics topics	Prof. Dr.-Ing. Bernd Engel Prof. Dr.-Ing. Michael Kurrat
Technology Assessment	Opportunities of new technologies for societal challenges, Risks and side effects of emerging technologies, Systematic analysis and assessment of their societal impacts	Prof. Dr.-Ing. Michael Kurrat Prof. Dr.-Ing. Michael Terörde Prof. Dr.-Ing. Markus Henke Prof. Dr.-Ing. Bernd Engel

Seminars: For Doctoral Students

Seminar	Contents	Lecturer
Doctoral Seminar in High-Voltage Engineering	Understanding systems thinking and system theory	Prof. Dr.-Ing. Michael Kurrat
Doctoral Seminar in Sustainable Energy Systems	Development of energy supply and climate targets, Storage systems, Hydrogen utilization	Prof. Dr.-Ing. Bernd Engel

Practical Courses

Practical Courses	Contents	Lecturer
Electric Mobility	Battery diagnostics, Electrode fabrication, Electrode packaging, Power electronics and electrical machines, drivetrain simulation	Prof. Dr.-Ing. Michael Kurrat
Innovative Energy Systems	Introduction to energy systems, Contribution of energy systems to the energy transition in prosumer households, Key components, Photovoltaic cells, PV Inverters, Off-Grid systems, Heat pumps, Energy management	Prof. Dr.-Ing. Bernd Engel
Analysis, Simulation, and Planning of Power Networks	Introduction to network modeling and calculation with DIgSILENT PowerFactory, Introduction to data processing and modeling with Python, Application of Python in energy system modeling and analysis	Prof. Dr.-Ing. Bernd Engel
Electrical Engineering Laboratory Course: Advanced Battery Technologies (eLVBatt)	Impedance spectroscopy for unstable states, Pressure distribution in LIBs, Electrode surface analysis, Explosion tests with LIBs, Simulation and modeling of batteries	Prof. Dr.-Ing. Michael Kurrat
High-Voltage Engineering	High-Voltage measurement techniques, Insulation technology, Generation of high DC and AC voltages, Lightning impulse voltage, Dielectric breakdown tests, Application of augmented reality, Switching tests of circuit breakers	Prof. Dr.-Ing. Michael Kurrat

Student Projects and Theses 2024

Student Projects

Author	Title
Abdulbaki Kocabasa	State of Charge Estimation for Lithium-ion Batteries by Using Long Short-Term Memory and Random Forest Model
Erdene Otgonpurev	Investigation of the coupling between electrochemical and thermal models for simulating the temperature distribution of a LIB
Eugen Winterfeld	Analysis of the suitability of prosumer households with their flexibly controllable systems for system services
Hannah Nowak	Potential analysis for the application-oriented multiple use of domestic battery storage systems
Idoya Fernandez-Roncal	Implementation and evaluation of variable and dynamic grid fees on the grid utility of prosumer households
Jan Ackermann	Development of a methodological approach for estimating the topology and cable routing in wind farms
Joachim Henning	Analysis of the correlation between market prices and the structure of electricity generation
Louisa Schlüer	Research on the international rollout of smart metering systems and possible implementation of energy management
Mara Luisa Hiller	Characterization of graphite in lithium-ion batteries, taking into account varying resynthesis proportions in the context of battery recycling
Tim Düwel	Development of a voltage-regulated electrolysis model for investigating dynamic power consumption

Bachelor Thesis

Author	Title
Adem Cubukcuoglu	Update and commissioning of an automated control system for a Marx generator
Antonius Holfeld	Investigation of techno-economic aspects of active power control in battery storage systems at medium voltage and upstream transformer stations
Daniel Gasek	Development of regulations for generation facilities and battery storage systems in prosumer households
David Menzel	Further development of a bidirectional optimization model for electric vehicles with regard to performance-dependent efficiency and battery aging
Jannes Hedden	Investigation of the influence of varying binder systems using symmetrical pouch cells

