FGE FORSCHUNGSGESELLSCHAFT ENERGIE

Annual Report 2020

Aachener Beiträge zur Energieversorgung
Band 198

IAEW High Voltage Equipment & Grids, Digitalization & Energy Economics

RWTH AACHEN UNIVERSITY

FORSCHUNGSGESELLSCHAFT ENERGIE

Annual Report 2020

Aachener Beiträge zur Energieversorgung
Band 198

IAEW High Voltage Equipment & Grids, Digitalization & Energy Economics | RWTH AACHEN UNIVERSITY

Dear Friends of the Institute, Dear FGE Members, Ladies and Gentlemen,

I am pleased to be able to present to you with this report an overview of the developments of the IAEW in the past year. For our Institute, 2019 has seen fundamental changes. Under the umbrella of the IAEW, which is now called Institute for High Voltage Equipment and Grids, Digitalization and Energy Economics. The three chairs will cooperate with each other. The new structure provides for a Chair for High Voltage Equipment and Technology, a Chair for Active Energy Distribution Grids and my Chair for Transmission Grids and Energy Economics. The appointment procedures for the first two professorships are currently underway. I will serve as acting head of these chairs until they are filled. We have every reason to hope that the appointments will be completed this year. The new structure will thus include the chairs of the former Institutes for High Voltage Technology as well as for Power Systems and Power Economics.

In the new IAEW, interdisciplinary and cross-topic research questions, such as the joint consideration of components and systems, transmission and distribution networks, and technology and economics, can be dealt with on an inter-departmental basis. The institute's research spectrum also includes questions relating to the electricity system, other grid-bound energy systems, and primary and secondary technology, which is becoming increasingly important in the course of digitalization. The main focus of the inter-departmental cooperation will be on fields of competence in which we jointly pursue questions of asset management, protection and stability as well as flexibility coordination. In addition to extensive digital simulation possibilities, test and inspection laboratories with a total space of more than 3000 m² are also available for this purpose.

In addition, we rely on increased cooperation with our partners within RWTH Aachen University. For example, the Automation of Complex Power Systems chair of my colleague, Prof. Dr. Antonello Monti, will become an associated chair at the IAEW. We are also cooperating closely with the Research Association for Electrical Systems and Power Economics (FGH e. V.) and the Fraunhofer Institute for Applied Information Technology. Together with the latter, RWTH Aachen University established in April 2020 the Fraunhofer Center Digital Energy in Aachen, in which the IAEW, and especially the professorship for Active Energy Distribution Grids, will be involved.

Our research projects are developed in close cooperation with practical applications, in particular with the member companies of the Forschungsgesellschaft Energie (FGE e. V.), with ministries and regulatory authorities in Germany and abroad, and with the European energy industry. Together with our research partners, we were again able to acquire a number of research projects in the reporting period. These will be discussed in detail in this annual report.

We were also able to expand our teaching activities. We offer our students 24 courses relating to the IAEW's expanded range of topics. In addition to the purely subject-related events for students, the colloquia, seminars and conferences that we offer in cooperation with FGE for students and the professional public are particularly well received. Especially the exchange with practitioners on the topics of the energy industry enables a profitable interlocking of teaching and practice for our students.

In 2019, a total of 77 students will have successfully completed their bachelor's thesis, 115 students their master's thesis and 14 doctoral candidates their dissertation at the IAEW. Christina Brantl, Nicolas Thie, Raphael Houben, Lukas Löhr and Maximilian Borning have also received awards from renowned institutions for their research work. These results show the high level of scientific excellence achieved by our employees. I would like to take this opportunity to congratulate them once again and to thank them for their dedication.

Professor Dietmar Meurer, who had successfully given the lecture "Power Cable Engineering" since 2002, ended his teaching activities last winter semester. My special thanks go to him for his great commitment to the education of students. Mr. Bernd Seiler, of our electrical and electronics department, retired after eleven years at the Institute. I would also like to thank him for his work over the past years.

The past year was also marked by two outstanding events, the FGE conference of the Forschungsgesellschaft Energie and the High Voltage Technology Colloquium in honor of the emeritus colleagues, Prof. Dr. Gerhard Pietsch and Prof. Dr. Klaus Möller.

Finally, I would like to commemorate my predecessor and doctoral supervisor, Prof. Dr. Hans-Jürgen Haubrich, who passed away unexpectedly last July. He had a great influence on the Forschungsgesellschaft Energie e.V. (FGE) as well as the Institute of Power Systems and Power Economics. We will honor his memory.

With kind regards

Your

Univ.-Prof. Dr.-Ing. Albert Moser

Content

FGE and IAEW Brief Profile


FORSCHUNGSGESELLSCHAFT
ENERGIE

Research Focus/ Organizational Structure

IAEW Research Focus

Following the reorientation of electrical energy research at RWTH Aachen University, three chairs now cooperate with each other in the IAEW: The Chair for High Voltage Equipment and Technology, the Chair for Transmission Grids and Energy Economics and the Chair for Active Energy Distribution Grids. The pooling of energy technology teaching and research resources opens up an enormous potential for advancing the challenging tasks of energy system transformation from an interdisciplinary and systemic perspective. We are thus in a position to address and answer questions from the energy and network industry ranging from materials and components through fundamental energy system analyses to concepts of digitalization and sector coupling at all network levels in an integrated manner. In addition, the interdisciplinary integration of the chairs broadens the range of solutions that the IAEW can offer.

Our vision is to research solutions for the energy system transformation – from materials and components to the digitalized energy system from technical, economic and regulatory perspectives.

The Chair for High Voltage Equipment and Technology pursues in particular research into

- new types of voltage loads
- environmentally friendly switchgear
- cable and overhead line technologies
- DC technologies and protection concepts
- the integration of DC systems into existing AC grid structures

The Chair for Transmission Grids and Energy Economics deals with

- the operation and planning of future energy systems under consideration of sector coupling
- the simulation and design of energy markets
- the study of security of supply and system stability

The Chair for Active Energy Distribution Grids focuses on the following main topics:

- planning and operation of energy distribution networks
- coordination of decentralized flexibility in local markets and neighborhoods
- development of digitalization and cyber security concepts for energy systems
- development of innovative protection concepts and stability studies

The chapters on the individual chairs provide a more detailed description of their respective research topics. In order to also promote the exchange of staff across the chairs as well as content and methodology synergies, the competence areas Asset Management, Flexibility Coordination and Protection & Stability have been established. These areas of competence hold interdisciplinary workshops, prepare dissertations conduct joint studies.

The interlocking of the chairs in terms of content is promoted by the joint management of the Institute. Furthermore, joint use of the administrative infrastructure results in a variety of synergy effects. The IAEW can be described in organizational terms as follows:

Organization Chart IAEW

December 31, 2019

Director of the Institute
Univ.-Prof. Dr.-Ing. Albert Moser, tbd, tbd

	tbd	Univ.-Prof. Dr.-Ing. Albert Moser	tbd	
Administration	**Chair for High Voltage Equipment and Technology**	**Chair for Transmission Grids and Energy Economics**	**Chair for Active Energy Distribution Grids**	
Institute Management Dr. Regina Oertel	**Academic Director** Dr.-Ing. Ralf Puffer **Chief Engineer** Marvin Bendig, M.Sc.	**Chief Engineers** Dr.-Ing. Philipp Baumanns André Hoffrichter, M.Sc.	**Chief Engineers** Dr.-Ing. Denis vom Stein Maria Vasconcelos, M.Sc.	**Coordination FHG-RWTH** Dr.-Ing. Michael Andres
Technical Offices and Administration Dipl.-Betriebsw. Norbert Horndt	**Insulation Systems** Bastian Soppe, M.Sc.	**Energy System Planning** Patrick Larscheid, M.Sc.	**Energy Distribution Grid Planning** Jens Priebe, M.Sc.	
	Primary Technology & Diagnostics Dr.-Ing. Tobias Frehn	**Power System Operation** Patrick Schultheis, M.Sc.	**Energy Distribution Grid Operation & Digitalisation** Thomas Offergeld, M.Sc.	
	DC-Systems Philipp Ruffing, M.Sc.	**Energy Markets** Lara Lück, M.Sc.	**Distributed Flexibility** Wilhelm Cramer, M.Sc.	
		System Stability Carola Cieslak, M.Sc.	**Stability in Energy Distribution Grids** Dominik Willenberg, M.Sc.	

Area of Expertise **Asset Management**

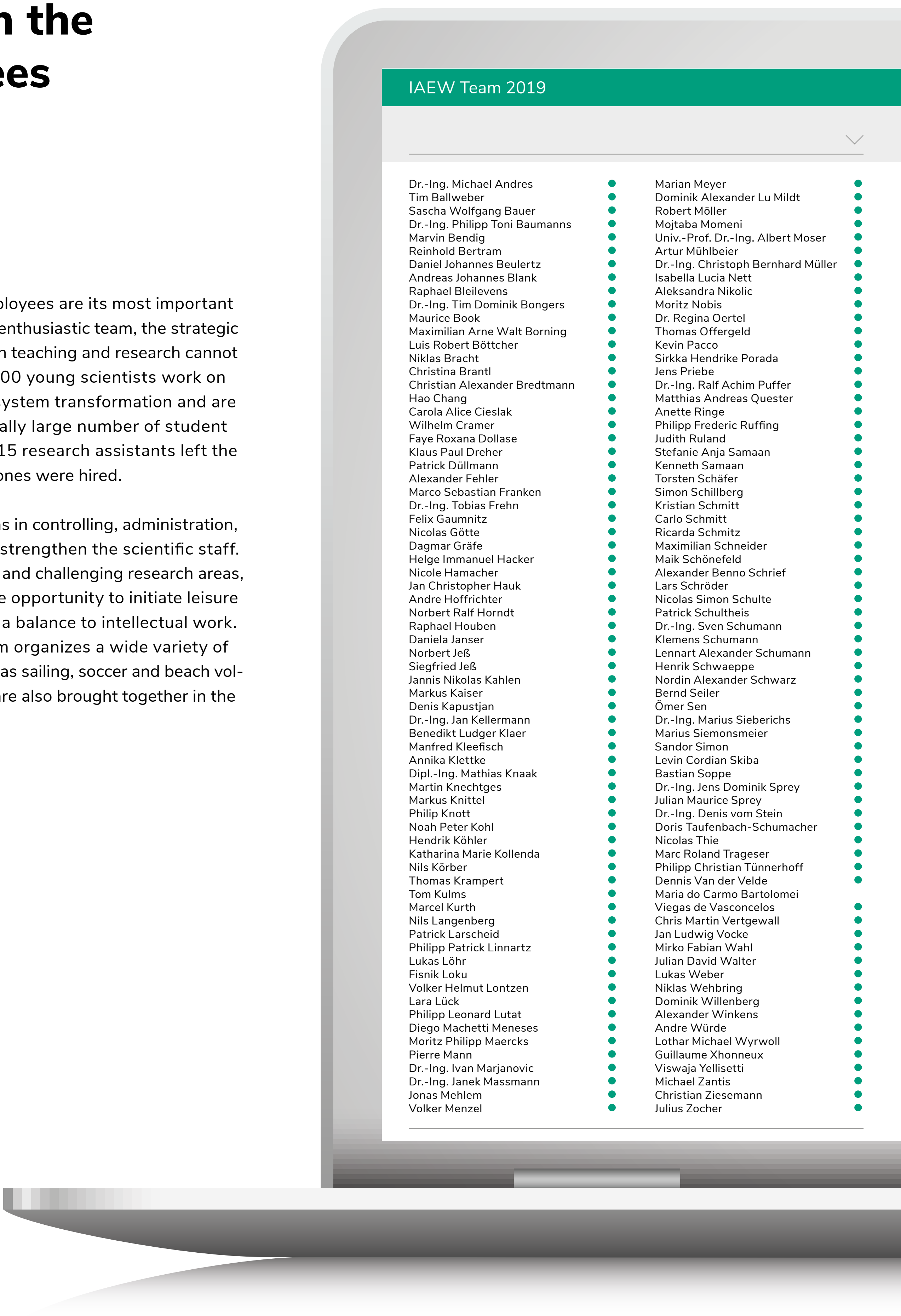
Area of Expertise **Flexibility Coordination**

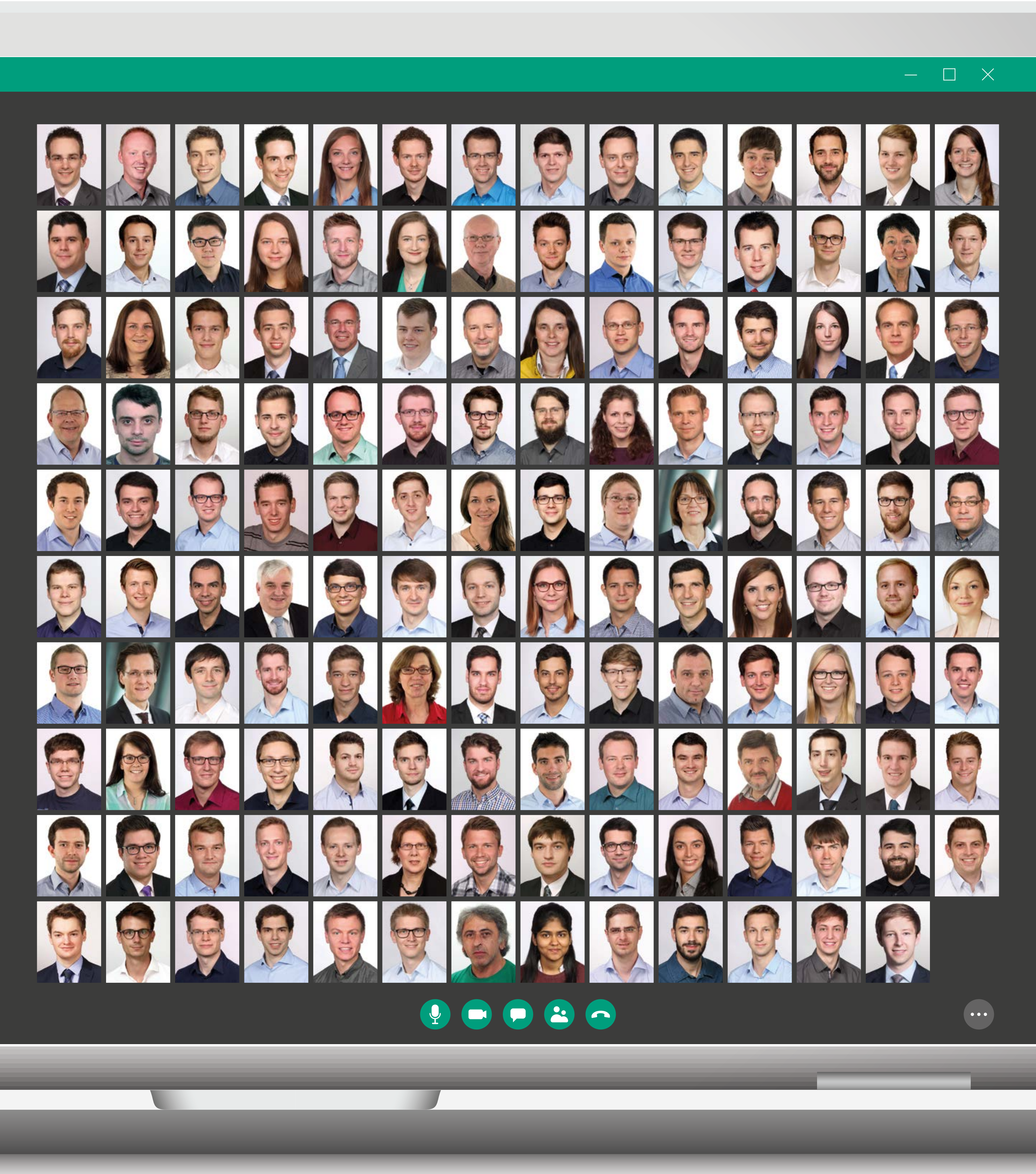
Area of Expertise **Protection and Stability**

Focus on the Employees

For the IAEW, its employees are its most important resource. Without an enthusiastic team, the strategic goals of the Institute in teaching and research cannot be achieved. About 100 young scientists work on solutions for energy system transformation and are supported by an equally large number of student employees. In 2019, 15 research assistants left the Institute and 15 new ones were hired.

The experienced teams in controlling, administration, IT and the workshop strengthen the scientific staff. In addition to exciting and challenging research areas, the institute offers the opportunity to initiate leisure activities together as a balance to intellectual work. For example, the team organizes a wide variety of sports activities, such as sailing, soccer and beach volleyball. Musical skills are also brought together in the institute band.










Forschungsgesellschaft Energie e.V. (FGE) – an Overview

The aim of the Forschungsgesellschaft Energie e. V. (FGE) is to promote research at RWTH Aachen University in the field of energy economics, conversion, distribution and application. Energy technology issues are just as much a subject of research as energy industry topics. The FGE also promotes knowledge exchange among its members and supports the training of young engineers. The society pursues exclusively and directly non-profit purposes.

The FGE fulfills its tasks in close cooperation with the Institute for High Voltage Equipment and Grids, Digitalization and Energy Economics (IAEW). It has initiated or edited numerous research activities, lecture evenings and publications. The present FGE annual report reports on current research results. Events such as the annual general meeting, the biennial FGE conference, FGE colloquia as well as FGE seminars offer both the possibility of further professional training within the framework of FGE and the opportunity to maintain old connections and make new ones.

A further FGE concern is to intensify the contact between its members and young students. For this purpose, FGE members can present new projects of their company to a professional audience at the FGE colloquia that take place regularly and introduce themselves to interested students. Furthermore, the contact to the students is maintained via so-called graduate cards. FGE member companies receive a short description and curriculum vitae from students who are about to finish their studies. This “matchmaking” is very well received by the graduate students. The member companies also welcome this project, as it gives them the opportunity to get into contact with very good and capable graduates. Not only have numerous contacts been made so far, but a number of graduates have also found their next challenging task in one of the FGE member companies.

The FGE currently has over 70 energy supply, industrial and consulting companies as members. It is pleasing to note that companies from neighboring countries are also FGE members.

The new challenges in the European energy industry are also reflected in FGE member companies. In addition to industrial and energy supply companies, electricity trading and consulting companies are increasingly applying for FGE membership.

The FGE Board of Trustees consists of elected representatives from the circle of members and the Rector of RWTH Aachen University. Chairman of the board of trustees is Dr. Joachim Schneider divisional director of innogy SE. Professor Albert Moser is in charge of the management.

Organizational Chart FGE

General Meeting

Board of Trustees

Dr.-Ing. J. Schneider (Chairman of the Board)
Univ.-Prof. Dr.-Ing. A. Moser (Executive Director)
Dr.-Ing. J. Büchner
Dipl.-Ing. W. Fischer
Dipl.-Ing. M. Jesberger
Dipl.-Ing. T. Meyerjürgens
Dr. rer. nat. T. Pape
Univ.-Prof. Dr. rer. nat. h.c. mult. U. Rüdiger
Dr.-Ing. M. Schumacher
Dipl.-Ing. D. Spohn

Representative of FGE

Dr. Regina Oertel

FGE Event Formats

FGE Conference

The FGE Conference takes place as a two-day lecture event every two years in Aachen and is aimed at decision-makers from energy supply companies, industry, consulting companies, government and research. The consistently high number of participants confirms the choice of topics and speakers and demonstrates the great interest in these events.

The FGE Conference 2019 on the topic "Energy. Digital. Cross-Sectoral" took place on 26/27 September 2019 at the Hotel Pullmann Aachen Quellenhof.

FGE Colloquia

The FGE colloquia take place every semester. Three events are offered, two lectures and since 2019 a panel discussion, the so-called Rogowski evening. Experts from industry, energy supply companies, universities and government report on current developments in energy technology, economics and politics. The colloquia serve on the one hand to exchange information on current developments in industry and research, and on the other hand to improve contacts between young academics and industry.

FGE Seminar

The FGE seminar takes place as a one-day lecture event every two years in Aachen and is aimed at experts from energy supply, industry, consulting companies, authorities and research.

Due to the corona pandemic, the FGE seminar planned for autumn 2020 cannot take place.

More information on the events can be found in the chapter "Teaching and Networks".

Member Companies of FGE and their Representatives

As of December 31, 2019

50Hertz Transmission GmbH, Berlin
Dr. F. Golletz, Managing Director

ABB AG, Mannheim
Dr.-Ing. M. Schumacher, Member of the Board

Amprion GmbH, Dortmund
Dr.-Ing. K. Kleinekorte, Managing Director

Austrian Power Grid AG, Wien (A)
DI Mag. (FH) G. Christiner, Chairman of the Board

Avacon Netz GmbH, Helmstedt
Dr. S. Tenge, Chief Technology Officer, Avacon AG

BET Büro für Energiewirtschaft und technische Planung GmbH, Aachen
Dr.-Ing. A. Kox, Managing Director

BW PARTNER WPG/Stbg., Stuttgart
N.N.

Capgemini Consulting, Köln
A. Weiler, Vice President

con|energy ag, Essen
Dr. R. Dudenhausen, Member of the Board

Consentec GmbH, Aachen
Dr.-Ing. W. Fritz, Managing Director

CONSULECTRA Unternehmensberatung GmbH, Hamburg
Dr. rer. nat. T. Pape, Managing Director

ConVista Consulting AG, Köln
C. P. Borgmeyer, Managing Partner

Creos Deutschland GmbH, Homburg
J. Apelt, Managing Director

Currenta GmbH & Co. OHG, Leverkusen
Dr. C. Czauderna, Head of Operations Site Services

DNV GL-Energy Advisory GmbH, Hamburg
Dipl.-Kfm. C. F. Hülsen, authorized signatory

Dortmunder Energie- und Wasserversorgung GmbH
P. Flosbach, Managing Director

E-Bridge Consulting GmbH, Bonn
Dr.-Ing. J. Büchner, Managing Director

E.DIS AG, Fürstenwalde/Spree
Dr.-Ing. A. Montebaur, Chairman of the Management Board

EEX European Energy Exchange AG, Leipzig
Dr.-Ing. Dr. rer. pol. T. Paulun, Chief Strategy Officer

envelio GmbH, Köln
Dr.-Ing. S. Koopmann, Managing Director

e.venture consulting GmbH, Berlin
Dr. C. Wiebe, Partner und Managing Director

EWE Netz GmbH, Oldenburg
Dipl.-Ing. T. Maus, Managing Director

EWR Netz GmbH, Alzey
Dipl.-Ing. J. Krämer, Managing Director

Fichtner GmbH & Co. KG, Stuttgart
Dipl.-Ing. R. Epping, Managing Director

FourManagement GmbH, Düsseldorf
Dipl.-Ing. C. Schrader, Managing Director

GE Grid GmbH, Frankfurt
Dipl.-Ing. T. Schwarz, Managing Director

HAMBURG WASSER - Hamburger Stadtentwässerung AöR, Hamburg
Dipl.-Ing. H. Hannemann, Managing Director Technology

illwerke vkw AG, Bregenz (A)
Dipl.-Ing. H. Mennel, Member of the Board

Industrial Consulting International, Mettmann
Dr. rer. pol. W. Dotzenrath

innogy SE, Essen
Dr.-Ing. J. Schneider, Member of the Board

KELAG – Kärntner Elektrizitäts-AG, Klagenfurt (A)
Dipl.-Ing. Dr. R. Draxler,
Managing Director of KNG-Kärnten Netz GmbH

KISTERS AG, Aachen
Dr. H. Schell, Sales Manager Energy

Maschinenfabrik Reinhausen GmbH, Regensburg
Dipl.-Ing. W. Breuer, Managing Director

Max Bögl Wind AG, Ulm
Dipl.-Ing. J. Zinner, Central Area Manager Hydraulic Accumulators

MDN Main-Donau Netzgesellschaft mbH, Nürnberg
Dr.-Ing. P. Wolffram, Commercial Managing Director

Mitteldeutsche Netzgesellschaft Strom mbH, Halle (Saale)
Dr.-Ing. A. Schweer, Managing Director

MVV Netze GmbH, Mannheim
Dipl.-Ing. F. Pavel, Managing Director

Netz Leipzig GmbH, Leipzig
Dipl.-Ing. (FH) A. Kühnl, Managing Director

Netze BW GmbH, Stuttgart
Dr. M. Konermann, Managing Director

NKT GmbH & Co. KG, Köln
Dr. rer. nat. V. Waschk, Director

Omexom Service GmbH, Berlin
Dr. F. W. Knebel, Head of Infrastructure VINCI Energies Deutschland GmbH, Mannheim

ORES, Eupen (B)
R. Mergelsberg, Director Ores Wallonie Ost

Paatz Scholz van der Laan GmbH, Grünwald
K. Ernst, Senior Consultant

Pfalzwerke Netz AG, Ludwigshafen
Dr. K. Zimmer, Director of Network Planning and IH Strategy

Pfisterer Kontaktsysteme GmbH & Co KG, Winterbach
Dipl.-Ing. (FH) F. Hardt, Head of Product Management and Development, Pfisterer Holding AG

ProCom GmbH, Aachen
Dr. M. Scheidt, Managing Director

PSI Software AG, Aschaffenburg
Dipl.-Ing. (FH) W. Fischer, Business Unit Manager

Regionetz GmbH, Aachen
Dipl.-Ing. S. Ohmen, Managing Director

RheinEnergie AG, Köln
Dr. A. Cerbe, Member of the Board

Schneider Electric GmbH, Seligenstadt
Dr.-Ing. J. Dams, Vice President Energy

Siemens AG, Erlangen
Dipl.-Wirt.-Ing. R. Christian, CEO Division Energy Management

Smart Wires Inc, Union City (CA)
Dr.-Ing. D. Schweer, Power System Engineer der Smart Wire Grid Europe Limited, Dublin

SOPTIM AG, Aachen
Dr.-Ing. O. Scheufeld, Management Consultant

SPIE SAG GmbH, Langen
Dipl.-Volksw. A. Pilot, Member of the Executive Board

SPRINT! Energy Consulting GmbH, Essen
Dipl. Geophysiker, MBA A. Stephan, Managing Director

Stadtwerke Aachen AG, Aachen
Dipl.-Kfm. Dipl.-Verw.-Wiss. W. Ullrich, Member of the Board

Stadtwerke Bochum Holding GmbH, Bochum
Dipl.-Ing. D. Spohn, Managing Director

Städtische Werke Netz + Service GmbH, Kassel
Dipl.-Ing. E. Weldner, Managing Director

Statkraft Markets GmbH, Düsseldorf
Dr.-Ing. P. Siemes, Portfolio Manager

Stromnetz Berlin GmbH, Berlin
Dipl.-Ing. J. Schunk, Head of Assets

Stromnetz Hamburg GmbH, Hamburg
Dipl.-Ing. T. Volk, technical Director

Süwag Energie AG, Frankfurt
Dipl.-Ing. J. Köchling, technical Director der Syna GmbH

SWO Netz GmbH, Osnabrück
Dipl.-Ing. H.-W. Hölscher, Managing Director

TenneT TSO GmbH, Bayreuth
Dipl.-Ing. T. Meyerjürgens, Managing Director

The Boston Consulting Group GmbH, München
Dr.-Ing. D. Schlecht, Principal

TIWAG-Tiroler Wasserkraft AG, Innsbruck (A)
Dipl.-Ing. Dr. P. Bauhofer, Head oft he Energy Strategy and Energy Efficiency Department

Tractebel Engineering GmbH, Bad Vilbel
Dr. R. Bucher, Head of Power Transmission and Distribution

TransnetBW GmbH, Stuttgart
Dipl.-Ing. M. Jesberger, Managing Director

Trianel GmbH, Aachen
Dipl.-Volksw. S. Becker, Managing Director

umlaut energy GmbH, Aachen
Dr.-Ing. C. Hille, Managing Director

Voith Hydro GmbH & Co. KG, Heidenheim
Dipl.-Ing. (FH) M. Wirth, Director Sales

VOLTARIS GmbH, Maxdorf
K. Vortanz, Managing Director

VSE Aktiengesellschaft, Saarbrücken
Dr.-Ing. G. Clemens, Member of the Board

wesernetz Bremen GmbH, Bremen
Dr.-Ing. K. Münch, Executive Assistant

Westnetz GmbH, Dortmund
Dr. J. Grönner, Managing Director Integration/Asset Management

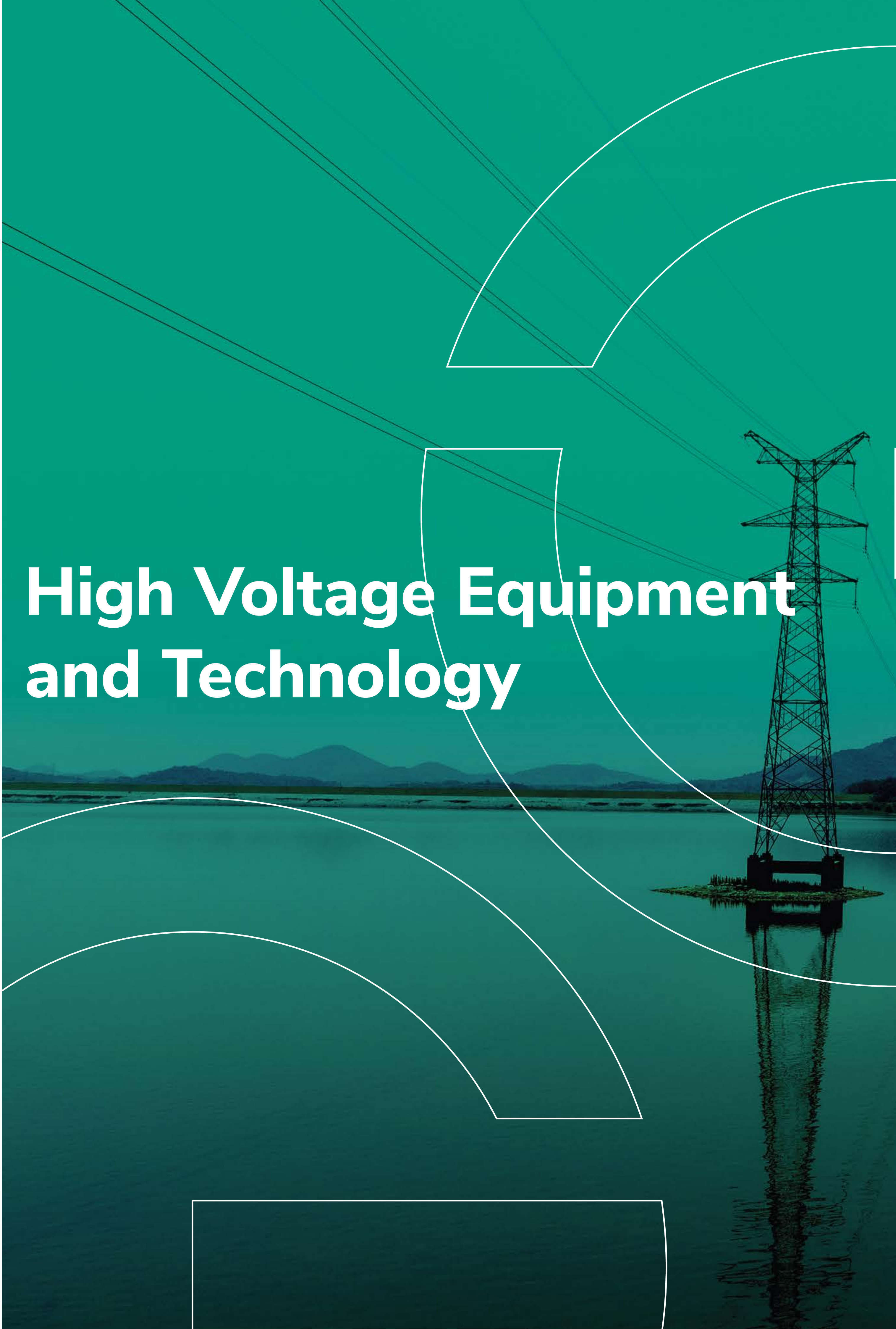
Individual members

- Univ.-Prof. Dr.-Ing. H.-D. Kochs, Duisburg
- Dr.-Ing. R. Taud, Uttenreuth
- Dipl.-Ing. W. Wilhelm, Andernach

Honorary members

- Dr.-Ing. R. Bierhoff, Essen
- Dipl.-Ing. M. Fuchs, Kirchheim bei München
- Prof. Dr.-Ing. R. Windmöller, Ennepetal

High Voltage Equipment and Technology




FGE
FORSCHUNGSGESELLSCHAFT
ENERGIE

Chair for High Voltage Equipment and Technology

The ongoing transformation towards decarbonized power generation and distribution is constantly presenting even conventional disciplines such as high-voltage engineering with new challenges. The planned integration of high-voltage direct current (HVDC) transmissions between generation centers in northern Germany and load centers in the south, some of which are already being implemented, requires a multidisciplinary approach to a wide range of issues. The influence on the fault currents by the converters on the AC side and the lack of a current zero crossing in case of faults in the DC system require the development of new protection and current interruption concepts. The agreed upon cable priority of the planned routes and the resulting partial implementation using 525 kV DC cables leads to unprecedented voltage loads on insulating materials, especially at interfaces in cable fittings. However, the increased use of DC technologies does not exclusively result in the increased occurrence of high DC fields. Due to the fast switching converter circuits, insulating materials must also withstand high-frequency electrical fields. As voltage levels in electric vehicles continue to rise, such issues are becoming increasingly relevant for the automotive industry as well. In mobile applications it is additionally necessary to use and classify low-density insulating materials.

An environmentally friendly energy supply is not only based on CO_2-neutral generation; the components of the energy distribution should also be implemented in an environmentally friendly way. Today's high-voltage switchgear increasingly relies on the insulating medium Sulphur hexafluoride (SF_6), which is an outstanding insulating and quenching gas, but also the strongest known greenhouse gas. The use of alternative gases requires an extensive investigation of their properties and a redesign of switchgear technologies.

Digitalization in the energy sector offers great potential in the field of asset management. New types of sensor and monitoring systems can make future renewal and maintenance concepts more efficient and thus more economical.

The Chair for High Voltage Equipment and Technology looks back on many years of experience in the fields of switchgear and insulation systems. With comprehensive laboratory equipment as well as extensive competencies in the fields of FEM and EMT simulations, the Chair is well equipped for research and development activities in the areas described above.

Core competencies

The wide-ranging issues in high-voltage engineering require a close interaction of different scientific methods. The combination of simulative and experimental approaches ensures a high quality of results:

- **Experimental investigations**
  The Chair has a large number of laboratories for the generation of high voltages and currents of various frequencies and shapes and the testing of a wide variety of test objects at its disposal. Furthermore, a laboratory-scaled test environment is available to investigate protection and control strategies in future multi-terminal HVDC transmission networks.

- **FEM-Simulations**
  Typical high-voltage engineering questions can usually only be answered in depth on a laboratory scale. In order to ensure applicability and to develop a deeper physical understanding of observed effects, the Chair uses simulations using the finite element method. These allow the numerical description of, for example, electric fields or arcing processes in almost any arrangement.

Figure: Control area of the new DCLab of the Chair for High Voltage Equipment and Technology

- **EMT- und Real-Time Simulations**
  Field or laboratory tests are not suitable for the analysis of larger electrical systems such as HVDC converters, or for the examination of entire transmission systems. In order to investigate transient effects and component loads, especially as a result of faults, and to develop strategies for their safe control even before commissioning, the chair uses EMT simulations (EMT = "Electromagnetic Transients"). Furthermore, the models developed at the chair can also be used to analyze control effects in the sub- and supersynchronous time domain – especially in synergy with existing real-time simulators – and to further develop concepts.

Innovation

In the field of integration of DC systems into existing AC grid structures, the chair examines issues related to protection and control technology, DC insulation technology and the interruption of DC currents. New protection concepts for inverters and inverter-dominated AC grids are first developed in simulation and validated in our own Power-Hardware-in-the-Loop environment. The investigations of insulating materials for DC applications cover a wide frequency range in test setups developed specifically for this purpose and can thus also map the use in converters. For the testing of DC switchgear, the institute has a powerful pulse current source at its disposal to simulate various test current scenarios.

For the substitution of the climate-gas SF_6, the institute carries out extensive investigations of the behavior of possible substitutes both as insulating and quenching gas. Both atmospheric gases, such as carbon dioxide or air, as well as fluorinated alternative gases, such as C5-perfluoroketone or C4-perfluoronitrile, are considered.

The application of innovative low-cost sensor technologies is investigated at the institute on different components of the distribution network level. Thereby, operating and fault conditions are simulated and typical ageing characteristics of components are considered in order to contribute to the digitalization of asset management at the medium voltage level.

High Power Test Circuit DCLab

An innovative test facility for components of future DC systems

Known protective systems and components from AC technology are suitable for use in future DC systems (e. g. in meshed grid operation or in e-mobility) only to a limited extent. The reason for this is especially the lack of a natural current zero crossing, which is typically used for current interruption. Furthermore, the shape of DC fault currents depends on various system parameters and cannot be defined in a generally valid way. New designs of DC equipment are essential. Proof of their functionality requires suitable test facilities that adequately reproduce real stresses. Conventional test circuits are not suitable for this purpose. At the IAEW, an innovative high-power test facility has been developed and put into operation that simulates arbitrary DC fault current characteristics.

The generation of flexibly controllable test currents is based on a modular power electronic buck converter. The high-power test circuit is fed from 120 individual test circuit cells, which together generate test currents with amplitudes of up to 30 kA for a duration of 50 ms. Additionally, a driving voltage of 8 kV and a testing energy of 2 MJ are provided. Variable test current characteristics can be realized by selective control of the test circuit cells. It is possible to simulate unipolar mathematical functions and current characteristics derived from field measurements. A continuous current source (5 kA_{DC}, 120 kW) is integrated into the test field infrastructure to investigate the thermal behavior of components in nominal and overload scenarios. Thus, investigations on various DC equipment can be carried out in the high-power test facility which contribute to a safe and reliable grid operation.

i

Project Acronym
DCLab

Project Duration
Oct 2015 – Sept 2019

Contact
Nils Langenberg, M.Sc.
n.langenberg@iaew.rwth-aachen.de
+49 241 80 92945

Supported by:
Federal Ministry for Economic Affairs and Energy
on the basis of a decision by the German Bundestag

Figure: The energy store of the innovative DC high performance test circuit. The almost 2 MJ stored energy permits realistic investigations of future DC equipment.future DC equipment.

Dry Syntactic Foam for Hollow-core Composite Insulators

Electrical characterization of an ultra-lightweight filler to be used in station-post hollow-core composite insulators

Hollow-core composite insulators (HCIs) have been in use since the 1980s as an alternative to hollow-core ceramic insulators. HCIs have been traditionally used in outdoor facilities as housing for high voltage (HV) equipment like circuit breakers, instrument transformers and surge arresters and are characterized by their lightness and high mechanical strength. In recent years, these properties have led to new applications, such as station post insulators (SPIs) in the ultra-high-voltage (UHV) range.

To be used as SPIs, the internal volume of HCIs is filled with a light insulating medium. This avoids internal flashovers, which can occur due to moisture condensation on the inner surface of the fibre-reinforced plastic (FRP) tube. Suitable insulating media are either gases such as sulphur hexafluoride (SF_6) or nitrogen (N_2), or polyurethane foams. PU foams are preferred because they do not require a monitoring system to detect gas leaks. However, PU foams release a considerable amount of heat during their production. This effect is enhanced with large insulators such as those used in the UHV range. Therefore, research is being carried out on alternative lightweight insulating fillers that neither cure exothermically nor exhibit toxic properties.

This project investigates a novel plastic foam named dry syntactic foam (DSF). The DSF consists of a mixture of gas-filled polymeric hollow microspheres (HMS) with an average diameter of 12 µm. When the spheres are exposed to a certain temperature, the plastic shell becomes soft as the pressure inside the sphere increases. This causes the plastic expansion of the shell and a tenfold increase in the volume of the sphere. Both expanded and unexpanded HMS are used to produce the foam, in order to achieve a homogeneous pore distribution. The figure shows an electron microscope image of the surface of the DSF in which the closed pore structure can be seen.

To realize a possible application of the DSF in HCIs, the most important electrical properties are determined for different densities. Due to the increasing gas content with decreasing densities, both permittivity and loss factor decrease. The permittivity is close to one, as is the case with gases, and the dissipation factor of the DSF is in the range of 0.5 %.

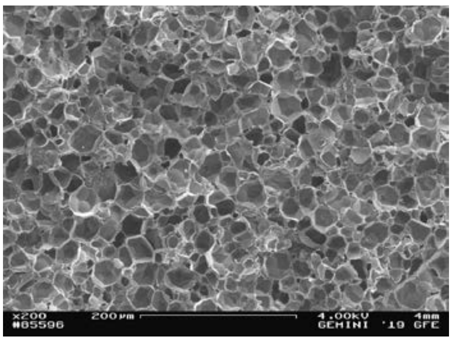


Figure: SEM image of the dry syntactic foam

The dielectric strength does not show a clear dependence on the density, which is ascribed to the influence of two opposite effects, namely the number of interfaces and the pore size. Higher densities require more HMS per unit volume: as a result, the average pore size decreases and the number of interfaces increases. Additionally, special attention is given in this project to the interface formed by the FRP tube and DSF. This is of considerable importance, since the foam has no natural adhesion to the FRP material. The application of different adhesion promoters, which avoid moisture ingress in the interface, is being also investigated.

i

Project Acronym
TSS

Project Duration
Nov 2019 – Jan 2021

Main Partner
Reinhausen Power Composites GmbH

Contact
Diego Machetti, M.Sc.
d.machetti@iaew.rwth-aachen.de
+49 241 80 92949

Figure: MMC Test Bench – Lab demonstrator for HVDC system investigations

MMC Test Bench

Test bench for the investigation of control and protection schemes of HVDC grids

Multi-Terminal DC (MTDC) grids are considered as the key technology for the expansion of the European power grid, in particular for the vast integration of wind energy from the North and Baltic Seas into the surrounding AC transmission systems. In addition, offshore HVDC systems will increase the interconnection of the European market areas. However, prior to the implementation of offshore MTDC grids, a number of regulatory and technical challenges, the lack of technical standards and the lack of experience with their operation and protection needs to be overcome.