Author	Title
Johannes Schott	Investigation of the breakdown frequency of a ball-ball arrangement in a CO2/O2 mixture when subjected to lightning surge voltage
Johannes Wache	Investigations into the suitability of wavelet analysis for the parameterization of lithium-ion battery cell models
Jost Maenicke	Design and development of a dashboard for the public presentation of project-specific research aspects of the Hydrogen Terminal Braunschweig research project
Julia Schild	Planning, implementation, and evaluation of measurements of electric vehicles in an employee parking lot
Julius Fürst	Specification of algorithms for energy management in prosumer households
Karanbir Singh	Simulative evaluation of interharmonic harmonics and their effects on flicker values in the grid
Kerim Özdemir	Testing of 3D printing technology for the prototype production of field control rings for vacuum circuit breakers
Laura Heßler	Analysis of non-static grid fees and electricity tariffs as well as the resulting potential for multiple use of domestic battery storage systems
Lukas Heller	Exploratory evaluation of measured smart meter data and comparison with standard load profiles
Mads Burgdorf	Development of a characterization strategy for battery components using symmetrical cells
Morten Müller	Evaluation of the rollout of smart metering systems and possible communication channels for distributed energy management in an international comparison
Muhammed Öztürk	Dielectric characterization of battery separators and determination of the influence of silver conductive paint
Niklas Zawade	Development of a Monte Carlo simulation to analyze the effects of EnWG 14a on controlled charging
Oscar Steiner	Development and implementation of target cost accounting for alternatively powered agricultural machinery in German agriculture
Rika Webel	Simulative investigation of frequency determination methods
Sophie Springub	Economic analysis of instantaneous reserve provision with a battery storage system in the low-voltage grid
Stefan Winkelmann	Development of a techno-economic model for comparing grid expansion and intelligent consumption control
Steffen Clausen	Evaluation of different topologies of electrolysis rectifiers for the provision of system services

Master Thesis

Author	Title
Abbas Salamehzavareh	Analysis of partial discharge measurement at 50 Hz and in the kilohertz range on model arrangements
Ahmed Hassan	Further development of a model for the optimal dimensioning of households with prosumer system
Alexander Pagel	Optimization of the experimental strategy for cyclic cell aging phenomena considering mechanical compression
Amando Pöschl	Model-Based Systems Engineering (MBSE) with SysML and its application in the field of hybrid-electric commuter aircraft
Cedric Jackmann	Pressure-optimized formation and cyclic aging of lithium-ion pouch cells considering different separator materials
Christian Krüger	Methodical investigation of the degassing time of lithium-ion pouch cells during formation
Danièl Müller	Applicability of electrical and electrochemical characterization methods to lithium–sulfur cells with polymer-based solid electrolyte
David Cziumplik	Design and construction of an AMF contact test system for high-voltage vacuum circuit breakers
Emmanuel-Wilson Bauni Kamga	Grid integration of a 2.0 MW emergency power system into the power supply grid of VW Kraftwerk GmbH
Erdene Otgonpurev	Investigation of the parameterization of a physicochemical model according to Newman for a lithium-ion pouch cell battery
Eugenia Gelwert	Analysis of import and subsidy options for green H2 products from sun-rich countries
Gokul Gopakumar	Function development for determining the remaining capacity of a lithium iron phosphate cell for use in a battery management system
Haitian Zhao	Comparison and simulation-based evaluation of different DC/DC converter models under fault conditions using a buck topology
Haolin Guo	Development of a method for selecting a DC protection system in the NetFlexum project using MBSE
Hava Cesur	Analysis of the impact of battery storage systems on electricity costs in prosumer households: A focus on load factors and aging processes
Huanni Zhu	Model-based development of PHiL experiments for DC systems
Inken Häußler	Development of a bidirectional optimization model for the charging management of electric vehicles
Jakob Hefenbrock	Investigation of the parameterization of a physical-chemical model for a lithium-ion battery cell using three-electrode cell tests

Author	Title
Jan Ackermann	Development of a methodology for the precise prediction of electrical power and losses in wind turbines using PandaPower
Janina Gottschalk	Investigation of chemical changes in lithium-ion batteries due to contamination additives in the context of recycling
Jan-Malte Barth	Conceptualization and design of a test bench for investigating the communication compatibility of charging stations
Julian Garthoff	Investigation of pressure-optimized charging strategies for lithium-ion cells considering mechanical pressure profiles
Julius Trützschler	Development of a method for cross-process quality analysis in the congestion relief processes of German transmission system operators
Keno Giesselmann	Evaluation of grid-friendly and grid-supporting charging approaches for electric vehicles based on measurement data from a commercial vehicle fleet
Kevin Preißner	Testing the compatibility between battery storage systems and sattery inverters
Lara Prüßmeier	Development of a bidirectional charging model considering different grid conditions
Linda Bolte	Modeling of a self-commutated three-phase inverter for testing current control concepts in MATLAB Simulink
Lisa Ermer	Investigation of the influence of dynamic electricity tariffs on the multiple use of domestic battery storage systems: stakeholder analysis, conceptual design, simulation, and potential analysis
Manuel Suilmann	Development of an operating strategy for the combination of battery storage system, electrolyzer, and PV system using mathematical optimization
Marcel Bialojahn	Evaluation of the forecasting quality of different methods for load forecasting in multi-family buildings
Max Gand	Creation, simulation implementation, and validation of grid scenarios with a focus on instantaneous reserve provision
Maximilian Jantos	Detailed technical description and standardization options for systems for exponential growth in renewable energy generation, local use, and production of green hydrogen for countries in North Africa
Meike Hastedt	Optimization of balancing methods in industrial battery storage systems
Michael Schreiber	Sustainable battery storage: Creation of an optimization model for first- and second-life battery systems
Nicolas Hebeler	Laboratory implementation and testing of a bidirectional test setup for electric vehicles
Nils Osterkamp	Further development of a self-learning reactive power control system in active reactive power management