Within the framework of the Horizon2020 project PROMOTioN (Progress on Meshed HVDC Offshore Transmission Networks), a HVDC test bench has been set up at the IAEW which will enable further progress in the technical development of HVDC networks.

At the heart of this test bench are eight laboratory-scaled Modular Multilevel Converters (MMCs), which can be configured as half-bridge, full-bridge or mixed-cell converters. The scaled MMCs comprise 10 cells per arm, have a nominal DC voltage of $U_{DC,n}$ = 400 V and a nominal power of $P_{DC,n}$ = 6 kW. Within the test bench, DC networks can be replicated in both monopolar and bipolar configuration using cascaded frequency-dependent pi-sections. To investigate the interactions between HVDC grids, offshore wind turbines and AC transmission systems, the electrical DC grid is embedded in a real-time simulation of the surrounding transmission systems using Power Hardware-in-the-Loop (PHiL).

Due to its high flexibility, the test bench enables the IAEW to investigate a wide range of challenges associated with future DC grids and their interactions with AC transmission systems using innovative approaches.

Project Acronym
PROMOTioN

Project Duration
June 2016 – Sept 2020

Main Partners
ABB AB, DNV GL AS, KTH, KU Leuven, TenneT TSO BV, Siemens AG, DTU, FGH e. V., Tractebel S.A. et al

Contact
Philipp Ruffing, M.Sc.
p.ruffing@iaew.rwth-aachen.de
+49 241 80 92948

Supported by
This project has received funding from the European Union's Horizon 2020 research and innovation programme

PROMOTioN
PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS

Digitalization of the Asset Management

Development of a cost-effective measurement system for local distribution substations to support maintenance and renewal planning

The field of asset management offers high potentials for economic and technical optimization in the context of digitalization. In the area of maintenance and renewal planning at the medium and low-voltage level, the current condition assessment of the equipment is often carried out by inspection personnel through purely visual inspections. The subjective assessment of the condition, which depends on the experience of the inspection personnel, is already reaching its limits and does not allow an objective assessment of the condition of the equipment park based on measurement data. Monitoring systems are already in use today to monitor equipment at high and extra-high voltage levels. Due to the lower investment costs and the high number of local distribution substations compared to substations at the high and extra-high voltage level, the use of these monitoring systems is not an economic alternative. One approach to reduce investment costs is the use of micro-electromechanical sensors (MEMS). Micro-electromechanical sensors from the consumer and automotive industries are subject to positive economies of scale due to high production volumes, so that sensor technology represents a possibility for the construction of a cost-effective monitoring system. The applicability of MEMS sensors will be investigated in this project.

The tasks of the IAEW in the project consist of the development of a laboratory environment that allows the development of measurement methods for MEMS sensor technology and can be tested on real equipment in normal and fault operation. The amount of data to be transmitted to the distribution network operator can be reduced by a Smart-Data approach and the development of sensor-related algorithms.

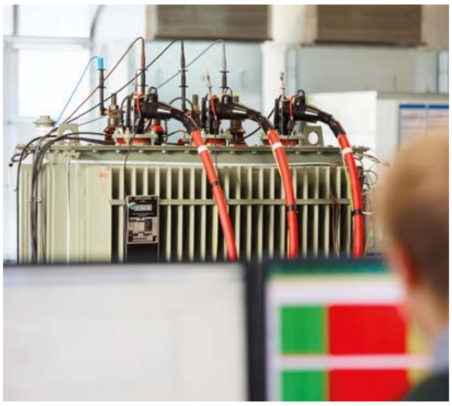


Figure: Acceleration measurements on a 400 kVA local network transformer in an open circuit test

Within the scope of the project, the MEMS sensor technology will be evaluated with conventional measurement technology in laboratory tests and in the field, possible environmental influences on the measurement system will be identified and, if necessary, adapted.

Failures in the medium and low voltage range will be analysed with the focus on local distribution substations as the failure location. Failure-relevant measured variables will be identified and appropriate use cases for further investigation will be defined with the corresponding measured variables. The acquisition of the measured variables should be non-invasive at the operating equipment so that the measuring systems can also be used subsequently in already existing stations. Acceleration is a promising measurement variable for the detection of age- and fault-relevant features for the diagnosis of the equipment within a local distribution substation. Acceleration measurement offers the potential of non-invasively tracing back mechanical changes to the active part of a local network transformer or changes to the drive of medium-voltage switchgear. At the Centre for Network Integration and Storage Technologies acceleration measurements are currently being carried out on local distribution network transformers under variation of electrical input variables.

i

Project Acronym
MAKSIM

Project Duration
Sept 2018 – Aug 2021

Main Partners
Maschinenfabrik Reinhausen GmbH,
Fraunhofer-Gesellschaft,
Robert Bosch GmbH

Contact
Andre Würde, M.Sc.
a.wuerde@iaew.rwth-aachen.de
+49 241 80 49331

Supported by:

Federal Ministry
for Economic Affairs
and Energy

on the basis of a decision
by the German Bundestag

Environmentally-friendly Medium-Voltage Switchgear

Interruption capability of medium-voltage load break switches utilizing atmospheric quenching and insulation gases

Marvin Bendig, M.Sc.

Figure: Working on a test vessel

Medium voltage load break switches are essential components in today's energy systems. As part of secondary medium-voltage switchgear, they are responsible for interrupting load currents and ensuring a safe insulation distance in the off-state. In the course of the ongoing medium voltage grid expansion, mainly gas-insulated switchgear filled with sulfur hexafluoride (SF_6) is installed. The use of SF_6 permits a compact and reliable switchgear design. However, SF_6, with a global warming potential of 23.500 CO_2 mass equivalents, is the most potent greenhouse gas known. A substitution of SF_6 while keeping the size and reliability of the switchgear is desirable. In the process of substituting SF_6 in medium voltage switchgear the load break switch is the critical component, as the gas serves as an insulating and quenching medium. Possible substitutes have a lower dielectric strength as well as a lower arc quenching capability. Hence, a fundamental redesign of the load break switch is necessary.

The objective of this thesis is the identification and quantification of the main influencing parameters on the switching capability of a medium-voltage load break switch filled with an alternative insulating gas. In a parametric study the thermal interruption capability and the dielectric recovery are determined for different design parameters of a model load break switch. Nitrogen (N_2) and carbon dioxide (CO_2) as well as mixtures of these gases are investigated as to their suitability as quenching and insulating gases. A sufficient arc cooling is essential for a sufficient interruption performance and can be ensured by a convective cooling by axial arc blowing and by the "Hartgas"-effect, which results from polymer ablation close to the arc. Both mechanisms can be influenced by the design of the load break switch. In particular the applied blowing pressure has a significant impact on the interruption performance. At a sufficient blowing pressure, the use of polypropylene as a nozzle material can be beneficial. From the experimental results of the study a catalog of design criteria is derived. These criteria are used to develop a demonstrator of an environmentally friendly medium-voltage load break switch. At the end of the thesis, the demonstrator's interruption capability is successfully subjected to a standard-compliant test.

Contact
Marvin Bendig, M.Sc.
m.bendig@iaew.rwth-aachen.de
+49 241 80 90008

Selective Line Protection Concepts for Integrated AC-DC Transmission Grids

Ensuring selectivity of AC and DC line protection considering converter control concepts

Christina Brantl, M.Sc.

The increasing integration of high-voltage direct-current (HVDC) transmission systems into existing AC grids and the planned development towards multi-terminal HVDC systems leads to new challenges for line protection in transmission grids. While Modern Modular Multilevel converters (MMCs) can contribute to the fault current, their behaviour deviates from the characteristic behaviour of synchronous generators under AC fault conditions. On the one hand, their possible short circuit current contribution is limited by the limited current carrying capability of the power-electronic components and delayed by measurement and control systems. On the other hand, the behaviour of the MMCs under fault can be influenced by the implemented controls. However, the characteristic current profiles of AC faults, especially under asymmetric fault conditions, cannot be replicated. Apart from these changes under AC fault conditions, DC-side line faults pose a new challenge for protection systems, as they require, among other things, a reaction of the protection system within a few milliseconds.

Therefore, this thesis first evaluates the functionality of existing AC line-protection concepts, like distance and different protection, in interaction with different converter control concepts via a simulation in PSCAD|EMTDC. In a second step, it analyzes system behaviour in the event of DC-side faults. For DC line faults there do not yet exist any standard protection and fault clearing concepts. The analyses therefore take into account different possible DC-side system configurations and implementations of selective DC-side fault clearing strategies. In a third step, the thesis investigates the interaction between the AC- and DC protection system under fault conditions.

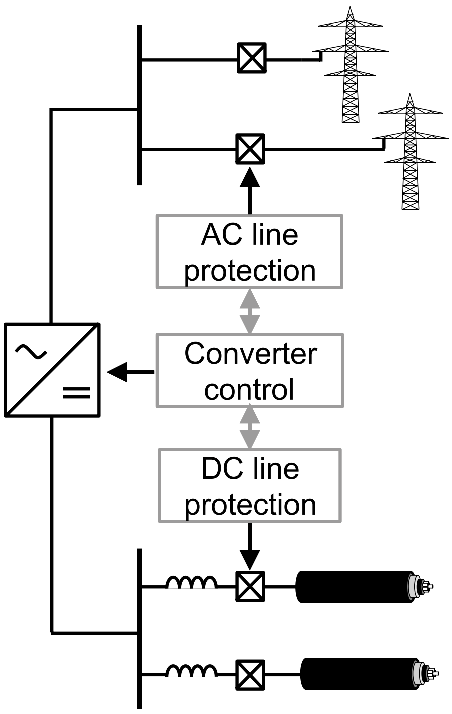


Figure: Protection and control system at the interface betwen AC and DC grids

Based on these analyses, requirements for future line protection concepts are derived. These protection concepts will have to take into account the converter design and control. AC protection with distance protection relays is especially challenging in this regard. For selective DC-side protection strategies based on DC circuit breakers, the design of the protection system has to consider the current limiting reactance, the breaker opening times and the impact on the converter. On the basis of the main factors influencing the protection systems, suitable protection and control combinations are identified, implemented in the simulation framework and evaluated for different topologies. Finally, possible future grid code specifications relating to AC and DC protection systems are discussed.

Contact
Christina Brantl, M.Sc.
c.brantl@iaew.rwth-aachen.de
+49 241 80 93054

Series Connection of Gas and Vacuum Circuit Breakers

A hybrid switching concept for the substitution of SF_6 in circuit breakers for the high and extra high voltage level

Nicolas Götte, M.Sc.

Figure: Test laboratory for synthetic circuit breaker testing

Nowadays, gas circuit breakers are used almost exclusively in high-voltage and extra-high-voltage grids to interrupt operating and short-circuit currents. Due to its outstanding quenching and insulating properties, sulphur hexafluoride (SF_6) is currently used as filling gas. As SF_6 is the most potent greenhouse gas known, there are worldwide efforts to substitute it with alternative, environmentally friendly gases in the future. However, all potential gas alternatives have a lower performance than SF_6. Vacuum circuit breakers have become established in medium-voltage networks due to their reliability and cost-efficiency. In the future, the use at higher voltage levels of up to 145 kV can be expected, but at even higher voltage levels the technology is currently uneconomical and has hardly been tested. In order to realize environmentally friendly circuit breakers also at high and extra-high voltage levels, new concepts are therefore being investigated. One possible approach is a series connection of gas and vacuum circuit breakers as hybrid circuit breaker.

The aim of this work is to characterize the interaction between gas and vacuum arcs in the region around current zero. The lower breaking capability of the gas circuit breaker when using alternative gases is compensated by the vacuum circuit breaker. The gas circuit breaker takes over a large part of the dielectric requirements, thus allowing existing technologies from the medium voltage for the vacuum circuit breaker. Depending on which network fault occurs, the hybrid switchgear behaves differently. The concept shows its strengths with short line faults on overhead lines. The post-arc current of the vacuum circuit breaker is identified as an important parameter. It influences the interaction between the two circuit breakers in the series connection around current zero. In the first phase after current zero, the post-arc current has a dominating influence on the voltage distribution, after which a transition phase leads to a capacitive voltage distribution between the two circuit breakers. In order to influence the voltage distribution between the circuit breakers, both capacitive and resistive voltage controls are investigated and the influence on the behavior of the series connection is evaluated. A resistive control of the vacuum circuit breaker is particularly suitable. In addition to the voltage distribution, the capacitive control has a negative influence on the switching behavior of the series connection. With the experimental results, a simulation model based on black box models has been created and thus the behavior of the series connection can be evaluated for further network faults and higher voltage levels.

i

Contact
Nicolas Götte, M.Sc.
n.goette@iaew.rwth-aachen.de
+49 241 80 93042

Investigation of the Breakdown Voltage of Mineral Oils, Silicone Oils and Synthetic Esters at Medium-frequency Voltages

Robert Möller, M.Sc.

The further development of power electronic semiconductors enables the use of inverters in the medium voltage grid. The frequency of the intermediate AC circuit in high-power DC/DC converters in the medium-frequency range can be between 1 and 10 kHz, which enables a reduction in system size and an increase in efficiency of the converter. Specifically, a compromise between the specific frequency-dependent losses and the reduced transformer surface can be achieved in this frequency range for the transformer in the inverter.

In the medium frequency range, the insulation of the transformer, which can be implemented as oil insulation due to the thermal requirements, is not sufficiently investigated with regard to the breakdown voltage. This can lead to electrical failure if the transformer is undersized or an inefficient transformer design if the transformer is oversized. The voltage form at the transformer varies depending on the inverter concept. There are essentially two different concepts for inverters, which deliver a sinusoidal voltage or an almost rectangular voltage at the transformer.

An air-coupled resonant circuit and a newly developed Solid State Marx generator are used to determine the breakdown voltage of different insulating oils at different voltage forms. Furthermore, the dissipation factor and permittivity of the insulating oils are determined in a frequency range from 50 Hz to 50 kHz.

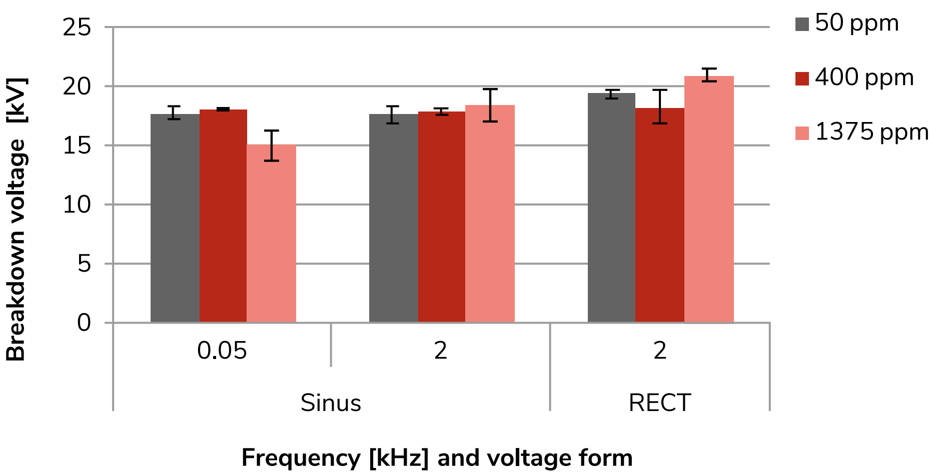


Figure: Breakdown voltage of MIDEL 7131 at water contents between 50 and 1375 ppm at 50 Hz and 2 kHz for sinusoidal and RECT voltages for homogeneous electric fields

This is used for the subsequent calculation of the losses.

Results with sinusoidal voltages show a dependency of the breakdown voltage on the electrode and voltage form. While in homogeneous electric fields the breakdown voltage tends to increase with increasing frequency, in inhomogeneous electric fields it decreases with frequency. Furthermore, it can be observed that the breakdown voltages of rectangular voltages are in the range of sinusoidal voltages.

The losses, which increase with increasing frequency and with rectangular compared to sinusoidal voltages, do not seem to have any influence on the breakdown voltage. The breakdown voltage, which decreases with frequency, suggests a higher influence of pre-discharges on the electrical breakdown at higher frequencies. In homogeneous fields, the influence of impurities in the oil or micro tips on the electrode surface is reduced.

i

Contact
Robert Möller, M.Sc.
R.Moeller@mangoldt.com

HVDC Grid Protection Based on Fault-Blocking Converters

Philipp Ruffing, M.Sc.

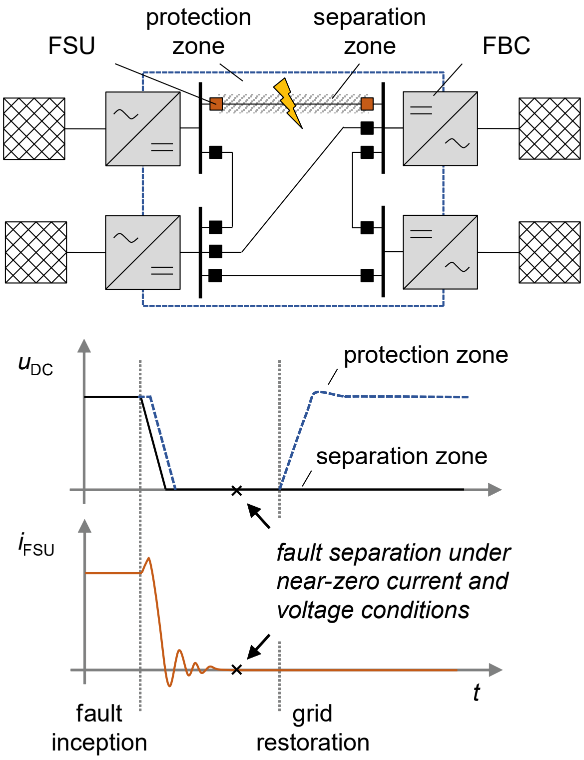


Figure: Schematic representation of the DC fault separation process in MTDC networks protected by FBCs

Multi-terminal HVDC systems are envisioned as a technically and economically promising solution for the large-scale integration of renewable energy sources into the power generation portfolio. To limit the impact of contingencies in HVDC networks, which might transmit several gigawatts of electric power, on surrounding AC transmission systems, DC faults must be separated quickly and reliably from the remaining part of the system. Several strategies have been proposed to enable the fast separation of faulted DC lines, either based on fast DC circuit breakers or fault-blocking converters (FBC), like full-bridge MMCs.

Due to their high degree of controllability even during fault situations, HVDC networks based on fault-blocking converters enable a quick de-energization of the DC system and hence allow the separation and isolation of a faulted line under near-zero current and voltage conditions, as illustrated in Fig. 1.

Consequently, such protection systems allow the application of fault separation units (FSU) with reduced current breaking requirements compared to full-size DC circuit breakers.

This work evaluates the potential and improves the performance of MTDC protection systems based on fault-blocking converters. To enhance the speed of the fault separation process and reduce the requirements on the switchgear during current interruption, a DC fault control method is developed which enables the dynamic adjustment of the DC terminal currents and voltages as well as the currents flowing into the faulted line. In this way, the protection system allows the application of fault separation units with low or even no DC current interruption capabilities – e.g. conventional vacuum circuit breakers – while enabling a fast fault separation. To facilitate a quick recovery of the DC grid voltage and its power flow, restoration methods for monopolar and bipolar HVDC networks are examined and refined.

Based on the definition of functional requirements, including requirements on interoperability and extensibility, as well as quantifiable performance indicators, the entire process from fault detection to system recovery is assessed in the relevant network and circuit configurations. A qualitative comparison with protection systems based on fast DC circuit breakers located at every line end of a HVDC network indicates that the investigated protection system can be a competitive solution depending on the network's size and the requirements of the surrounding AC systems. Finally, the thesis provides an overview of possible protection strategy applications based on fault-blocking converters in extended HVDC grids.

Contact
Philipp Ruffing, M.Sc.
p.ruffing@iaew.rwth-aachen.de
+49 241 80 92948

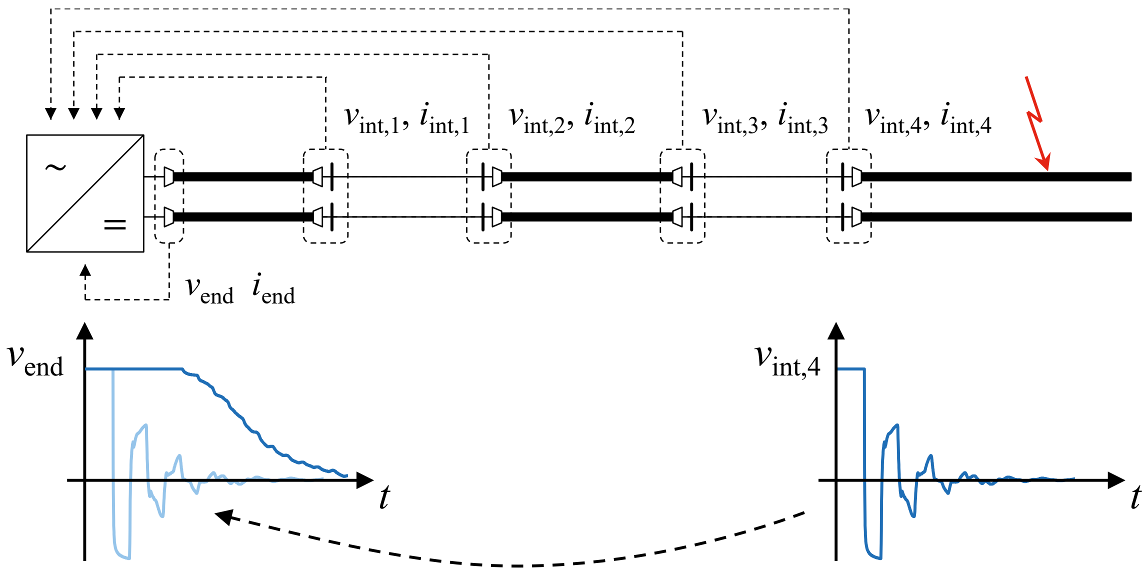


Figure: Protection of VSC-HVDC systems with mixed usage of power cables and overhead lines

Protection of VSC-HVDC Systems with Mixed Usage of Power Cables and Overhead Lines

Philipp Tünnerhoff, M.Sc.

The integration of VSC-HVDC transmission systems into existing AC grid structures is identified as a key solution to increase the accessibility of remotely located renewable generation. At the same time, realising new transmission corridors is often confronted by public objection. In an effort to reduce planning and commissioning processes, transmission systems with mixed usage of power cables and overhead lines are expected to assume an increasingly important role in the future transmission grid. However, several technical challenges still have to be addressed, in particular the reliable, fast and selective handling of line faults. Since line protection concepts proposed for VSC-HVDC systems today typically only account for either pure cable or pure overhead line transmission, a comprehensive investigation of the transient fault behaviour in mixed systems is needed to be able to assess and further develop existing methods.

In this work, topological impact factors on the voltage and current characteristics are analysed based on electromagnetic transient simulations in the time domain. As a result of travelling wave reflection and transmission effects, which occur at every transition point between a cable and an overhead line section, the initial fault impacts at the transmission line ends and segment interfaces can vary significantly depending on the line topology and the fault location. On the one hand, amplified wave fronts can cause increased voltage and current stresses compared to pure cable or overhead line systems. On the other hand, the initial fault effects at the line terminations can be attenuated significantly without a clear indication of travelling wave fronts. Since most of the proposed fault detection and localisation methods rely on an identification of steep voltage and current changes, comprehensive line protection is no longer guaranteed.

To address these challenges, distributed voltage and current measurements are introduced at the line transition points as well as end-to-end and interface-to-end communication channels to transmit the measurement data to the line ends. On this foundation, additional voltage-based detection criteria and a rate-of-change-of-current-based localization algorithm are incorporated into the protection concept, along with further enhancements, e.g. for applications in multi-terminal DC systems. The functionality and flexible applicability of the methods developed here are validated in simulation test systems that exhibit the successful detection, separation and localization of faults in all of the investigated scenarios.

Contact
Philipp Tünnerhoff, M.Sc.
philipp.tuennerhoff@amprion.net

Publications

Bendig, Marvin; Krampert, Thomas; Götte, Nicolas; Schaak, M.; Ermeler, K.; Kalter, A.
Investigations on the effect of the nozzle material on the interruption capability of a medium voltage load break switch
Plasma physics and technology, 6 (1), 15-18

Brantl, Christina; Ruffing, Philipp Frederic; Tünnerhoff, Philipp Christian; Puffer, Ralf
Impact of the HVDC system configuration on DC line protection
CIGRE International Symposium: Going Offshore – Challenges of the Future Power Grid, Aalborg (Denmark), 4 Jun 2019 - 7 Jun 2019

Brantl, Christina; Ruffing, Philipp Frederic; Tünnerhoff, Philipp Christian; Puffer, Ralf
Impact factors on the 2nd zone of distance protection under integration of modular multilevel converters
54th International Universities Power Engineering Conference, Bucharest (Romania), 3 Sep 2019 - 6 Sep 2019

Brantl, Christina; Tünnerhoff, Philipp Christian; Peitz, A.; Schnettler, Armin
Impact factors on the active power flow recovery in multiterminal HVDC systems after DC fault clearing
15th IET International Conference on AC and DC Power Transmission, Coventry (UK), 5 Feb 2019 - 7 Feb 2019

Götte, Nicolas; Bendig, Marvin; Krampert, Thomas; Nikolic, Paul Gregor
Switching Behaviour of a Series Connection of a Vacuum Interrupter and a Gas Circuit Breaker
Plasma physics and technology, 6 (3), 223-226, 2019

Kahlen, Jannis Nikolas; Mühlbeier, Artur; Andres, Michael; Rusek, Bartosz; Unger, Dennis; Kleinekorte, Klaus
Electrical Equipment Analysis and Diagnostics: Methods for Model Parameterization, Fault and Normal Condition Simulation
5th International Conference on Condition Monitoring, Diagnosis and Maintenance, Bucharest (Romania), 9 Sep 2019 - 11 Sep 2019

Kriegel, Martin; Fjeld, Elin; Pedersen, Atle; Nikolic, Paul Gregor; Krampert, Thomas; Snajdr, Jaroslav
Benchmark Case of Multiphysics Simulation for Temperature Rise Calculation
5th International Conference on Condition Monitoring, Diagnosis and Maintenance, Bucharest (Romania), 9 Sep 2019 - 11 Sep 2019

Langenberg, Nils; Krampert, Thomas
Development of a modular high power test setup for components of future DC grids
Testing and measuring on electric high-voltage equipment - 8, 148-153, 2019

Langenberg, Nils; Krampert, Thomas; Heidemann, Matthias
Development of a Modular High-Power Test Circuit for Components of Future Direct Current Grids; 1st ed. 2020
21st International Symposium on High Voltage Engineering, Budapest (Hungary), 26 Aug 2019 - 30 Aug 2019

Leterme, Willem; Jahn, Ilka; Ruffing, Philipp Frederic; Sharifabadi, Kamran; van Hertem, Dirk
Designing for High-Voltage dc Grid Protection: Fault Clearing Strategies and Protection Algorithms
IEEE power & energy magazine, 17 (3), 73-81, 2019

Methling, Ralf; Franke, Steffen; Götte, Nicolas; Wetzeler, Sebastian; Uhrlandt, Dirk
Analysis of C_2 Swan Bands in Ablation-Dominated Arcs in CO_2 Atmosphere
Plasma physics and technology, 6 (1), 82-86, 2019

Meyer, Georg; Biller, Maximilian; Jäger, Johann; Romeis, Christian; Shang-Jäger, Li; Dauer, Maximilian; Krebs, Rainer; Schäkel, Nils; Braun, Benjamin; Stumpe, Maximilian; Tünnerhoff, Philipp Christian
Digital System Protection Design – A new Toolchain for Protection System Automation
25th International Conference on Electricity Distribution, Madrid (Spain), 3 Jun 2019 - 6 Jun 2019

Quester, Matthias Andreas; Loku, Fisnik; Yellisetti, Viswaja; Puffer, Ralf
Online Impedance Measurement of a Modular Multilevel Converter
IEEE PES Innovative Smart Grid Technologies Europe (ISGT-Europe), Bucharest (Romania), 29 Sep 2019 - 2 Oct 2019

Quester, Matthias Andreas; Yellisetti, Viswaja; Loku, Fisnik; Puffer, Ralf
Assessing the Impact of Offshore Wind Farm Grid Configuration on Harmonic Stability
IEEE Milan PowerTech, Milan (Italy), 23 Jun 2019 - 27 Jun 2019

Ruffing, Philipp Frederic; Brantl, Christina; Puffer, Ralf
Post-Fault Voltage Recovery for Multi-Terminal HVDC Networks Based on Fault Blocking Converters
CIGRE International Symposium: Going Offshore – Challenges of the Future Power Grid, Aalborg (Denmark), 4 Jun 2019 - 7 Jun 2019

Ruffing, Philipp Frederic; Collath, Nils; Brantl, Christina; Schnettler, Armin
DC Fault Control and High-Speed Switch Design for an HVDC Network Protection Based on Fault-Blocking Converters
IEEE transactions on power delivery : PWRD, 34 (1), 397-406, 2018

Schaak, Martin; Ermeler, Kristian; Bendig, Marvin; Krampert, Thomas
Comparison of SF6-free load-break switching principles
25th International Conference on Electricity Distribution, Madrid (Spain), 3 Jun 2019 - 6 Jun 2019

Stumpe, Maximilian
Entwicklung eines automatischen Wiedereinschaltkonzeptes für selbstgeführte HGÜ-Systeme mit Fehlerstromregelungsvermögen; 1. Auflage
Verlagshaus Mainz GmbH, Aachen, 2019

Tünnerhoff, Philipp Christian; Brantl, Christina; Ergin, D.; Schettler, F.; Schön, A.; Döring, D.
Impact of the DC circuit breaker design on selective fault detection and clearing methods in multi-terminal HVDC systems
15th IET International Conference on AC and DC Power Transmission, Coventry (UK), 5 Feb 2019 - 7 Feb 2019

Tünnerhoff, Philipp Christian; Brantl, Christina; Puffer, Ralf
Impacts of the mixed usage of cable and overhead lines on selective fault detection methods in multi-terminal HVDC systems
CIGRE International Symposium: Going Offshore – Challenges of the Future Power Grid, Aalborg (Denmark), 4 Jun 2019 - 7 Jun 2019

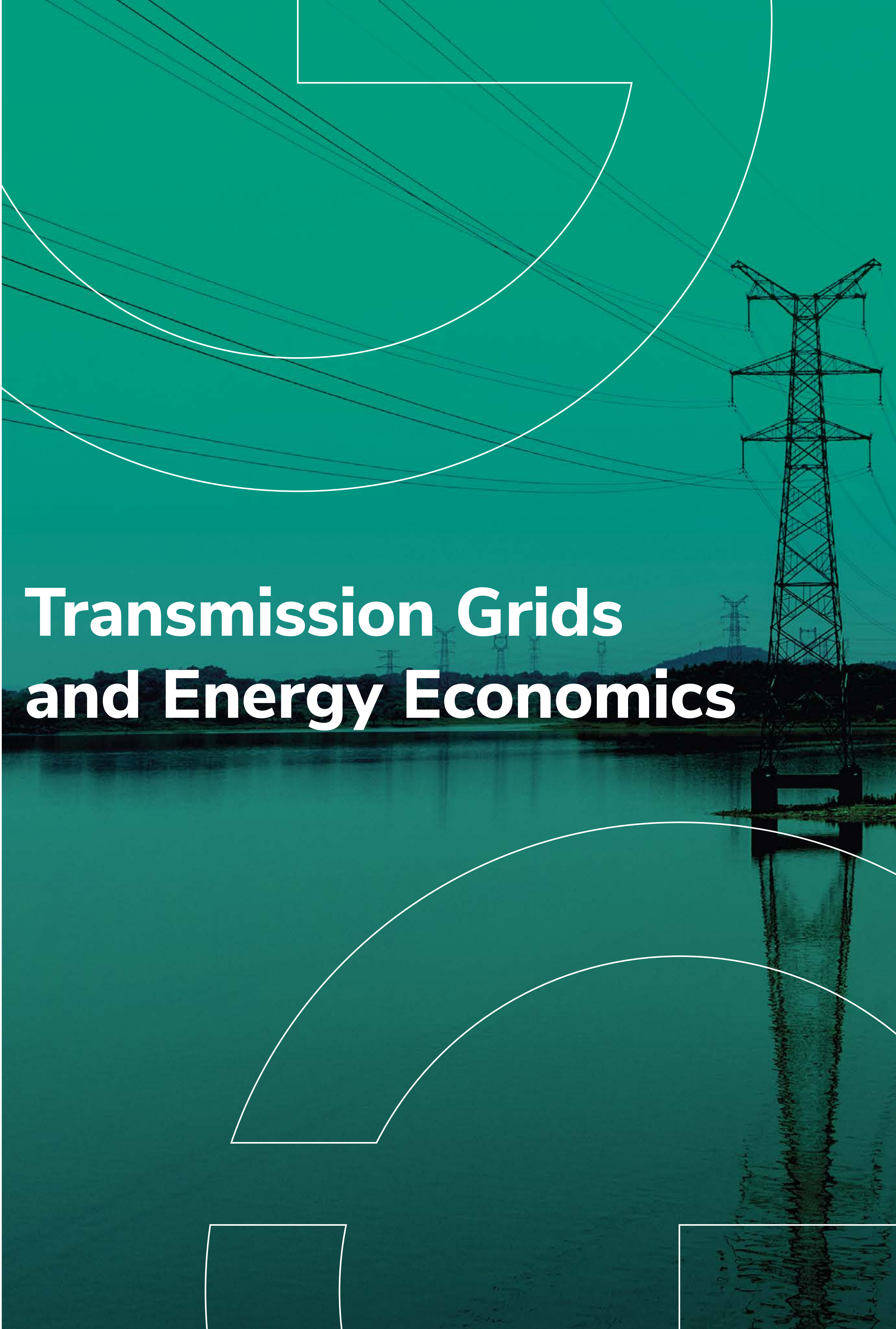
Tünnerhoff, Philipp Christian; Ruffing, Philipp Frederic; Puffer, Ralf
Power cable stresses caused by transmission line faults in next generation VSC-MMC systems
The Journal of Engineering : JoE, 16, 2318-2323, 2019

Inter-institutionel publications

Moormann, Andreas Manuel
Ermittlung robuster Schaltzustände für den Betrieb elektrischer Übertragungsnetze; 1. Auflage
Aachener Beiträge zur Energieversorgung, Band 196,
printproduction M. Wolff GmbH, Aachen, 2019

Moser, Albert
Jahresbericht 2019 des Instituts für Elektrische Anlagen und Energiewirtschaft der RWTH Aachen in Verbindung mit der Forschungsgesellschaft Energie an der RWTH Aachen e. V.
Aachener Beiträge zur Energieversorgung, Band 192,
printproduction M. Wolff GmbH, Aachen, 2019

Moser, Albert; Offergeld, Thomas; Linnartz, Philipp
Review Institute for High Voltage Technology 2018
sieprath GmbH, Aachen



Transmission Grids and Energy Economics


FGE
FORSCHUNGSGESELLSCHAFT
ENERGIE

Chair for Transmission Grids and Energy Economics

With the help of methods developed at the UEW and the cooperation within the IAEW, interdependencies can be identified at an early stage to set the course for the future energy supply system.

The Chair for Transmission Grids and Energy Economics (UEW) is part of the Faculty of Electrical Engineering and Information Technology at RWTH Aachen University. Under the direction of Univ.-Prof. Dr.-Ing. Albert Moser, the mathematical simulation, optimization and evaluation of the technical and economic expansion and operation of power supply systems are the main focus of research, teaching and industrial projects. The focus is particularly on markets and the generation and transmission of electrical energy in the transmission networks. The Chair for Transmission Grids and Energy Economics currently has about 50 full-time employees, including almost 40 scientists in four research groups.

In the future, research will focus on aspects of market design, security of supply, system stability and cross-sectoral integration of the energy supply system.

Energy System Planning

In the transmission grids, the development resulting from the energy turnaround and decarbonization is leading to a need for additional transport capacities and corresponding operational measures to increase the utilization of the existing grid. Additionally, the use of renewable energies requires a suitable coupling of the electricity and gas infrastructure and a coordinated expansion planning The research group is developing methods to evaluate future energy systems at the transport level with regard to the criteria security of supply, environmental compatibility and macroeconomic efficiency.

Power System Operation

Due to efforts towards a common European electricity market and changes in the generation structure of the European electricity supply system, the long-distance transport demand in the European transmission network increases. This also increases the coordination effort in grid operation. Against this background, the research group develops models and procedures in exchange with transmission system operators, regulatory authorities and component manufacturers to support the operation of the transmission grid and thus evaluate new operational management and operational planning concepts. The investigations are based on models of the real high-voltage and extra-high-voltage grid as well as the gas transmission grid in Germany and Europe, which are continuously improved.

Energy Markets

The increasing share of fluctuating feed-in and the decline in the share of conventional power plants as well as new types of consumers and storage facilities are influencing events on wholesale and balancing power markets. In addition, the accelerated coupling of the various energy sectors is creating new influences. Against this background, the research group pursues a wide range of questions. In business studies, profit-maximizing optimizations are used to determine the revenues of plant portfolios on electricity markets. A central element of economic studies is the deterministic or stochastic simulation of markets and, based on this, for example the evaluation of flow-based coupled European bidding zones.

System Stability

The increasing number of active network components causes a fundamental change in the dynamic system characteristics. This can lead to critical system states close to the stability limit, especially in network situations with high resource utilization, and requires detailed analyses of different stability phenomena. The research group develops models and methods in order to identify and assess critical states and fault scenarios within the transmission grid. The optimisation of established methods and models enables the analysis and evaluation of harmonic, transient, frequency and voltage stability in extensive transmission systems.

DEKASim

Energy system analyses and stability assessment of a gradual coal exit in Germany

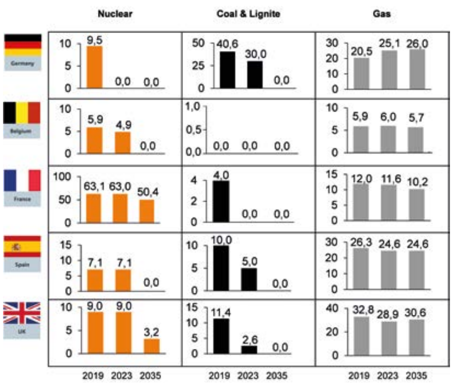


Figure: Development of conventional power plant capacities

Based on the conclusions of the Coal Commission and the resolutions of the Coal Exit Act, the German government has committed itself to a successive phase-out of coal-based electricity generation. In a first step, power plant capacities are to be reduced to 15 GW of both lignite and hard coal by 2023. A complete phase-out of coal-fired power generation is to be completed by 2038. It is also to be determined whether a phase-out is possible as early as 2035.

Against the background of declining conventional power plant capacities throughout Europe, the impact of the coal phase-out in Germany on supply and grid reliability and system stability has not yet been fully recorded and evaluated.

The aim of the DEKASim project is the simulative analysis and evaluation of the German and European energy system in the support years 2023 and 2035. The effects of a simultaneous phase-out of nuclear energy combined with the reduction of coal-fired power plant capacities is investigated for 2023, while 2035 allows for analyzing the possibility of an early coal exit and the resulting systemic consequences. The key points of the scenario framework are developed by Siemens AG in coordination with the IAEW and include in particular assumptions regarding the decommissioning of coal-fired power plant capacities and their replacement by other generation technologies. In addition, established scenario frameworks (e.g. NEP, TYNDP and national grid development plans) are used to complete the scenario.

Based on the energy system simulations, the effects on the European electricity market and the congestion management requirements in the transmission grid are evaluated. The system stability is then assessed in the form of the stability indicators short-circuit power, reactive power demand and frequency stability. The following systemic effects become apparent:

- The decommissioned coal-fired power plants will be replaced to a large extent by gas-fired cogeneration. In one of the scenarios considered for Germany, for example, the average electricity price rises to €36/MWh (2023) and €52/MWh (2035). In isolated situations, reserve power plants are used in 2035.
- Due to strong renewable feed-in in northern Germany, there is a high need for congestion management in north-south transmission in 2023. By 2035, this bottleneck situation will be alleviated by the expansion of PST and HVDC transmission systems, so that the congestion management requirement will be approximately at today's level.
- An isolated German coal phase-out will have only a minor impact on the stability indicators in the European interconnected grid. However, high local reactive power requirements are evident in Germany.

i

Project Acronym
DEKASim

Project Duration
Apr 2019 – Dec 2019

Main Partners
RWTH Aachen, Siemens

Contact
Lothar Wyrwoll, M.Sc.
l.wyrwoll@iaew.rwth-aachen.de
+49 241 80 97882

Investigation of SSSC as Power Flow Control Measure in the German Transmission Grid

A study for Smart Wires Inc.