Author	Title
Peter-Matthias Reimers	Design, analysis, and evaluation of charging infrastructure for battery electric multiple units using the example of Goslar and Bad Harzburg
Qianyu Wu	Grid forming wind farm converter controllability fault ride through study with participation of HVDC
Qincheng Yang	Development of a methodolgy of preference ranking methods for selecting a dc protection system in the ethan project using MBSE
Ramona Hilse	Technical and economic analysis of local and central strategies for phase-accurate charging of electric vehicles in low-voltage grids
Rika Webel	Simulative investigation of frequency determination methods
Shubham Kumar	Metrological investigation of the reconsolidation properties of alternative extinguishing gases for high-voltage switchgear
Siyuan Chen	Simulating and characterizing battery aging in battery storage systems for enhanced prosumer optimization considering wear costs
Stefan Klöpping	Design and construction of a laboratory inverter for prospective use as a functional model for novel power converter control systems
Stefanie Schürmann	Investigation of lithium-ion cells as a function of cell size and impurity additives
Steffen Viere	Modeling and analysis of the electrical energy requirements of irrigation systems
Tianjiao Jiang	Potential analysis for user-based multiple use of battery storage systems and electric vehicles
Timo Jelden	Development and experimental validation of protection concepts for DC faults in HVDC systems
Timo Prescher	Implementation of data-driven analysis and evaluation for real reactive power management in the distribution grid
Tobias Jesberger	Dielectric investigation of the external flashover mechanism of a vacuum circuit breaker using breakdown current measurement
William Kusno	Development of a GIS-based methodology for estimating reactive power potentials and losses in PV systems
Xuan Thien Le	Development of an adaptive energy management strategy to account for uncertainties
Yuhe Niu	Theoretical investigations of a physical-chemical lithium-ion battery cell model with sensitivity analysis to evaluate the influence of parameters during fast charging
Zhimin Wei	Detection and simulation of safety-relevant battery cell faults in electric vehicles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Student Projects and Theses 2025

Student Projects

Author	Titel
Jonas Schenk	Assessment of the energy industry integration possibilities of electrolysers and battery storage systems for energy flexibility, taking into account regulatory framework conditions for sustainable green energy storage
Julian Bär	Regionalized potential analysis of instantaneous reserve provision from battery storage systems
Lea Schultz	Investigation of the influence of the solder seam of internal shields on the electrical strength of vacuum circuit breakers
Lenja Ottenhues	Implementation and simulation-based evaluation of variable grid fees for prosumer households in terms of grid utility and economic efficiency
Lennart Jantzen	Hotspot and vulnerability analysis of a medium-voltage switchgear
Malte Gramzow	Model structures for mapping the frequency-dependent behavior of grid-forming inverters
Marvin Bückers	Investigation of the influence of various parameters on the electrical strength of a quasi-homogeneous arrangement under AC loading

Bachelor Thesis

Author	Title
Constantin von Lützow	Investigation of the grid impacts of profit-optimized domestic battery storage systems
Harm Weyberg	Development and evaluation of operating strategies for providing instantaneous reserve capacity with a battery storage system in the low-voltage network
Jan Philip Richter	Further development and expansion of a database for the use of coherent time series
Jonas Keppeler	Design of a battery storage system model and evaluation of the dynamic limits of the system in terms of providing instantaneous reserve
Juan Carlos Fleischhauer González	Investigation of the external electrical strength of a vacuum circuit breaker with variation of the contact gap
Justus Elte	Determination of the lightning impulse withstand voltage of a vacuum test vessel
Kiron Islam	Development of a consistent database for energy management