In the German transmission grid, the progressive expansion of power plants based on renewable energy sources and the further integration of the European electricity markets, especially through the Clean Energy Package, are expected to increase the future need for transport capacity. This requirement often cannot be met, and expensive remedial measures are necessary. In addition to the use of conventional grid expansion to meet this increased need for transport capacity, power flow control measures are also considered as so-called Ad-Hoc measures within the process of the German Network Development Plan (NDP).

In a study conducted with Smart Wires Inc., the use of the power electronic device Static Synchronous Series Compensator (SSSC) as a power flow control measure in the German transmission grid is investigated. The main characteristics of this device are its flexibility in terms of short installation time, modular design and small space requirements. The modular design also allows redundancy requirements to be met by adding just one module. For 2023, which is considered to be challenging in terms of grid security, a scenario with a high line loading has been chosen in which only the expansion measures included in BBPIG and EnLAG are taken into account. Based on this grid situation, the integration of four SSSCs at the locations of the phase-shifting transformers (PST) already considered in NEP 2030 (version 2019) results in an expected reduction of 17 % in redispatch and curtailment measures.

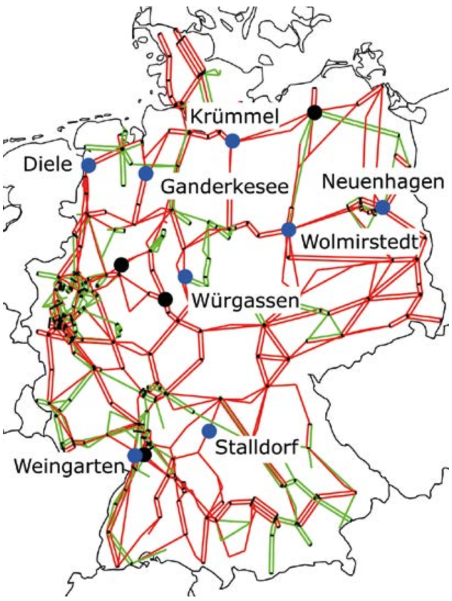


Figure:
Locations of modularly distributed SSSC

Due to the flexibility described above, it is possible to install the SSSC at almost any location. A further distribution of the SSSC based on the existing congestions and free line capacities (cf. Figure 1) leads to a doubling of the benefit with regard to the necessary redispatch and curtailment measures while using the same number of modules, thus offering an advantage compared to the use of phase-shifting transformers. The study does not consider the interactions with the use of overhead line monitoring. On the one hand, this leads to the fact that a higher number of modules is necessary despite the overload capacity of the SSSC, but it also offers the the prospect that, in the event of a future introduction of overhead line monitoring, the addition of further modules will provide a flexible solution.

i

Project Acronym
SSSC Project

Project Duration
Oct 2019 – Mar 2020

Main Partner
Smart Wires Inc.

Contact

Annika Klettke, M.Sc.
a.klettke@iaew.rwth-aachen.de
+49 241 80 93040

NEMO VII

Supporting the BNetzA (Federal Network Agency) in the audit of the Grid Development Plan 2030 (2019)

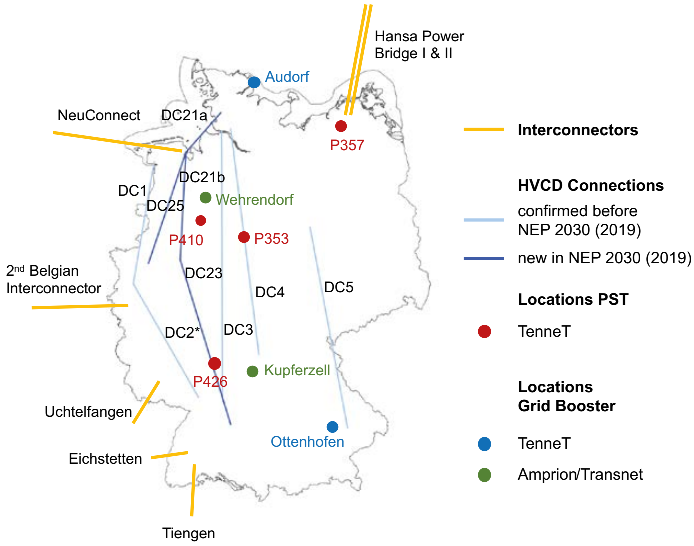


Figure: Selection of evaluated grid expansion measures

In the Grid Development Plan (German: Netzentwicklungsplan – NEP) 2030 (2019), the IAEW as an independent third party supports the Bundesnetzagentur (Federal Network Agency – BNetzA) in auditing the proposed grid expansion measures from the german transmission system operators (TSOs). The IAEW uses its own models and procedures to verify model and procedure approaches as well as quantitative investigation results of the TSOs. The evaluation results are published in an export report and BNetzA considers the results when examining proposed grid expansion measures.

In a first step, IAEW examines the modelling of the energy industry scenarios. A particular focus is on the first-time consideration of flow-based market coupling (FBMC). It is shown that the modelling of the TSOs corresponds to the state of the art and that TSOs and IAEW calculate comparable results.

In the next step, the evaluation of individual grid expansion (see Figure) measures is carried out. The assessment is mainly based on welfare changes in the market, redispatch requirements and CO_2 savings.

The results of the study show that the interconnectors HansaPowerBridge I, Hansa-PowerBridge II and NeuConnect provide added value both from a market and a German transmission network perspective. They relieve the north-south transport in the transmission grid with the consequence of lower redispatch quantities. The 2nd Belgian interconnector enables increased exports to Belgium, the Tiengen interconnector enables increased exports to Italy. Therefore, the market-based added value of these two interconnectors is offset by significantly higher redispatch quantities. The two interconnectors to France (Uchtelfangen and Eichstetten) have little impact on welfare gains.

Four HVDC connections are newly proposed by TSOs in the NEP 2030 (2019). Of those, DC 23 and DC 21a in particular will lead to redispatch savings in the medium and long term. The two HVDC links DC 21b and DC 25 can avoid the need to lower feed-in from renewable energy units. The four ad-hoc phase shifting transformer (PST) show potential for reducing the need for redispatch. The amortization periods for PSTs are between one to four years (P357), three to six years (P410 and P353) and 10 to 15 years (P426).

With the 100-MW network booster P365 in the TenneT network area, a total of roughly 180 GWh/a of redispatch can be saved in 2025 for a monitoring area of the TenneT network area. The 500-MW grid booster P411/P427 allows of 319 GWh/a monitoring the area of Amprion and TransnetBW.

i

Project Acronym
NEMO VII

Project Duration
Nov 2018 – Apr 2020

Main Partner
Bundesnetzagentur

Contact
Lara Lück, M.Sc.
l.lueck@iaew.rwth-aachen.de
+49 241 80 97883

Determining Dynamic Reactive Power Demand

The consideration of expansion planning for reactive power compensation devices as an aspect of grid planning is becoming increasingly relevant due to the decommissioning of conventional power plants. In the course of this planning process, both the reactive power demand for operational voltage control and the demand for voltage control in the event of system faults to maintain voltage stability must be determined. The four German transmission system operators have therefore initiated the project "Determining Dynamic Reactive Power Demand", in which a method for the expansion planning of reactive power compensation devices is developed, taking into account the steady-state and dynamic reactive power demand in transmission systems. It focuses on the placement and technology selection of compensation devices for the transmission grid. The technologies considered include different passive (MSC and MSR) and active (STATCOM and synchronous condenser) compensation devices.

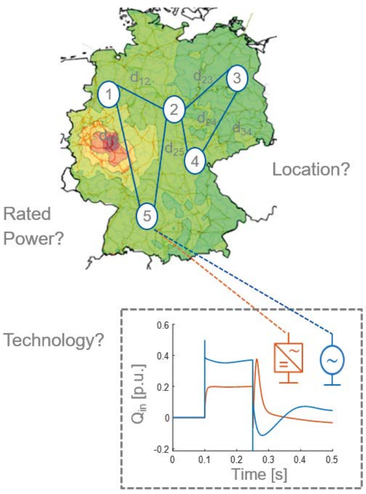


Figure: Placement of reactive power compensation devices

Operational Reactive Power Demand

To identify the steady-state reactive power demand, different characteristic grid usage cases (GUCs) are considered. The aim of the expansion planning is to ensure the compliance of the reactive power compensation devices to the steady-state voltage limits. Existing grid reserves for voltage control, such as transformers with ratio tap changers, can be considered as flexibilities in the expansion planning. In addition to the consideration of individual GUCs, the demand of controllable reactive power within the intra-hour transition of these discrete GUCs is taken into account. The installation of active devices is intended to limit positive and negative voltage gradients caused by these power-flow shifts in the grid.

Reactive Power Demand during Disturbances

With regard to planning-relevant system disturbances, the dynamic reactive power demand for maintaining voltage limits in the event of (n-1) and (n-k) outages is taken into account. In addition, the need for controllable reactive power to ensure a return of the system voltages to a valid and stable operating point after three-phase short circuits is considered. For this purpose, the FRT characteristics are defined as time-dependent voltage limits in accordance with the technical connection guidelines. The latter require, in particular, an appropriate modelling of the voltage controlling behavior of STATCOMs and synchronous condensers within the scope of the expansion planning process.

Method

The expansion planning is realized as a two-stage process based on a mixed-integer optimization. While the target functions consider investment and operating costs, the identified requirements regarding voltage control are formulated as constraints. In the first stage, the steady-state reactive power demand is determined. After the corresponding identified devices have been installed, critical intra-hour transitions and system disturbances are determined and analyzed based on GUCs with valid voltage profiles.

i

Project Acronym
Dynamic power factor compensation

Project Duration
May 2019 – Feb 2021

Main Partners
50Hertz Transmission GmbH
Amprion GmbH
TenneT TSO GmbH
TransnetBW GmbH

Contact
Stefanie Samaan, M.Sc.
s.samaan@iaew.rwth-aachen.de
+49 241 80 96734

Planning of Future Energy Systems

Multi-stage energy system planning under consideration of regulatory framework

Daniel Beulertz, M.Sc.

The expansion of renewable energies (RES) will make a significant contribution to achieving the European climate goals. With a 67 % share of renewable electricity generation in 2017, wind power and photovoltaics are central components of the ongoing transformation process of the German and European energy systems. The spatial and temporal dependence of these technologies on meteorological conditions (cf. Figure) distinguishes them significantly from conventional power plants and makes their integration a central challenge for the future energy system. At the same time, a holistic assessment of the transformation path over several years is required to cope with the ageing power plant stock and to ensure security of supply over the entire period. Furthermore, this is the only way to identify the necessary transition technologies that are needed to meet the climate targets for all years.

Requirements for future energy systems:
Due to the strong expansion of wind power and photovoltaic plants and their volatile feed-in characteristic, the residual load to be covered by conventional power plants and storage facilities is subject to greater fluctuations and shows steeper gradients. In order to cover this residual load while maintaining security of supply, flexibility on the generation and demand side must be taken into account. These include:

- Flexible conventional power plants
- Electrical storage facilities
- Sector coupling
- International electricity exchange
- Load management

The transformation to an energy system based on renewable energies requires that the expansion of renewable energies, the transmission grid and the use of flexibility measures be given equal consideration and that investment and operation be brought into line at optimal cost. However, the interdependencies between the expansion of renewable energies, grid expansion and flexibility measures increase the complexity of determining the optimal transformation path and require innovative solutions and methods.

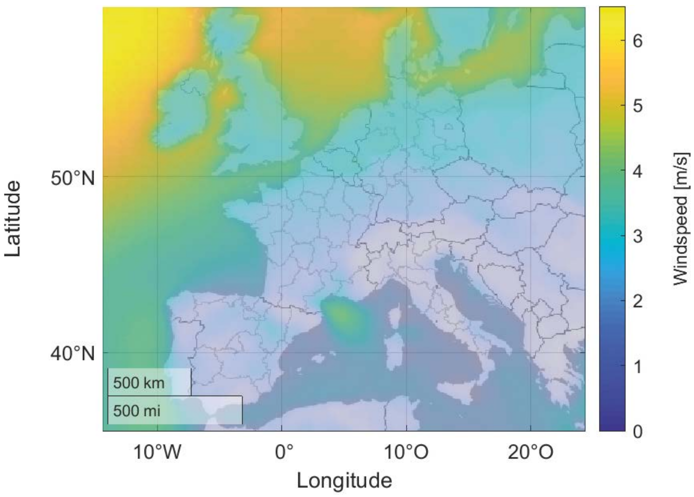


Figure: Long-term average wind speed in Europe

The aim of this research work is the development of a multi-stage expansion planning procedure to derive optimal transformation paths for energy systems under consideration of regulatory framework conditions. The focus of the approach is on the detailed modelling of the characteristics of renewable energies, which is necessary to be able to assess the challenges of integrating renewable energies. Furthermore, the consideration of the transmission network and flexibility options forms a central part of the work.

i

Contact
Daniel Beulertz, M.Sc.
d.beulertz@iaew.rwth-aachen.de
+49 241 80 96721

Frequency Stability in the Renewable Continental European Power System

Christian Bredtmann, M.Sc.

Due to the expansion of generation plants based on renewable energies, there will be an increasing number of converter-based plants in the Continental European power system in the future. Many of these plants do not make an intrinsic contribution to frequency support, as there is no electromechanical coupling with the electrical grid. In addition, the decommissioning of large power plants is forecast to continue, so that the proportion of generation plants electromechanically coupled to the grid will decline. Overall, this leads to a reduction in rotating masses and thus to a decrease in stabilising influences on the grid frequency. For this reason, it is necessary to investigate a potential threat to frequency stability while also examining the extent to which converter-based systems with appropriate control can have a supporting effect on grid frequency in the future.

The aim of the research work is to allow a quantification of these effects in a renewable Continental European synchronous area, so that a method for time domain simulation with adequate dynamic models was developed.

The developed method and models allow the consideration of given regional differences in the generation structure and the location dependence of the grid frequency by means of a high-resolution multi-node grid model in order to answer questions regarding regional minimum shares for the inertia reserve and primary control. The component models and applied methods have been analysed, adapted and further developed with special regard to their suitability for frequency stability studies and with focus on wind energy, photovoltaic and energy storage systems with parameterisable frequency support. The compromise found between sufficient accuracy and model reduction was successful, so that the large-scale grid of the Continental European synchronous area can be simulated in near real time with the developed method.

The exemplary investigations of a scenario of the year 2050 with a share of power feed-in from plants based on renewable energies of about 58 % in Europe and about 89 % in Germany show that the characteristic values for frequency stability are within the currently valid limits even without frequency support from converter-based plants, so that there is no threat to frequency stability. In addition, the investigations indicate that inverter-based systems with appropriately equipped control systems can provide both virtual inertia and primary control and show corresponding stabilizing effects. A purely proportional control is not able to significantly minimize the transient frequency gradients. This could be achieved by a combined PD control. Further investigations into the location dependence of the inertia show that there is a significant local influence on the maximum frequency gradients in the vicinity of the frequency supporting systems. The maximum occurring frequency gradients in the synchronous area could not be reduced. However, a virtual inertia reserve can be used to decrease frequency gradients in regions of low inertia.

i

Contact
Christian Bredtmann, M.Sc.
christian.bredtmann@rwth-aachen.de

Coordinated Congestions Management in the German Transmission and Distribution Grid

Hao Chang, M.Sc.

Background

The phase-out of a large number of conventional power plants substituted by a significant growth of distributed power generation by renewable energy (RE) sources together with the surge in electricity demand due to the increase of sector coupling are the cause of an increasing number of grid congestions in both the distribution and transmission grids. On the other hand, due to digitalization and penetration of ICT, grid services will not only be offered by flexible power plants but also progressively by active consumers.

As many of these flexible resources will be allocated to the distribution grid level, the interaction between the transmission and distribution system operators will become more frequent and the question arises as to how a coordinated flexibility activation between them can be achieved to allow a more synergized flexibility usage.

In this context, different coordination schemes for congestion management have been proposed and explicitly modelled taken into account characteristics of the respective coordination concept as wells as the integration of new flexibility resources to solve grid congestion.

Coordination concepts

In principle, a distinction can be made between a hierarchical and a centralized coordination of the interaction between different network operators. Whereas in a hierarchical coordination the planning of congestion management measures is carried out individually by the respective network operator in compliance with a defined priority rule, in centralized coordination the total number of required alleviation measures are determined jointly by all affected network operators, taking into account the available degrees of freedom and respective network restrictions.

Therefore, these different concepts must be evaluated based on technical and economic criteria.

Results

Preliminary studies show that in future the integration of consumer-side flexibility will bring significant advantages for congestion management in both the transmission and distribution networks. It was observed that new types of flexibility options will significantly improve RE integration. The use of these flexibility options must be coordinated in order to guarantee network security in the respective grid area and to increase the efficiency of congestion management from a system point of view.

As Figure 1 shows, centralized coordination between transmission and especially the 110 kV distribution network operators can achieve savings of around 20 % compared to other coordination schemes in terms of flexibility usage due to the resulting synergy effects across the voltage levels.

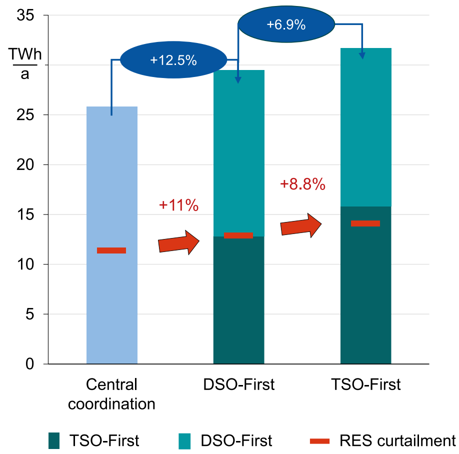


Figure: Redispatch volume based on different coordination concepts

Contact
Hao Chang, M.Sc.
h.chang@iaew.rwth-aachen.de
+49 241 80 96731

Identification of System Splits in the European Interconnected Transmission Grid

Carola Cieslak, M.Sc.

Motivation and Goal

The growing share of renewable energies and the liberalization of the electricity markets are placing an increasing burden on the European interconnected transmission grid. Power generation takes place far away from consumer centers and the energy is transmitted over increasing distances. Overall, the number of grid situations with high utilization of the interconnectors between countries and control areas is rising. As a result, the risk of cascading line outages increases, which can lead to a separation of the interconnected grid into asynchronous regions. Such a system split already occurred in 2006 in the European interconnected transmission grid. Within the resulting subnetwork topologies, high power imbalances and frequency gradients can occur which can no longer be mitigated by classic power-frequency control. For the conceptual design and parameterisation of emergency measures in the event of a system split, design-relevant scenarios are required which include both the initial grid situation and, in particular, the emerging subnetwork topologies. Therefore, the aim of the thesis is the determination of design-relevant system splits for the European interconnected transmission grid.

Method

System splits result from cascading line outages in the transmission grid. Due to the large number of possible initial triggers of a cascade as well as the high number of possible cascade progressions, a complete simulation and analysis of all possible variants is not feasible in practice. In this thesis, a multi-stage procedure is developed which, using graph-theoretical and heuristic methods, but also detailed time domain simulations, identifies critical network states after the occurrence of initial (n-2) line failures and determines the resulting sub-network topologies. The resulting subnetwork topologies are then used to determine the design-relevant system split scenarios.

First, characteristic network use cases are determined by use of a cluster technique. For each of these network use cases, critical initial (n-2) line failures are then determined heuristically using methods of graph theory. For instance, the concept of electrical betweenness is applied. Subsequently, an iterative procedure determines potential line outage cascades and the resulting system split scenarios for each specific initial (n-2) line failure. With this approach, a pre-selection is made for system split scenarios which then are analysed in more detail by means of time domain simulations. These simulation results enable the analysis of the occurring system split topologies and the stability of the resulting network areas and therefore the definition of design-relevant system split scenarios.

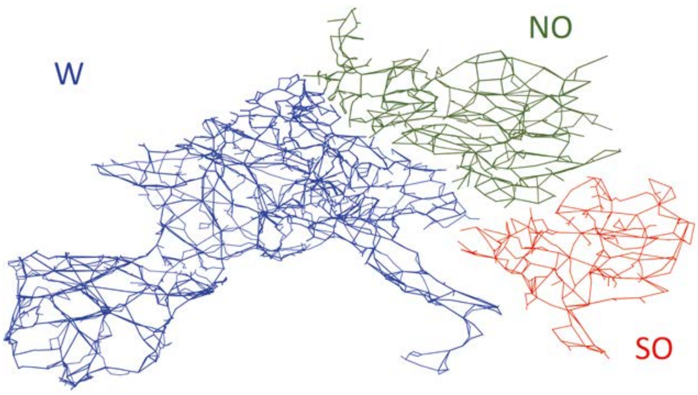


Figure: Representative Determined System Split in the European Interconnected Transmission Grid

Contact
Carola Cieslak, M.Sc.
c.cieslak@iaew.rwth-aachen.de
+49 241 80 97689

Identification of Transformation Paths for Electrical Transmission Grids

Integrated simulation of expansion planning and grid operation for the identification of efficient grid structures

Marco Franken, M.Sc.

The decarbonization of the energy systems characterized by an increased integration of renewable generation units requires additional transmission capacities. Simultaneously, time intensive planning and approval processes as well as a lack of social and public acceptance delay the construction of required transmission capacities. Therefore, the availability of expansion measures and technologies has to be integrated into transmission expansion planning (TEP) approaches. To ensure system security at both short-term as well as long-term planning stages, cost-efficient expansion measures for maintaining system security have to be identified in context of transformation paths.

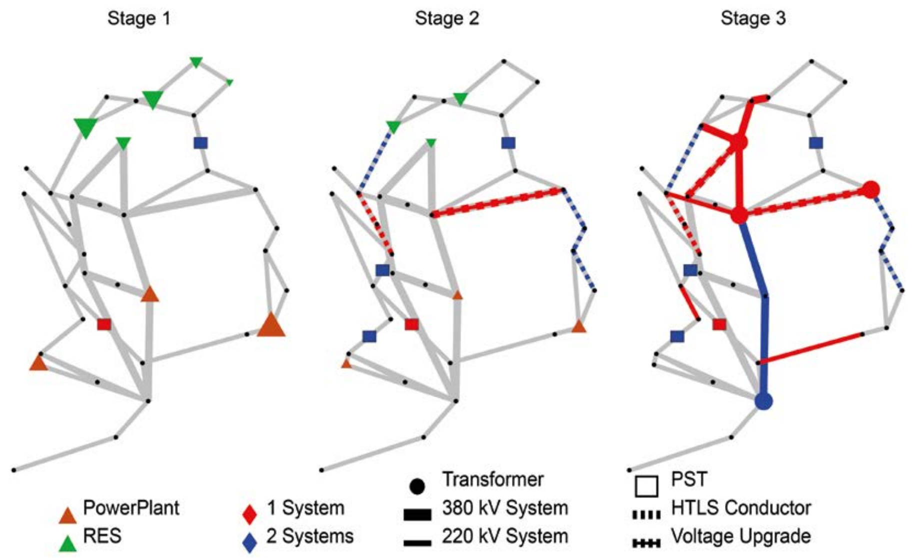


Figure: Required measures for maintaining system security

This research work focuses on the development of a TEP approach for the identification of suitable and efficient transformation paths for electrical transmission grids. The identification is based on an integrated simulation of expansion planning and grid operation. The approach aims to minimize overall investment and operational costs of the planning horizon including several planning stages. The expansion portfolio includes classical AC expansion and reinforcement measures as well as power flow controlling devices such as high voltage direct current (HVDC) systems or phase shifting transformers (PSTs). The flexibilities of the grid operation contain the optimized operation of power flow controlling devices as well as the determination of congestion management interventions such as redispatch of conventional power plants or curtailment of renewable energies.

The integrated optimization of expansion planning and grid operation allows the analysis of planning and operational interdependencies between different technologies and measures. Intertemporal interdependencies between several stages are captured by the simultaneous analysis of all stages within the planning horizon to exploit additional efficiency potentials.

This approach enables the quantification of the impact on expansion costs provided by different technologies such as HVDC systems or PSTs in context of planning and designing future grid structures. Due to the integrated simulation of expansion planning and grid operation, the decision trade-off between resolving network congestions using expansion measures or congestion management interventions is determined endogenously. Furthermore, the benefit provided by foresighted planning processes over several planning stages can be shown by comparing the transformation path identified by this procedure with the transformation path identified by a sequential planning that considers only the congestion situation at the current stage.

Contact
Marco Franken, M.Sc.
m.franken@iaew.rwth-aachen.de
+49 241 80 97698

Simulation of Transmission System Operation in Future Energy Systems

Modelling of transmission system operation considering grid- and market-related measures as well as curative system operation concepts

André Hoffrichter, M.Sc.

The politically driven transformation process to decarbonize the energy system is accompanied by far-reaching changes in the load and generation structure and, as a result, increased power flows in the electrical transmission grid. In contrast, the decentralization of the generation structure and the increasing coupling of the sectors electricity, heat, gas and transport will provide additional flexibility for congestion management in the transmission grid. Additional operational measures in future transmission system operation are provided by the expansion of HVDC systems and phase-shifting transformers as well as by the implementation of curative system operation concepts.

Simulation model

Within this research work, a simulation model is developed that models transmission grid operation taking into account future operational measures in the context of planning processes and energy system analysis. Grid-related (transmission switching, transformers, HVDC systems, reactive power compensation), market-related and cross-sectoral measures are considered at transmission level (thermal and hydraulic power plants, central power-to-heat, wind offshore) and aggregated at distribution level (wind onshore, PV, distributed power-to-heat, combined heat and power, storage systems, load management, power-to-gas, electric mobility). In addition, preventive and curative measures are modeled and the applicability to large-scale transmission system structures is ensured.

In order to reduce the mathematical complexity, the simulation approach is divided into two sub procedures. The target of first sub procedure is the preselection of suitable transmission switching actions that are the input of the second sub procedure. The second sub procedure uses a linear approximation of power flow changes to optimize the preventive and curative use of all grid-related and central and distributed market-related measures to ensure system security. Hence, it is ensured no operational current limits are exceeded in normal and contingency situations as well as no voltage magnitudes and voltage angle differences exceed their operational limits in normal operation.

Results

The simulation model is applied to a scenario 2035 of the European energy system with a focus on the German transmission system. Within the investigations, different system operation concepts are analysed and, in particular, the influence of new operational measures on the redispatch volume is quantified.

The investigations show cross-sectoral and distributed flexibility options are used extensively to substitute the reduction of the infeed of renewable energies. The curative use of grid- and market-related measures enables a significant reduction of preventive redispatch volumes. However, the results suggest that the efficacy of curative measures depends largely on the operational and technical design of the system operation concept.

This includes permissible curative power adjustments as well as the interaction of weather-dependent permanent admissible transmission loadings with the dimensioning of temporary admissible transmission loadings. The simulation model allows comprehensive investigations of these interdependencies.

Contact
André Hoffrichter, M.Sc.
a.hoffrichter@iaew.rwth-aachen.de
+49 241 80 97654

Consideration of Uncertainties in the Determination of Remedial Measures in Transmission Grid Operational Planning

Annika Klettke, M.Sc.

Introduction

The increasing share of power plants based on renewable energy sources and the further integration of the European electricity market lead to a higher need for transport capacities in the transmission grid. This transport requirement can often not be satisfied, resulting in the need for remedial measures to ensure grid security. The basis for the determination of remedial measures is the deterministic (n-1) criterion based on forecasted congestion. However, estimates of the congestions are subject to uncertainties. These include the uncertain grid topology as well as forecast errors regarding the feed-in from power plants based on renewable energy sources. Basically, two approaches are conceivable that take these uncertainties into account in the deterministic determination of remedial measures. One possibility is the application of adding security margins to the maximum permissible currents of lines and transformers; another possibility is the consideration of multiple outages with an increased probability of cascading failures within the (n-1) criterion.

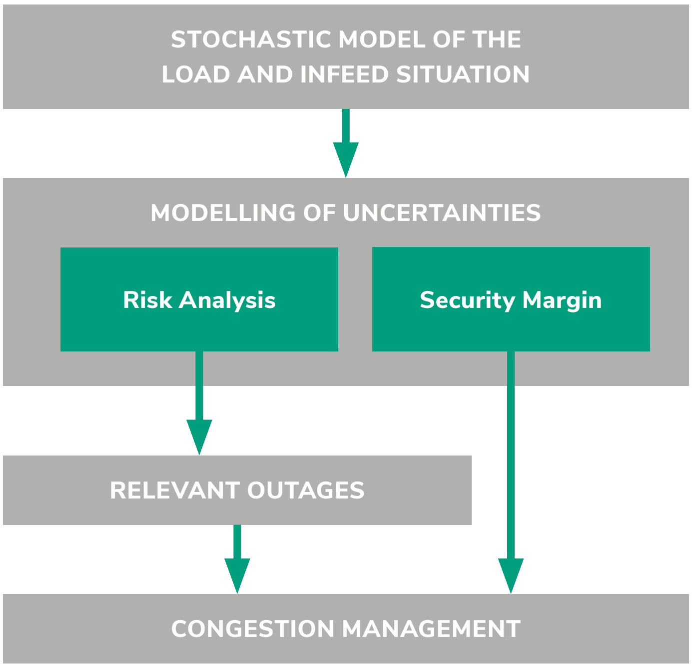


Figure: Overview Method

Method

The aim of this research is therefore to develop a method that can properly determine security margins and relevant multiple outages. In Figure 1, an overview of the method is given. The main part of the method is an analytic determination of the probabilistic power flow on the basis of the convolution of distribution functions of grid usage. With the generation of the stochastic model, the existing stochastic dependencies in the forecast errors are summarized into correlation groups which are stochastically independent of each other, thus making the convolution approach with its low computational time usable. This probabilistic load flow model is used for the modeling of uncertainties in risk analysis in the form of a cascade simulation for the identification and evaluation of multiple outages as well as in the stochastic determination of security margins.

Results

The method is applied to congestion management scenarios in the past (2017) and the future (2023). The results show a growing risk of the occurrence of cascading failures after multiple failures comparing the two years. The probabilistic evaluations on multiple outages indicate a need for an adjustment of the relevant outages per investigation year; an intraday adjustment is not shown to be necessary. The consideration of a security margin in the determination of the remedial measures for congestions can also reduce the risk of a critical cascading failure after the consideration of multiple failures and insecurities. However, this may require the start-up of expensive power plants due to corresponding start-up times.

Contact
Annika Klettke, M.Sc.
a.klettke@iaew.rwth-aachen.de
+49 241 80 97887

Reactive Power Procurement within Transmission and Subtransmission Grids

Design options for reactive power dispatch within the operation of transmission and subtransmission grids

Patrick Larscheid, M.Sc.

The expansion of distributed generating units (DGU) leads to a replacement of conventional generating units within the electric power system. This increasingly results in situations in which conventional generating units are not available for voltage control. On the other hand, DGU are able to compensate for this demand of reactive power provision to a certain extent. Current research shows that from a grid planning point of view, concepts of inter-coordinated reactive power provision between different voltage levels result in macroeconomic benefits. However, an increasing reactive power provision of DGU leads to an increase of losses within the DGU. Subject to current regulations, this reactive power provision is mostly exempt from charges for the grid operators. For an increasing reactive power feed-in by DGU, this might lead to an inefficient reactive power dispatch within grid operation.

Consequently, the question arises as to what extent new design options for reactive power procurement within the transmission and subtransmission grid can stimulate an efficient reactive power dispatch in grid operation. These design options incorporate appropriate concepts for an inter-coordinated reactive power dispatch between transmission and subtransmission level as well as appropriate remuneration schemes for the reactive power provision of grid users. This research project therefore investigates the economic impact of different regulatory designs of reactive power procurement within the operation of transmission and subtransmission grids.

For the evaluation of the design options, simulations of the grid operation of transmission and subtransmission level are conducted. In order to model the individual behaviour of each grid operator, the simulation approach uses a separate reactive power optimisation for each grid area of the grid operators. The concepts for inter-coordinated reactive power dispatch determine the degrees of freedom for the optimisation. The chosen remuneration scheme for the reactive power provision

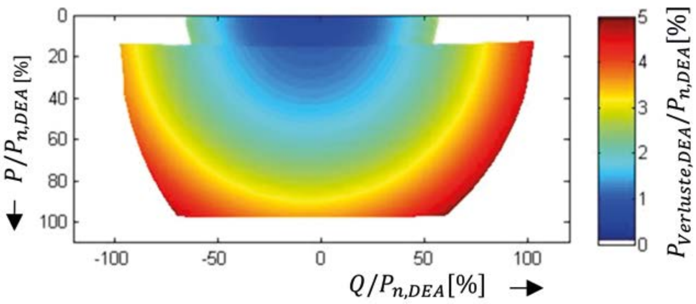


Figure: Model of internal losses of an representative wind park with doubly fed induction generators

determines the components of operational costs within the optimisation. In order to adequately esti-mate the internal losses of DGU, the implementation incorporates explicit models of the internal operational equipment of the operational units. The design options under consideration are evaluated based on the sum of losses of all grid operators and grid users. The results of a combined optimisation of all grid operators considering all losses are used as a benchmark.

Contact
Patrick Larscheid, M.Sc.
p.larscheid@iaew.rwth-aachen.de
+49 241 80 97888

Evaluation of Regulatory Instruments for Synchronizing the Expansion of Renewable Energy Systems with the German Transmission Grid

Lara Lück, M.Sc.

The expansion of renewable energy systems (RES) promoted by the Renewable Energy Sources Act (German: Erneuerbare-Energien-Gesetz (EEG)) has led to increasing congestions in the transmission grid in recent years. Increasing costs of congestion management are prompting political discussions on the use of regulatory instruments to synchronize the allocation of new RES with the expansion of the transmission grid's transport capacities. A number of different regulatory instruments are being debated. The question of which instruments offer added value in macroeconomic terms remains unresolved, since shifting the locations can mean a reduction in costs in congestion management, but also an increase in costs in the generation system if locations with lower electricity yields are used.

The aim of this thesis is therefore to assess the macroeconomic added value of regulatory instruments for synchronizing the expansion of wind energy and photovoltaic units with the German transmission grid with regard to their macroeconomic impact on the generation system and grid operation.

To answer this question, a model is developed and a simulation tool implemented (see Figure) which can simulate the regional distribution of wind energy as well as roof and ground-mounted photovoltaic systems. Relevant drivers are economic efficiency, land suitability and societal reservations, which together with regulatory instruments provide for a differentiation between sites and have to be considered. Based on the determined spatial distribution of future RES plants, the change in costs for electricity generation and redispatch and feed-in management measures can be derived using market and grid operation simulations.

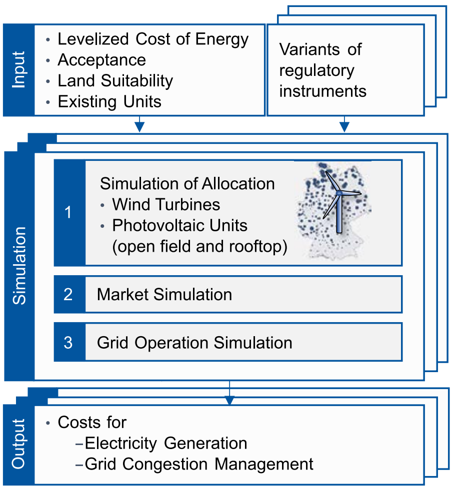


Figure: Simulation Approach

In representative studies, parameter estimates are first made to realistically simulate the relevant drivers. It is shown that a good agreement with the historical stock can be achieved by a suitable choice of parameters. Existing regulatory approaches – the quantity control of the total expansion and the reference yield model – are taken into account. This is followed by the evaluation of additional control instruments for onshore wind energy plants in 2025. Results of six variants show reductions but no complete avoidance of transmission grid congestions. Cost savings in congestion management are, however, offset by additional costs in the generation system, resulting in a slightly positive or negative added value depending on the economic variant. A certain excess of the transport capacity of the transmission system through plant allocation proves to be quite efficient from a macroeconomic point of view.

Contact
Lara Lück, M.Sc.
lara.lueck@iaew.rwth-aachen.de
+49 241 80 97883

Voltage Stability during Volatile Transmission Tasks

Investigation of voltage-stability in the German electrical power system in the long-term period

Moritz Maercks, M.Sc.

Today's transmission grid has been designed to transport reserve power between basically independent areas. Due to the fundamental change in the composition of power plant units brought about by the German energy transition as well as increasing international power trading, transmission networks will transmit power over long distances more frequently in the future. Especially the high share of generation from facilities based on renewable energies causes an increased volatility of the transferred power. Various research projects and studies show that the modified supply task substantially affects voltage stability. Therefore, German transmission system operators build reactive power compensation systems for enhanced voltage control. It is not yet analysed to what extent voltage stability is influenced by dynamic effects and whether the integration of dynamically controllable reactive power sources and rapid interventions in power system operation would be beneficial or crucial. Thus, in this research project a method was developed to examine interdependencies causing voltage instability for the long-term horizon. The method allows the simulation of power systems for the long-term horizon to investigate voltage stability, neglecting short-term effects and frequency stability. Various models particularly allow for the consideration of volatile feed-in/feed-out situations, automatically switched tap-changing transformers, rule-based applied reactive power compensation systems, voltage-dependent loads including load recovery effects, component outages including secondary failures due to the triggering of various protection systems, and dynamically changing control power supply. The resulting differential algebraic system is solved using an implicit integration method. The solution is performed piecewise with appropriate reinitializations due to events changing the equation system, for example in the event of component failures. The investigations examine the effects of critical component failures causing voltage instability. By simulating secondary failures with varied reaction times to carry out grid operating measures, the necessity of taking dynamic interdependencies into consideration when investigating long-term voltage stability is shown. The Figure shows initial simulation results of a small test network with a volatile supply task.

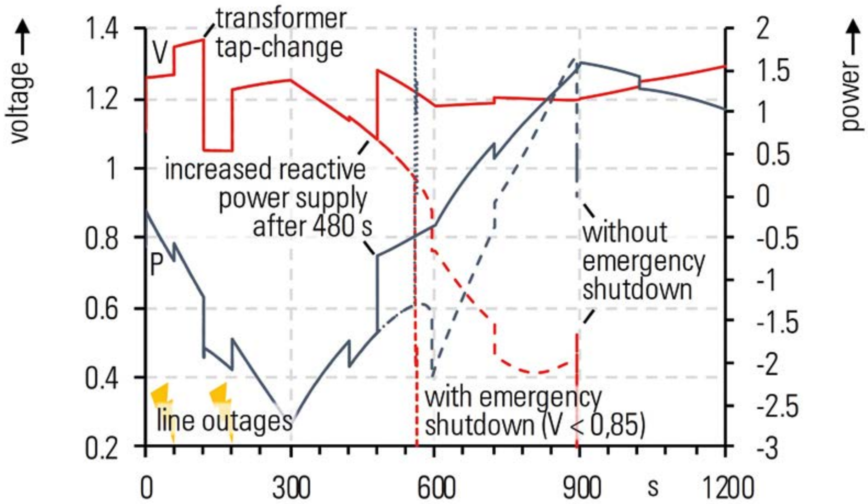


Figure: (In-)stable simulation results (voltage V and load P at load) during volatile supply task.

Contact
Moritz Maercks, M.Sc.
moritz.maercks@rwth-aachen.de

Stochastic Unit Commitment in Day-Ahead and Intraday Electricity Markets

Moritz Nobis, M.Sc.

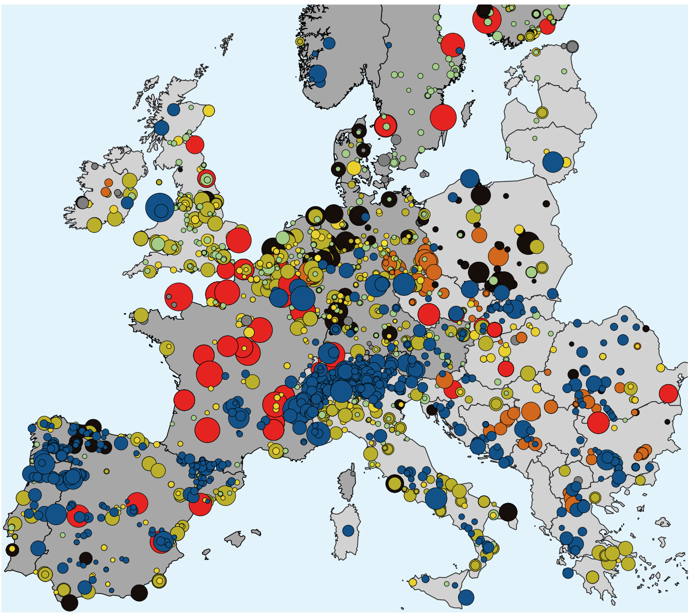


Figure: Consideration of all hydro-thermal units in Europe in the day-ahead and intraday simulation in a spatially high-resolution

The decarbonization of energy generation is leading to a steady increase in generation capacity from weather-dependent wind energy and photovoltaic plants prone to forecasting errors. As a result, trading volumes on the intraday market, which enables the intraday trading of forecasting errors from renewable energies and the electrical load until a few minutes before physical delivery, are also gradually increasing. The volume uncertainty on the intraday market leads to price uncertainty. This makes the intraday market increasingly relevant in unit commitment decisions for all market participants.