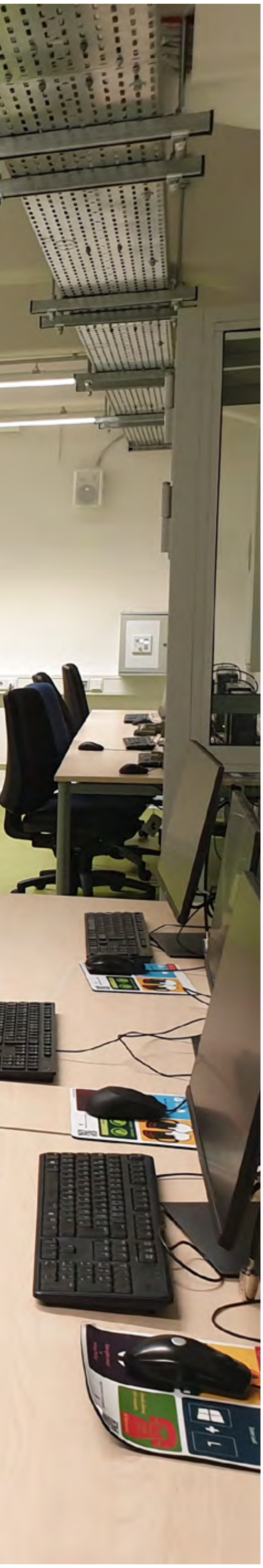
Author	Title
Lars Kisser	Evaluation of the potential of different types and topologies of electrolysis rectifiers in terms of their suitability for the power grid and processes
Mahmud Akbari	Commissioning of a vacuum test vessel for determining electrical strength in a vacuum
Manuel Meinecke	Investigation of separator-dependent forming strategies for pouch cells using pressure profiles
Matteo Weinrich	Analysis of the impact of tariff level changes in the smart meter gateway on HEMS optimization results
Nina Victor	Potential analysis of the profit-driven multiple use of domestic battery storage systems
Sophie Springub	Economic analysis of instantaneous reserve provision with a battery storage system in the low-voltage grid
Tim Beuchel	Research and analysis of market-based forms of procuring momentary reserves in other countries and investigation of their transferability to Germany

Master Thesis

Author	Titel
Andreas Laufer	Model-based analysis of separator compression resistance and its influence on lithium-ion cell performance
Artur Schmidt	Conceptualization of a system implementation and potential analysis of bidirectional charging in commercial fleet applications
Carolin Stützer	Development and testing of a tool for automated parameterization of PowerFactory network models
Constantin Carolus	Strategic analysis of grid expansion and resulting investment requirements in the medium- and low-voltage grid in Weiden in the context of the requirements of the accelerated energy transition
Elias Oppermann	Evaluation of the forecasting accuracy of various methods for PV generation forecasting at the prosumer level
Franklin Brice Kuipou	Dynamic modeling of fuses and investigation of behavior in future low-voltage networks
Haonan Gu	Circuit design for high-frequency high-voltage generation
Harun Al-Sarea	Analysis and modeling of contact losses in medium-voltage switchgear, taking various influencing factors into account
Jonas Keppeler	Design of a battery storage system model and evaluation of the dynamic limits of the system in terms of providing instantaneous reserve

Author	Titel
Kai Schulze	Investigation of the external electrical strength of a vacuum circuit breaker with varying internal shields
Klaas Koring	Investigation and improvement of a distribution function for active power operating points of offshore wind farms when operating on a redundant grid connection system
Konstantin Wenzlaff	Analysis and evaluation of decentralized heat supply in households using hybrid heat pumps
Kristin Köser	Economic evaluation of the synergy potential of a hybrid battery storage electrolyzer project
Lisa Ermer	Investigation of the influence of dynamic electricity tariffs on the multiple use of domestic battery storage systems: stakeholder analysis, conceptual design, simulation, and potential analysis
Liu Kaiyu	Planning and preparation of tests for various fault conditions in a DC model network using DoE as part of the SMS-II project
Louisa Schlüer	Further development of a dimensioning model for energy systems in residential buildings and analysis of significant influencing parameters
Mara Luisa Hiller	Methodological investigation of a characterization strategy for anode-side coating components for lithium-ion cells
Maximilian Schultz	Technical and economic analysis of the star point treatment of 20 kV networks within Braunschweig
Mi Zhang	Comparison and simulation-based evaluation of methods for controlling current limitation in the event of a fault using the example of buck topology
Nan Dong	Correlation studies between different setting parameters of the electrochemical impedance spectroscopy and the obtained impedance spectra
Qie Yixuan	Investigation of the pressure-dependent cell performance of lithium-ion cells and parameterization of a pressure-dependent EECM model
Shiyuan Wang	Literature-based data collection and processing of components and systems in onboard electrical network
Shridhar Paramesh	Investigation of calendar and cyclic aging of sodium-ion cells and modeling of cell behavior
Stefan Gosling	Optimization of the energy supply system at the Steinhof wastewater treatment plant from a financial perspective
Steffen Bollhorn	Techno-economic analysis of suitable voltage levels for the provision of instantaneous reserve from battery storage systems
Thorben Wehmeier	Development and optimization of marketing strategies for battery storage systems on the balancing energy and spot markets
Timon Justi	Evaluation of the accuracy of different methods for forecasting the electrical demand of heat pumps at the prosumer level