The bottom-up modeling of techno-economic causal relationships in electricity markets via computer models is of central importance for energy system planning. However, no method is currently able to adequately reflect forecasting uncertainties and risk metrics in large-scale systems due to complexity limitations. Thus, it is not yet possible to realistically map power plant operations for future energy systems.

Within the scope of this work, a method is developed which simulates the electricity market bottom-up by making block-specific commitment decisions for the entire power plant fleet of the European interconnected grid, taking into account all relevant technical and economic boundary conditions. This method considers forecasting errors of wind energy and photovoltaic plants and the electrical load and thus also depicts, in addition to a day-ahead market, an intraday market. The marketing risk resulting from forecasting uncertainty is included in the marketing decision by including conditional value-at-risk. Endogenous market coupling on the day-ahead and intraday markets is also integrated into the model. The method becomes applicable only through the development of an innovative nested mathematical decomposition, which couples an extended Benders formulation with a Lagrangian relaxation.

In a back test, the method shows realistic market prices and unit commitment decisions. By applying it to scenarios for 2023 and 2035, rising spot prices and a rising intraday-day-ahead spread can be derived. Intraday market coupling, which is currently being successively expanded, shows a wealth-optimizing and price-dampening effect. In addition, based on the scenarios, increasing contribution margins for gas-fired power plants can be expected, which will partly exceed annuity investment costs in 2035 and thus potentially set investment signals.

i

Contact
Moritz Nobis, M.Sc.
moritz.nobis@gmail.com

Investigating Interactions of HVDC Converters and the Transmission Grid

Development of a measurement-based approach for assessing harmonic stability in the frequency domain

Matthias Quester, M.Sc.

Converters such as modular multilevel converters (MMCs) and their control system can potentially interact with other active components as well as the grid impedance resulting in high oscillations and unstable systems. This stability phenomenon is often referred to as harmonic instability. To investigate this phenomenon, this work develops MMC models in the frequency domain to investigate potential interactions by the impedance-based approach. This approach applies frequency-dependent impedance models of two systems and assesses potential interactions by means of classical control theory tools such as the Nyquist criterion or phase and gain margins obtained from Bode plots. As traditional methods cannot be applied to black-boxed models, which are often provided when intellectual property is a concern, this work seeks to establish and validate a method which can be applied to power converters with pre-existing and/or black-boxed control systems. The method is applicable for both simulated converter circuits as well as physical test benches such as the MMC Test Bench at IEAW. By comparing simulation and laboratory results, modelling assumptions are challenged.

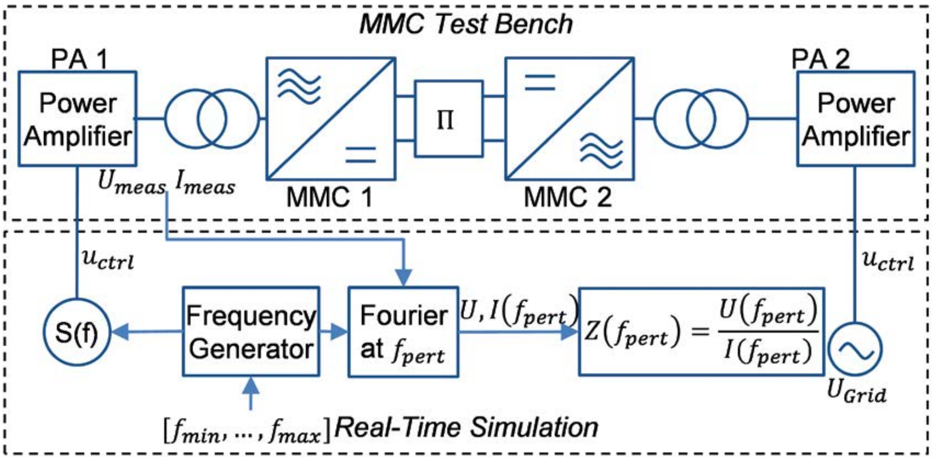


Figure: MMC Test Bench impedance measurement setup

Deriving the converter impedance

The power hardware setup to measure the MMC Test Bench impedance can be divided into two parts, the power hardware part (MMC Test Bench) and the simulated part (Real-Time Simulation). The MMC Test Bench uses two MMCs connected by PI sections on the DC side. Y-D transformers transform the grid voltage supplied by the power amplifiers from 208 V to 400 V as required by the converters. The real-time simulation is coupled with the MMC Test Bench through analogue input and output ports. The measured signals are comprised of the voltage signals U_{meas} and the current signals I_{meas} measured at the terminal of PA 1. The signals are processed in real-time by Fourier analysis over a running window calculating the voltage and current share at perturbation frequency, f_{pert} provided by the frequency generator. The resulting voltage $U(f_{pert})$ and current $I(f_{pert})$ at f_{pert} determine the frequency-dependent impedance $Z(f_{pert})$ of the MMC Test Bench. The developed impedance method implements a perturbation signal injection approach and Fourier analysis in real time so that only the computed impedance data needs to be saved with low sampling rate. Thus, no high resolution voltage and current measurement data for further post processing is required. As a result, a large number of measurements can be conducted and used for assessing the harmonic stability of different scenarios and converter control systems.

Contact
Matthias Quester, M.Sc.
m.quester@iaew.rwth-aachen.de
+49 241 80 97691

Local Balancing of Generation and Consumption

Requirements on the distribution system while increasing the local balance of generation and consumption

Patrick Schultheis, M.Sc.

Acceptance barriers in the realization of major infrastructure projects, such as extensive expansions of the transmission grid and increasing generation based on renewable energies, are leading to a paradigm shift in the electricity supply system in Europe. In this context, a frequently discussed trend is the active coordinated consumption of locally generated electricity. This trend is supported by both increasingly decentralized power generation as well as by a further digitalization of the power system, which in particular enables the control of new consumer technologies.

Objective

Either the integration of additional power generation plants or the integration of additional temporal flexibility options in the form of electricity storage systems can increase the local balance of generation and consumption. These can be used in order to locally balance consumption and production. The integration of both power generation plants and electricity storage systems affect the requirements on the local distribution grid. Therefore, the objective of this thesis is the investigation of the requirements on a distribution system consisting of power generation plants, electricity storage systems and on the grid while increasing the degree of local balance.

Measures for local balancing

As a measure of the consumption of local production in a local supply area, the degree of energetic self-sufficiency (DES) and the degree of power-related self-sufficiency (DPS) can be used. The former indicates the proportion of consumption that can be covered by local production in a given time period, whereas DPS describes the share of consumption which is actually covered at any point in time by local power generation.

Methods

In a two-step greenfield approach, first the integration of power generation plants increases the DES. Based on this, a genetic algorithm is then used to dimension the distribution grid and the electricity storage systems for a minimum required DPS. The local balancing is carried out by a bottom-up mechanism (based on a cellular approach): starting from households, balancing takes place within the smallest possible balancing area and the remaining performance deficit or surplus is passed to an overlaid balancing area, where again generation and consumption are balanced.

The resulting requirements on the local distribution systems show the interactions with the degree of local balance.

i

Contact
Patrick Schultheis, M.Sc.
p.schultheis@iaew.rwth-aachen.de
+49 241 80 97655

Impact of the Demand Structure on Sector-coupled Electricity and Gas Energy Supply Systems

Levin Skiba, M.Sc.

Greenhouse Gas Neutrality as the European Goal for 2050

In 2017, the global average temperature increase caused by humans reached 1.0 °C compared to the pre-industrial age [1]. Particularly the carbon dioxide (CO_2) emissions resulting from the combustion and use of fossil fuels cause the greenhouse effect, which is responsible for the heating of earth's atmosphere. Unless decisive measures are taken to limit the increasing concentration of CO_2 and other greenhouse gases (GHG) in the earth's atmosphere, a further global temperature increase with devastating consequences is to be expected [1]. Therefore, in the Paris Agreement of 2015 [2], the international community has set the goal of limiting the global temperature increase to a maximum of 2 °C and – if possible – to 1.5 °C compared to the pre-industrial age. To achieve this goal, greenhouse gas emissions need to be reduced worldwide. Based on the Paris Agreement, the European Union has set itself the goal of becoming GHG-neutral by 2050 [3, 4].

Necessity of Greenhouse Gas Neutral Energy Carriers impacts Development of Sector-Coupled Energy Systems

In order to achieve this goal, it is necessary to reduce the use of fossil fuels drastically. A significant proportion of energy conversion assets must be converted or replaced in such a way that either GHG-free or GHG-neutral energy carriers such as electricity from renewable sources, hydrogen or synthetic methane are used. It is currently unclear which assets will prevail in the respective consumer sectors and which energy carriers will cover future energy demand. These energy carriers have different systemic advantages and disadvantages due to their storability and transportability as well as their energy content, production efforts and import possibilities. Thus, the amount and temporal structure of demand has a considerable impact on the design of the future energy supply system by significantly influencing the necessary generation, storage, conversion and transmission capacities. Therefore, the question arises as to what effects different demand structures will have on the economically optimal sector-coupled energy supply system.

Simulative Analysis of Future Developments of the European Energy System

The aim of this research project is therefore to develop an investment simulation model for generation, storage, conversion and transmission capacities, taking into account different demand developments for electricity, hydrogen, methane and other energy carriers. The model is based on a linear optimization problem that minimizes investment and operating costs while maintaining essential constraints such as expansion restrictions, demand coverage, CO_2 emission restrictions and operating limits of assets. The method will be employed in a scenario simulating the development of the European energy system from 2020 to 2050. Variation simulations lay out possible exogenously given developments on the consumer side, which manifest themselves in different demands of the simulated energy carriers. The expected results allow conclusions regarding the effects of different demand structures on the optimal development of the European energy supply system. The finalization of this research project is expected for the end of 2020.

References

[1] IPCC, Global warming of 1.5°C, 2018.

[2] UNFCCC, Paris Agreement, 2015.

[3] EU Kommission, Commission proposal for a regulation: European Climate Law, 2020.

[4] EU Kommission, The European Green Deal, 2019.

i

Contact

Levin Skiba, M.Sc.

l.skiba@iaew.rwth-aachen.de

+49 241 80 96733

Publications

Arning, Katrin; Zaunbrecher, Barbara Sophie; Borning, Maximilian; van Bracht, Niklas; Ziefle, Martina; Moser, Albert
Does Size Matter? Investigating Laypeoples' Preferences for Roll-out Scenarios of Alternative Fuel Production Plants
8th International Conference on Smart Cities and Green ICT Systems, Heraklion (Greece), 3 May 2019 - 5 May 2019

Baumanns, Philipp Toni
Berechnung probabilistischer Kenngrössen zur Resource Adequacy in der europäischen Energiewende; 1. Auflage
printproduction M. Wolff GmbH, Aachen, 2019

Baumanns, Philipp; Gaumnitz, Felix; Ballmann, Ida; Moser, Albert
Bewertung der Versorgungssicherheit unter Berücksichtigung grenzüberschreitender Austauschkapazitäten im Übertragungsnetz
11. Internationale Energiewirtschaftstagung an der TU WIEN, IEWT, 13 Feb 2019 - 15 Feb 2019, Vienna, Austria

Beulertz, Daniel; Charousset, Sandrine; Most, Dieter; Giannelos, Spyros; Yueksel-Erguen, Inci
Development of a Modular Framework for Future Energy System Analysis
54th International Universities Power Engineering Conference, Bucharest (Romania), 3 Sep 2019 - 6 Sep 2019

Borning, M.; Moser, A.
Integrated Grid and Power Market Simulation: Investigating the Required Modeling Level of Detail
16th International Conference on the European Energy Market, Ljubljana (Slovenia), 18 Sep 2019 - 20 Sep 2019

Cieslak, Carola Alice; Grunwald, Lena
Modelling Synthetic Inertia of Wind Turbines for Dynamic Power System Stability Studies
54th International Universities Power Engineering Conference, Bucharest (Romania), 3 Sep 2019 - 6 Sep 2019

Fehler, Alexander; vom Stein, Denis; Schmid, D.; Moser, Albert; Rehtanz, Christian
Dezentrale Flexibilitätsbewirtschaftung – markt-, netz- und systemdienlicher Einsatz
11. Internationale Energiewirtschaftstagung an der TU WIEN, IEWT, 13 Feb 2019 - 15 Feb 2019, Vienna, Austria

Franken, Marco Sebastian; Barrios Büchel, Hans; Schrief, Alexander; Puffer, Ralf
Transmission Expansion Planning Considering Detailed Modeling of Expansion Costs
IEEE Milan PowerTech, Milan (Italy), 23 Jun 2019 - 27 Jun 2019

Franken, Marco Sebastian; Barrios Büchel, Hans; Schrief, Alexander; Puffer, Ralf
Identification of Suitable Locations for HVDC Links within Meshed AC Networks
IEEE PES Innovative Smart Grid Technologies Europe (ISGT-Europe), Bucharest (Romania), 29 Sep 2019 - 2 Oct 2019

Hoffrichter, Andre; Kollenda, Katharina Marie; Schneider, Maximilian; Puffer, Ralf
Simulation of Curative Congestion Management in Large-Scale Transmission Grids
54th International Universities Power Engineering Conference, Bucharest (Romania), 3 Sep 2019 - 6 Sep 2019

Hoffrichter, Andre; Offergeld, Thomas; Kulms, Tom; Blank, Andreas
Simulation of Transmission Grid Operation Incorporating Flexibility at Distribution Level
16th International Conference on the European Energy Market, Ljubljana (Slovenia), 18 Sep 2019 - 20 Sep 2019

Houben, Raphael; Löhr, Lukas; Moser, Albert
Integrated Optimization of Large Scale Power and Gas Flow Problems
Power and Energy Student Summit, Magdeburg (Germany), 9 Jul 2019 - 11 Jul 2019

Kellermann, Jan
Bewertung von Netzausbauplänen in Hochspannungsnetzen unter Berücksichtigung von betrieblicher Flexibilität und planerischen Unsicherheiten; 1. Auflage
Aachener Beiträge zur Energieversorgung, Band 194, printproduction M. Wolff GmbH, Aachen, 2019

Klettke, Annika; Petkov, Iliya; Moser, Albert
Modelling of Stochastically Dependent Forecast Errors for Load Flow Simulations in the Transmission Grid Using Convolution
21st European Conference on Power Electronics and Applications, Genova (Italy), 3 Sep 2019 - 5 Sep 2019

Klettke, Annika; Sieberichs, Marius; Moser, Albert
Operational concepts of HVDC in the context of security assessment in the German transmission grid
Global Energy Interconnection, 2, 130-132, Apr 2019

Knittel, Markus; Ghare, Rajat Satish; Schneider, Maximilian; Quester, Matthias Andreas
Performance of Local Shunt Controls in Transmission Grids for Transient Voltage Fluctuations
International ETG-Congress 2019

Knittel, Markus; Massmann, Janek; Schmitt, Carlo; Kamenschikow, Dmitrij
Dispatch of reactive power compensators in transmission grids
Electric power systems research, 180, 106-126, 2019

Knittel, Markus; Namockel, Nils; Schneider, Maximilian; Puffer, Ralf
Reactive Power Loop Flows in Transmission Grids
IEEE Milan PowerTech, Milan (Italy), 23 Jun 2019 - 27 Jun 2019

Maercks, Moritz; Moser, Albert
Herausforderungen bei der dezentralen Regelung von MSCDN während volatiler Übertragungsaufgaben
11. Internationale Energiewirtschaftstagung an der TU WIEN, IEWT, 13 Feb 2019 - 15 Feb 2019, Vienna, Austria

Marjanovic, Ivan
Bewertung von lastflussbasierten Kapazitätsmodellen unter Berücksichtigung von Unsicherheiten; 1. Auflage
Aachener Beiträge zur Energieversorgung, Band 197,
printproduction M. Wolff GmbH, Aachen, 2019

Massmann, Janek
Stabilitätsanalyse des Übertragungsnetzes unter Berücksichtigung hoher Durchdringungsgrade erneuerbarer Energien in den Verteilungsnetzen; 1. Auflage
Verlagshaus Mainz GmbH, Aachen, 2019

Mittelstaedt, Moritz
Methodik zur Bewertung der Spannungsstabilität in Übertragungsnetzen; 1. Auflage
Verlagshaus Mainz GmbH, Aachen, 2019

Müller, Christoph Bernhard; Hoffrichter, Andre; Wyrwoll, Lothar; Schmitt, Carlo; Trageser, Marc; Kulms, Tom; Beulertz, Daniel Johannes; Metzger, Michael; Duckheim, Mathias; Huber, Matthias; Küppers, Martin; Most, Dieter; Paulus, Simon; Heger, Hans Jörg; Schnettler, Armin
Modeling Framework for Planning and Operation of Multi-Modal Energy Systems in the Case of Germany
Applied energy, 250, 1132-1146, 2019

Nobis, Moritz; Blank, Andreas; Kollenda, Katharina Marie; Schwaeppe, Henrik; Vassilopoulos, Philippe; Martin, Arnault
Mid-Term Congestions Forecast in the GermanTransmission Grid
54th International Universities Power Engineering Conference,
Bucharest (Romania), 3 Sep 2019 - 6 Sep 2019

Nobis, Moritz; Clever, Jacqueline; Thie, Nicolas; Schnettler, Armin
Modeling forecasting errors of fluctuating renewables and electrical loads
16th International Conference on the European Energy Market,
Ljubljana (Slovenia), 18 Sep 2019 - 20 Sep 2019

Nobis, Moritz; Kulms, Tom
Evaluating regulatory measures in the German energy transition – A European multimodal market optimization approach including distributed flexibilities
42nd International Association for Energy Economics (IAEE)
Annual Conference, Montréal (Canada), 28 May 2019 - 1 Jun 2019

Nobis, Moritz; Schmitt, Carlo; Lindner, Alexander
Extended Benders Decomposition for CVaR-constrained unit commitment decisions in pan-European energy system models considering feed-in uncertainties
16th IAEE European Conference Ljubljana,
Ljubljana (Slovenia), 25 Aug 2019 - 29 Aug 2019

Schmitt, Carlo; Cramer, Wilhelm;
Bartolomei Viegas de Vasconcelos, Maria do Carmo; Thie, Nicolas
Impact of Spot Market Interfaces on Local Energy Market Trading
16th International Conference on the European Energy Market,
Ljubljana (Slovenia), 18 Sep 2019 - 20 Sep 2019

Schneider, Maximilian; Hoffrichter, Andre; Puffer, Ralf
Theoretical Potential of Dynamic Line Ratings for Congestion Management in Large-Scale Power Systems
IEEE Milan PowerTech, Milan (Italy), 23 Jun 2019 - 27 Jun 2019

Schultheis, Patrick; Pauschinger, Sophia; Moser, Albert
Influence of Flexible Consumers on Local Balancing of Generation and Consumption
IEEE Milan PowerTech, Milan (Italy), 23 Jun 2019 - 27 Jun 2019

Schultheis, Patrick; Peeters, A.; Moser, Albert
Positionierung und Dimensionierung von Batteriespeichern zum lokalen Ausgleich von Erzeugung und Verbrauch
11. Internationale Energiewirtschaftstagung an der TU WIEN, IEWT,
13 Feb 2019 - 15 Feb 2019, Vienna, Austria