Author	Titel
Xue Weisheng	Investigation of surface discharges on insulating materials
Yanan Huang	Design of a high-frequency high-voltage generator for dielectric testing of insulating materials used in electric mobility
Yasmin Ahmed	Conceptualization, implementation, and simulation-based evaluation of a minimally invasive control system at the low-voltage level
Yida Li	Partial discharge investigations on 3D-printed insulating materials for use in electromobility
Yongming Wang	Classification and Simulative Evaluation of Non-Isolated, Current-Limiting DC/DC Converter Topologies Based on Their Fault Behavior
Yuanye Zhang	Design of control and protection for a DC/DC converter as part of the NetFlexum research project



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Meyer, T.; Gentsch, D.; Kurrat, M.
Vacuum Contacts: Analysing Contact Lifespan for Enhanced Performance in Grids
28TH CONFERENCE AND EXHIBITION ON ELECTRICITY DISTRIBUTION (CIRED), GENF, SCHWEIZ, 16.–19.06.2025

Events 2024

Prof. Dr.-Ing. Michael Kurrat

17.01.2024
New year reception of VDE Braunschweig, Braunschweig

22.01.–23.01.2024
ETG Q2 Higher utilization of resources, Nuremberg

29.01.2024
Cleaning day elenia – Lab inventory

08.02.2024
Research exchange TU Darmstadt, Darmstadt

05.–06.02.2024
Inter-oPEn kickoff in Aachen

27.02.2024
Exchange of experiences of low voltage labs, Leipzig

06.03.2024
Feedback discussionsof DC-Team at PTB

13.03.2024
Biannual ICA-C Meeting 2024, Hannover

19.03.–20.03.2024
Excursion to Temes engineering in Otterfing

10.04.–11.04.2024
Advanced Battery Power, Münster

11.–12.04.2024
VDE Distribution grid meeting in Görlitz

18.04.2024
Doctoral student day

24.04.–26.04.2024
Research exchange TU Darmstadt and measurement campaign, Darmstadt

25.04.2024
Visit to Hanover Fair

25.04.2024
Zukunftstag

13.05.–15.05.2024
Switchgear testing in external test field for Pfiffner

14.05.–15.05.2024
DKE K124 meeting, Bonn

16.05.2024
Invitation for barbecue: Students & Profs in professional exchange

22.05.–24.05.2024
Pentecost excursion

22.05.–23.05.2024
Visiting Infineon for follow-up project

24.05.2024
CZC-Meeting, Ratingen

31.05.2024
Dissertation Philipp Adler – Second examiner

04.06.–05.06.2024
Research exchange TU Ilmenau, Ilmenau

06.06.–17.06.2024
Ideenexpo Hannover

07.06.2024
VDE Hansetag, Bremen

08.–16.06.2024
IdeenExpo, Hannover

13.06.2024
Exchange of experiences Profs Faculty 5

19.06.–20.06.2024
University development days 2024, TU Braunschweig

30.06.–04.07.2024
ICD International Conference on Dielectrics, Toulouse, France

04.–05.07.2024
Project meeting with cooperation partner ABB, Braunschweig

18.07.–19.07.2024
Research exchange with INP Greifswald, Braunschweig

06.08.–08.08.204
Project meeting with cooperation partner Pfiffner, Switzerland

12.08.2024
Tenure Track Kommission

13.08.2024
Company outing 2024

19.08.–22.08.2024
ICHVE International Conference on High Voltage Engineering, Berlin

28.–30.08.2024
9th ITG International Vacuum Electronics Workshop (IVEW) 2024, Bad Honnef

16.–17.09.2024
NEIS Conference

16.09.–18.09.2024
AG ET Workshop in Utecht

23.09–24.09.2024
Project meeting GreEner Tech, Wuppertal

23.09.–24.09.2024
Closed meeting EITP, Ilsenburg

25.09.–26.09.2024
Joint measurement campaign mit ABB

27.09.2024
Highlights of Physics – Raft trip, Hannover

01.10.2024
GIS-Application Forum

Prof. Dr.-Ing. Bernd Engel

06.10.2024
Tenure Track Commission

11.10.2024
BMBF-Joining forces to increase security in international research cooperation, Berlin

14.10.2024
Visit of representatives of Hyosung

16.10.2024
Cooperation agreement Faculty 5 with research institute KERI (South Korea)

22.10.–23.10.2024
NFF Workshop

24.10.–25.10.2024
Closed meeting "Future cities" Königslutter, research focus TU BS

30.10.2024
Faculty development meeting with presidium

05.11.2024
VDE-board and advisory board meeting PTB

11.11.–13.11.2024
Leadership of the VDE Hight voltage technology, Berlin

18.11.–22.11.2024
Measurement campaign INP

27.11.–29.11.2024
IBPC, Braunschweig

29.11.2024
Climate Foundation Ideas Competition, Stuttgart

03.12.–04.12.2024
Meeting HTSL- Research field for high-temperature superconductors, Munich

12.12.2024
Meeting BMBF AG1 security in research

17.01.2024
New year reception of VDE Braunschweig, Braunschweig

19.01.2024
Excursion SMA

24.01.–25.01.2024
Meeting future grids

05.03.–06.03.2024
Strategy workshop EFZN, Goslar

13.03.2024
Status conference energy grids Thuringia, Erfurt

08.04.2024
Dissertation Malte Schäfer – Second examiner

18.04.2024
BMWK Roadmap Sysstab.

25.04.2024
VDE FNN Forum, Berlin

15.05.–16.05.2024
Göttinger energy meeting

05.06.2024
Excursion Alstom, Salzgitter

06.06.–07.06.2024
FNN support group meeting, Berlin

18.06.2024
Inauguration H2-Terminal, Braunschweig

19.06.2024
BMWK meeting forum system stability, Berlin

26.06.2024
Kick-Off-meeting-PICNIC, Braunschweig

27.06.–28.06.2024
PV-Symposium advisory board meeting, Stuttgart

02.07.–03.07.2024
Kick-Off-Consortium meeting SysStab2030, Dortmund

17.07.2024
Pfendler – Second examiner

23.09.–24.09.2024
Closed meeting EITP, Ilsenburg

25.09.2024
VDE FNN-grid camp, Leipzig

07.10.–11.10.2024
Grid Integration Week, Helsinki

14.10.–15.10.2024
Kick-Off-meeting TEN.efzn, Hannover

29.10.2024
Shridar Balasubramanian – Chairmanship

07.11.2024
Excursion Landwind, Wolfenbüttel

13.11.–14.11.2024
Final meeting EU-Forschungsprojekt ALPHEUS, Brussels

18.11.–19.11.2024
Lower Saxony energy days, Hannover

22.11.2024
C2T Kick-Off-Workshop, Braunschweig

26.11.–27.11.2024
Project meeting PICNIC, Ettlingen

29.11.2024
Consortium meeting distribution grid 2030plus, Kassel

Events 2025

Prof. Dr.-Ing. Michael Kurrat

15.01.–16.01.2025
Prosecco workshop in Leuven

20.01.–24.01.2025
Measurement campaign TU Darmstadt, Darmstadt

22.01.2025
New year reception of VDE Braunschweig, Braunschweig

05.02.–06.02.2025
Meeting of ETG Vorstand and scientific advisory board, Regensburg

18.03.–19.03.2025
Project meeting GreEner Tech, Braunschweig

18.03.–20.03.2025
AG ET-Workshop, Bad Harzburg

31.03.–01.04.2025
NFF-Strategy workshop, Ilsenburg

31.03.–04.04.2025
EPE-Konferenz in Paris

01.04.–03.04.2025
Power station battery

03.04.–04.04.2025
Leadership of ETG Q2 High Voltage Engineering meeting, Köln

03.04.2025
Zukunftstag

10.04.–11.04.2025
2. DC distribution grid meeting in Görlitz

28.04.–29.04.2025
Project meeting with cooperation partner Pfiffner, Braunschweig

06.05–09.05.2025
Inter-oPEn kick off & Training modules RWTH Aachen

08.05.2025
PCIM Ausstellung in Nürnberg

12.05.2025
Dissertation Timo Meyer – First examiner

13.05.–14.05.2025
Meeting BK W3 “Electric energy supply and sustainable energy systems”, Chemnitz

20.–21.05.25
Research exchange with TU Ilmenau in Braunschweig

21.05–22.05.2025
ETG Congress 2025, Kassel

01.06.–06.06.2025
MeVArc - Mechanisms of Vacuum Arcs, Sweden

02.06.2025
NES-Excursion to Enercity, Hannover

05.06.2025
Invitation for barbicue: Students & Profs in professional exchange

10.06.–11.06.2025
Prosecco workshop in Braunschweig

10.06.–12.06.2025
Pentecost excursion, Berlin

11.06.2025
Authorities relay marathon

13.06.2025
38th Current Zero Club Plenary Meeting, Online

17.06.–18.06.2025
Inter-oPEn workshop “legal aspect of HVDC” RUG Groningen

21.06.2025
Campus Xperience

26.06.2025
Summer Festival of faculty

30.06.–03.07.2025
PowerTech 2025 Conference in Kiel

07.07.–08.07 2025
HVDC TT workshop TUBS

08.07.–09.07.2025
Meeting of appointment committee W3 “Electromagnetic compatibility and resillience”, Brunswick

22.07.2025
Dissertation Marc René Lotz – First examiner

12.08.2025
Company outing, 2025

18.08.2025
KERI- Visit of research institute, South Korea

24.08.–29.08.2025
ISH- International Symposium on High Voltage Engineering, Japan

09.09.–11.09.2025
AG ET-Workshop, Bremen

17.–18.09.2025
Hyosung & KERI - visit research institute & research facility , Südkorea

21.–26.09.2025
ISDEIV- International Symposium on Discharge and Electrical Insulation in Vacuum, China

Prof. Dr.-Ing. Bernd Engel

23.09.2025
GIS-application forum

01.10.–02.10.2025
100-year celebration elenia institute

07.10.–09.10.2025
Closed meeting EITP, Ilsenburg

08.10.–10.10.2025
IEEE PESS 2025

15.10.2025
Opening Ceremony of Hyosung Heavy Industries R&D Center Arnhem

05.11.–06.11.25
IBPC, Brauschweig

11.11.–12.11.25
High voltage days Berlin

25.11.2025
Meeting ETGboard and scientific advisory board, Aachen

23.01.2025
New year reception of VDE Braunschweig, Braunschweig

29.01.–30.01.2025
Meeting future grids

17.02.2025
Kick-Off Joint projects GFI-Pilot Erfurt

04.03.–05.03.2025
EFZN closed meeting, Goslar

07.03.2025
Visit of H2-Termial consortium at PTB, Braunschweig

10.03.–13.03.2025
PV-Symposium, monastery Banz

17.03.2025
Consortium meeting SysStab2030, Stuttgart

19.03.2025
Final event DigENet I BMWK, Berlin

20.03.2025
Final meeting SiNED, Braunschweig

26.03.2025
Round table electromobility BS-Energy

31.03.–01.04.2024
NFF-Strategy workshop, Ilsenburg

03.04.2025
Zukunftstag

23.04.2025
Greeting of new deans of studies

05.05.2025
FNN-Forum, Berlin

09.05.2025
Plenary assembly faculty day, Kassel

13.05.–14.05.2025
Göttinger energy days

20.05.2025
Grid Forming Seminar AVACON

21.05.–22.05.2025
ETG-Kongress, Kassel

22.05.–23.05.2025
FNN Supporters' meeting, Berlin

26.05.–27.05.2025
Consortium meeting NetFlexum PTB, Braunschweig

17.06.2025
Workshop BS-Netz

21.06.2025
Open house H2 Terminal

19.08.–21.08.2025
AG ES-closed meeting

02.09.–03.09.2025
Meeting of the scientific advisory board of PTB "Metrologie der Energiewende"

01.10.–02.10.2025
100-year celebration elenia institute

06.10.–10.10.2025
Grid Integration Week, Berlin

15.10.–16.10.2025
100-year celebration elenia institute

Academic Self-Governance 2024

University

MICHAEL KURRAT

- **Deanery meeting**
  10.02. | 15.02. | 31.05. |
- **Deanery**
  15.02. | 17.03. | 06.06. | 22.09. |
- **BMBF-Research security (FoSi)**
- **Ethic-Commission**
  15.03. | 25.09. | 29.10. |

BERND ENGEL

- **Energy Advisory Board**
  09.03. |
- **AG Sustainability**
  11.01. | 20.01. | 17.02. | 17.03. | 21.04. | 12.05. | 16.06. | 07.07. | 25.08. | 22.09. | 02.11. | 12.12. |

Faculty

MICHAEL KURRAT

- **Specialist representative meetings (FVV)**
  19.01. | 16.02. | 14.06. | 26.07. | 18.10. | 09.12. |
- **Faculty Council meeting (FKR) / Special FKR**
  22.01. | 19.02. | 22.04. | 13.05. | 17.06. | 29.07. | 16.09. | 21.10. | 18.11. | 13.12. | 16.12. |
- **Faculty Council meeting (Committees) unscheduled**
  03.02. |
- **Planning round EITP**
  02.02. | 17.05. | 05.07. | 30.09. |
- **Faculty Council EITP**

BERND ENGEL

- **Specialist representative meetings (FVV)**
- **Faculty Council meeting**
  24.01. |
- **Study Commission ET/WIING-ET/ NEEMO/ELSY/EMOB**
  10.01. | 28.09. | 13.12. |
- **Audit Committee ET/EMOB/ELSY/ NEEMO/QTEC**

elenia Institute

MICHAEL KURRAT

- **Managing Director**
- **Institute round (Board of Directors)**
  Ongoing – monthly
- **Board round elenia**
  20.02. | 19.03. | 29.05. | 17.06. | 15.07. | 19.09. | 29.10. | 19.11. |
- **Status meeting (Employee meeting)**
  Ongoing – monthly
- **Project Management Office**
  Ongoing – as required
- **Team leader meeting AG Energy technologies**
  Ongoing – monthly
- **Novice group (Doctoral seminar)**
  Ongoing – monthly
- **Mentor meetings**
  29.05. |
- **Mentor group**
  Once per semester
- **Student Colloquium**
  Ongoing – weekly
- **Freshmen welcome**
- 24.10. |

BERND ENGEL

- **Institute round (Board of Directors)**
  Ongoing – monthly
- **Board round elenia**
  31.01. | 14.02. | 16.05. | 13.06. | 16.06. | 11.07. | 17.10. | 14.11. | 12.12. |
- **Status meeting (Employee meeting)**
  Ongoing – monthly
- **Project Management Office**
  Ongoing – as required
- **Team leader meeting AG Energy technologies**
  Ongoing – monthly
- **Mentor meetings**
- **Mentor group**
  Once per semester
- **Student Colloquium**
  Ongoing – weekly

Academic Self-Governance 2025

University

MICHAEL KURRAT

- **Ethic-Commission**
- **BMBF-Research security (FoSi)**
  28.05. | 17.06.–18.06. |
- **Appointment Committee W3 Thermodynamics, BS**
  26.02.–28.02. |
- **Appointment Committee W3-Electrical power supply and sustainable energy systems, Chemnitz**
  13.05.–14.05. |
- **Appointment Committee W3 Electrochemistry, BS**
  21.02. |

BERND ENGEL

- **Energy Advisory Board**
  27.04. | 06.12. |
- **AG Sustainability**
  23.01. | 20.02. | 12.04. | 13.06. | 01.11. |

Faculty

MICHAEL KURRAT

- **Specialist representative meetings (FVV)**
  24.01. | 21.02. | 21.03. | 25.04. | 16.05. | 13.06. | 11.07. | 15.08. | 12.09. |
- **Specialist representative meetings Teaching and study (FVV-Lehre)**
  19.02. | 11.03. | 23.04. |
- **Faculty Council meeting (FKR)**
  27.01. | 24.03. | 28.04. | 19.05. | 16.06. | 14.07. | 18.08. | 15.09. | 20.10. | 17.11. | 15.12. |
- **Appointment Committee W3 EMV**
  04.03. | 08.07.–09.07. |

BERND ENGEL

- **Specialist representative meetings (FVV)**
  20.01. | 16.06. | 12.07. | 18.07. | 22.09 |
- **Faculty Council meeting**
  24.07. |
- **Study Commission ET/WIING-ET/ NEEMO/ELSY/EMOB**
  22.02. | 08.05. |
- **Examination Board ET/EMOB/ ELSY/NEEMO/QTEC**
- **Specialist representative meetings (FVV)**
  24.01. | 21.02. | 21.03. | 25.04. | 16.05. | 13.06. | 11.07. | 15.08. | 12.09. |
- **Dean of Studies since 04/2025**
  Ongoing – monthly

elenia Institute

MICHAEL KURRAT

- **Managing Director**
- **Institute round (Board of Directors)**
  Ongoing – monthly
- **Board round elenia**
  24.01. | 18.02. | 25.03. | 22.04. | 26.05. | 19.06. | 17.07. |
- **Status meeting (Employee meeting)**
  Ongoing – monthly
- **Project Management Office**
  Ongoing – as required
- **Team leader meeting AG Energy technologies**
  Ongoing – monthly
- **Novice group (Doctoral seminar)**
  Ongoing – monthly
- **Mentor meetings**
  13.01. | 11.02. | 23.06. | 17.07. |
- **Mentor group**
  Once per semester
- **Student Colloquium**
  Ongoing – weekly

BERND ENGEL

- **Institute round (Board of Directors)**
  Ongoing – monthly
- **Board round elenia**
  24.01. | 18.02. | 25.03. | 22.04. | 26.05. | 19.06 | 17.07. |
- **Status meeting (Employee meeting)**
  Ongoing – monthly
- **Project Management Office**
  Ongoing – as required
- **Team leader meeting AG Energy technologies**
  Ongoing – monthly
- **Mentor meetings**
- **Mentor group**
  Once per semester
- **Student Colloquium**
  Ongoing – weekly

Imprint

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