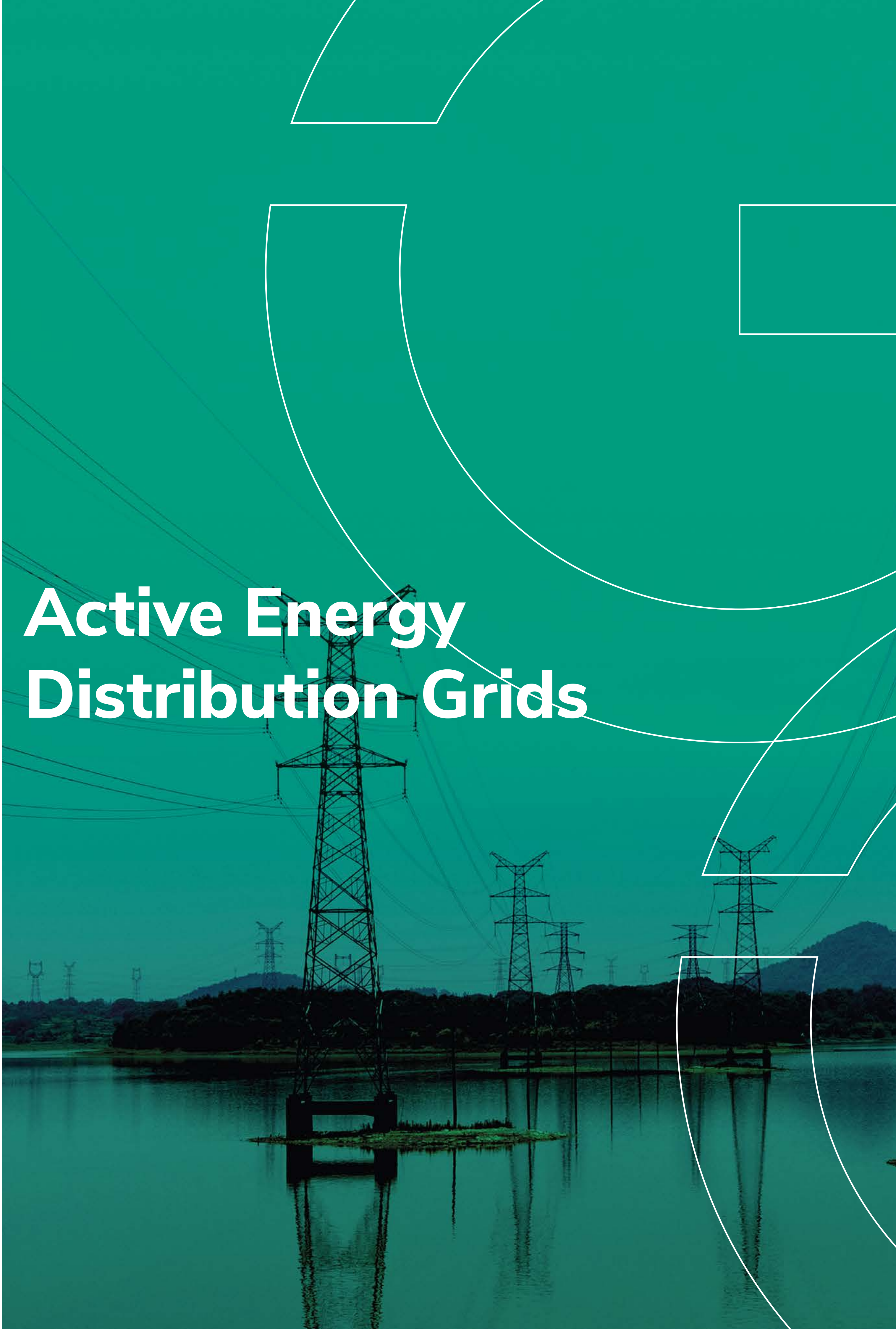
Siemonsmeier, Marius; Sprey, Jens; Palmowski N.; Moser, Albert
Congestion Management in European Transmission Grids – A Comparative Assessment of Different Concepts
16th International Conference on the European Energy Market,
Ljubljana (Slovenia), 18 Sep 2019 - 20 Sep 2019

Sprey, Jens D.
Bemessung der Frequency Restoration Reserve unter Berücksichtigung regionaler Kernanteile bei hohem Anteil erneuerbarer Energien
Aachener Beiträge zur Energieversorgung, Band 191,
printproduction M. Wolff GmbH, Aachen, 2019

Thie, Nicolas; Bartolomei Viegas de Vasconcelos, Maria do Carmo
Evaluating the Business Case for Flexibilities as RiskManagement in Direct Marketing of Renewable Energies
42nd International Association for Energy Economics (IAEE)
Annual Conference, Montréal (Canada), 28 May 2019 - 1 Jun 2019

Thie, Nicolas; Schwarz, Nordin Alexander; Junge, Eric; Hillenbrand, Sascha; Konermann, Martin
Evaluation of Grid Compatible Load Management Concepts for E-Mobility in Distribution Grids
54th International Universities Power Engineering Conference,
Bucharest (Romania), 3 Sep 2019 - 6 Sep 2019

Active Energy Distribution Grids




FGE
FORSCHUNGSGESELLSCHAFT
ENERGIE

Chair for Active Energy Distribution Grids

In the course of the shift from conventional, hierarchical energy systems towards a sustainable, small scale supply structure, distribution grids play a major role. The increasing share of distributed energy resources (DER) installed in distribution grids (over 90 % of the total capacity in 2018, [Bundesnetzagentur]) requires efficient coordination strategies at technological, infrastructural and operational levels. Besides the dimensioning and positioning of units used for the production, storage or cross-sectoral electrification of consumption, their impact on the existing infrastructure must be quantitatively assessed and suitable countermeasures must be identified. In particular, existing or potential market-oriented DER operational strategies, such as pooling for direct trading or trading on local markets, must be taken into account.

Besides the decentralization of generation and flexibility resources, two further influencing factors have a disruptive effect on the conventional planning and operation tasks of the energy sector. On the one hand, a cross-sectoral decarbonization is required to achieve international climate policy goals, which can be obtained mainly through the electrification of the heating and mobility sectors. The resulting sector coupling requires an overall planning of the technological (P2H, P2G, etc.) and infrastructural (electricity, gas, heating and charging infrastructures) expansion measures, which in a distributed context are increasingly assigned to the municipal remit. This planning further enhances the significance of efficiency measures counteracting the otherwise steep increase of the electricity demand. On the other hand, innovative coordination mechanisms for DER operation require suitable and resilient information and communication technologies (ICT). The digitalization of power systems thus complements the planning task by a coordinated set up of the ICT infrastructure. A key challenge in this context is ensuring security and reliability in order to avoid turning the ICT infrastructure into a critical vulnerability for power systems.

The Chair for Active Energy Distribution Grids develops holistic approaches for the increasingly interconnected and complex planning and operation of energy systems in cooperation with the Fraunhofer institutes FIT and FKIE. The Chair's test center for grid integration further enables an empirical testing and validation of the developed approaches.

Key competencies

An extensive understanding of the underlying physical and operational processes is a necessary prerequisite for a future-oriented research in active energy distribution grids. Our chair's basis for that was created over several years and in cooperation with distribution system operators, utilities and other industry partners through the development and upkeep of the following key competencies:

- **Expansion and target-grid planning:**
  Based on synthetic, real or model grids, reinforcement or expansion measures are determined taking future supply tasks, technical requirements and reliability of supply into account. Furthermore, optimal target-grids can be determined based on predefined supply tasks by means of a green-field approach.

- **Innovative grid operation:**
  innovative approaches for distribution grid operation, which primarily focus on the integration of distributed flexibility in operational processes, yield the potential for reducing or avoiding grid expansion and point out the necessary infrastructural and operational measures needed to implement them.

- **Stability analyses:**
  By means of stability analyses, conclusions regarding the transient operation for both the grid-coupled and the island operation modes can be drawn.

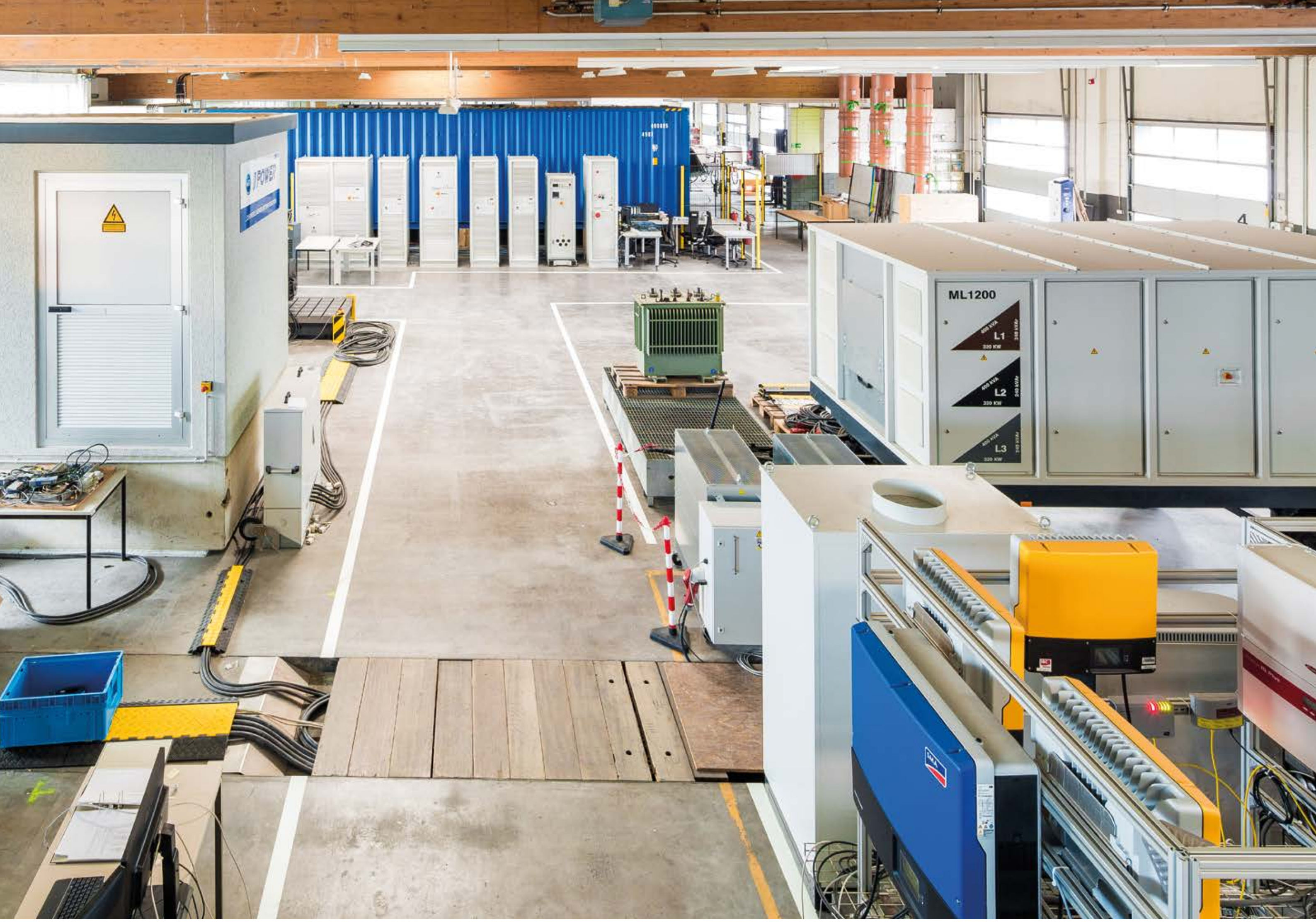


Figure: Center for Grid Integration

Innovation areas

The Chair's current research focus areas comprise mainly interface domains combining roles and responsibilities, sectors and branches. The classical grid expansion planning becomes an interconnected infrastructural planning, handling electrical, heating, and gas networks as well as charging and ICT infrastructures in an integrated manner. In this context, the planning of multimodal districts plays an increasingly significant role. We develop economic-ecological optimization methods for the identification of cross-building efficiency and expansion measures, which, under consideration of the current or future legal-regulatory framework, offers a substantiated basis for decision-makers.

A key prerequisite for the success of sustainable, sector coupling power systems is to enable a profitable operation of DER. Potential realizations of a multimodal operational planning of DER within local markets, district-level approaches or virtual power plants as well as the assessment of the resulting operational strategies are an ongoing research topic at our Chair.

A further area of research involves analyzing the impact of an increasing share of inverter-coupled units on distribution grids, in particular with respect to harmonic stability, innovative protection systems and the potential contribution of these units to the inertia in overlying grids. We also assess the potential added-value of innovative grid assets for grid operation, e.g. for load flow management.

A further key challenge is resilience in the context of increasingly digitalized power systems. The development of approaches for the prevention, detection and reaction of coordinated cyberattacks is an intensive interdisciplinary exercise, which aims at transferring the expertise and experience of the IT sector to the so far widely unexplored domain of digitalized distribution networks. We address these research questions at conceptual, simulative and experimental levels in the institute's Center for Grid Integration

Research Campus Flexible Electrical Networks (FEN)

Modeling, planning, conceptual design and assessment of future grids

Background and Motivation

In the past, alternating current technology prevailed over direct current technology due to the transformability of voltages. Today, key components for grids based on direct current technology are available due to technological progress of power electronic devices. In addition to their technical feasibility, decreasing costs also make these grids increasingly attractive from a scientific and industrial perspective. The increasing number of direct current-based grid users offers direct current technology the possibility of improving the efficiency of distribution grid operation. Moreover, the implementation of converters leads to controllable power flows, leading to higher flexibility. The aim of Research Campus Flexible Electrical Networks (FEN) is therefore the investigation of innovative direct current distribution grids for the future power supply.

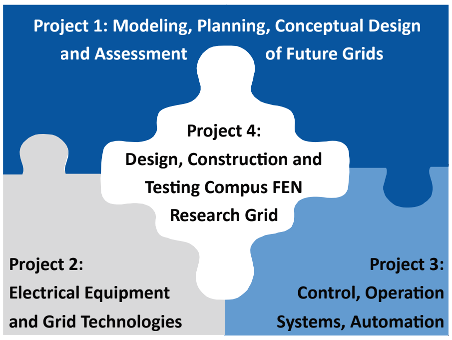


Figure: Projectstructur of 1th funding phase

Project Structure

For this purpose, a variety of RWTH Aachen University chairs and institutes with an electro- and socio-technical background conducts research in the field of distribution grids based on direct current technology in cooperation with a large number of industry partners. With regards to medium voltage grids, four projects (see Figure) have been funded by the Federal Ministry of Education and Research from Oct. 2014 until Sep. 2019. In the course of this, the IAEW acted as the leader for the project "Modeling, Planning, Conceptual Design and Assessment of Future Grids". In the following, the core findings of this project are described.

Simulation Findings

For medium voltage direct current (MVDC) grids, meshed grid structures that connect several primary substations proved to be advantageous due to the possibility of power flow control. Based on this, a sufficiently high reliability in the grid requires the design of a grid protection concept which allows several selective switch-off areas. Therefore, a detection and localization approach based on wavelets turned out to be very promising. Furthermore, simulations were able to prove that the single focus on the transition from MVAC to MVDC grids with remaining AC low voltage level networks cannot appropriately leverage the potential of DC technology. In addition, no ad-hoc transition of today's grid infrastructure will be expected.

Conclusion

Based on the results of the four projects, further questions are planned to be answered during a second phase of funding. There, an integrated planning of medium and low voltage and initial real mid-term applications will be the main research objectives.

i

Project Acronym
FEN

Project Duration
Okt 2014 – Sept 2019

Main Partners
E.ON SE, Infineon Technologies, Hitachi Europe, Hyosung Corporation, MR Maschinenfabrik Reinhausen, AixControl

Contact
Raphael Bleilevens, M.Sc.
r.bleilevens@iaew.rwth-aachen.de
+49 241 80 93049

Supported by:
Federal Ministry for Economic Affairs and Energy
on the basis of a decision by the German Bundestag

EU H2020 – PHOENIX

Electrical Power System's Shield against complex incidents and extensive cyber and privacy attacks

The PHOENIX project is a joint project funded by the European Union to improve the cyber security of the European electricity and energy system. The aim of PHOENIX is to support cyber-physical security through collaborative detection of abnormal incidents and attacks on security and privacy, to ensure continuity of operations, to increase resilience and to minimize their cascading effects. Within PHOENIX three strategic goals are pursued:

- Increasing the resilience against cyber attacks through the use of "security by design" and "security by innovation" security solutions.
- Coordination of European event detection and response to critical incidents and the restoration of a secure operating point.
- Support of research and innovation in the field of cyber security of critical infrastructures.

Figure: PHOENIX Logo

The consortium and the role of RWTH in PHOENIX

The PHOENIX consortium consists of 24 partners from ten different countries, covering all necessary stakeholders. The above-mentioned goals are achieved by developing and deploying a platform that uses a secure and privacy-compliant communication architecture. The core component of the platform is the module "Situational Awareness and Incident Mitigation", which performs intrusion detection, attack classification, risk assessment and activation of appropriate countermeasures. The IAEW and Institute for Automation of Complex Power Systems (ACS) of RWTH Aachen University will make a significant contribution to the development of this platform. In this context, methods for identifying and assessing vulnerabilities and potential threats as well as detection and correlation methods will be developed. Moreover, suitable countermeasures will be investigated. These methods will be validated in a laboratory environment to be deployed and further validated in large-scale pilots.

Large scale pilots

PHOENIX will include real-world scenarios to validate the effectiveness of the established platform in five European large-scale pilots in Italy, Sweden, Slovenia, Greece and Romania, covering the entire value chain from generation to consumption. Beyond the individual large-scale pilots, cascade effects on other critical infrastructures will be simulated and cross-border security and privacy compliance will be tested and validated at the respective sites. A further platform will be set up to enable the exchange of information and security incidents between the pilot sites on a pan-European level. Further information on the large-scale pilots and the platforms can be found on the official PHOENIX website https://phoenix-h2020.eu/.

i

Project Acronym
PHOENIX

Project Duration
Sept 2019 – Aug 2022

Main Partners
Capgemini, Thales Group, DNV-GL, ATOS IT, E.ON

Contact
Ömer Sen, M.Sc.
o.sen@iaew.rwth-aachen.de
+49 241 80 94913

Supported by
This project has received funding from the European Union's Horizon 2020 research and innovation programme

Quarter Electricity Heat Optimization

Integrative planning and metrological accompanied implementation of decentralized energy supply concepts in four model quarters

In the wake of the energy transition, municipal transition initiatives are increasingly focusing on the modernisation of the building sector. Available modernisation instruments are manifold and include the use of efficient electricity and heat generation systems (e.g. PV systems and heat pumps), the integration of energy storage systems and the refurbishment of building envelopes. In particular, inter-building energy supply solutions are considered to be especially relevant.

The research project EnEff:Stadt: Q-SWOP addresses the planning and implementation of such decentralized energy supply concepts in the form of demonstration cases in four model quarters. One essential challenge lies in the identification of a combination of measures - among a wide range of alternatives - by which the energy-related climate protection efforts of the various neighbourhood stakeholders can be realised as effectively and economically as possible.

To support decision-making in the integrative neighbourhood planning, a computer-based tool is employed. The method was originally developed as part of the predecessor project EnEff:Stadt: Modellstadt25+ / Lampertheim effizient (2012-2017). A key objective of the current project is to increase the applicability of this method. The findings gathered from the practical application, detailed construction planning and consecutive implementation of the refurbishment and construction measures are incorporated into further developments so as to increase the suitability for practical use.

The research is supported by a scientific measurement program which includes the installation of comprehensive measurement technology for the long-term collection of energy and weather data in selected buildings. A central component

Figure: Survey of the four model districts in the project EnEff:Stadt: Q-SWOP

in the derivation of requirements for further process developments is the analysis and evaluation of the data collected. Based on these findings, more attention will be devoted to features of real plant and user behaviour.

For a broader applicability, a further development path aims at the integration of prospective relevant technologies and efficiency concepts. With the increasing electrification of the individual transportation system, placement procedures for the charging infrastructure of electric vehicles for multiple users are gaining particular importance for neighbourhood development plans. Moreover, future district electricity concepts designed to provide a joint and coordinated electricity supply also require special attention.

i

Project Acronym
EnEff:Stadt: Q-SWOP

Project Duration
Okt 2018 – Sept 2023

Main Partners
RWTH Aachen, Energy Effizienz GmbH, Transferstelle Bingen

Contact
Nils Körber, M.Sc.
n.koerber@iaew.rwth-aachen.de
+49 241 80 93051

Supported by:
Federal Ministry for Economic Affairs and Energy
on the basis of a decision by the German Bundestag

U-Quality

Effects of future low-voltage grid usage cases on power quality and its control

For the reliable operation of components connected to the electrical power supply grid, it is necessary to maintain voltage quality characteristics. End customers within the electrical power system rely on a high voltage quality. Ensuring this quality is thus a central objective of distribution grid operators. The voltage quality is influenced by the components connected in the grid area, which can result in unbalanced loading of the phases, rapid voltage changes (e.g. flicker) or harmonics. The energy, mobility and heat transition is accompanied by an increased integration of converter-coupled components, e.g. charging infrastructure, into the low-voltage grids, although the resulting impact on voltage quality has not been fully researched.

The goal of the U-Quality research project is to investigate the impact of current and future grid utilization cases on the voltage quality in distribution grids. Based on this research, measures to improve voltage quality will be adapted and further developed and recommendations for grid operators, manufacturers and committees will be derived.

The main focus of the investigations at the IAEW in the U-Quality project is twofold: to measure real components and grid properties to represent the current situation, and to further develop and verify simulation models. Within the scope of the investigations, both high-current components such as charging stations for electromobility as well as common household loads and grid characteristics are measured. The knowledge gained from these measurements is used in the

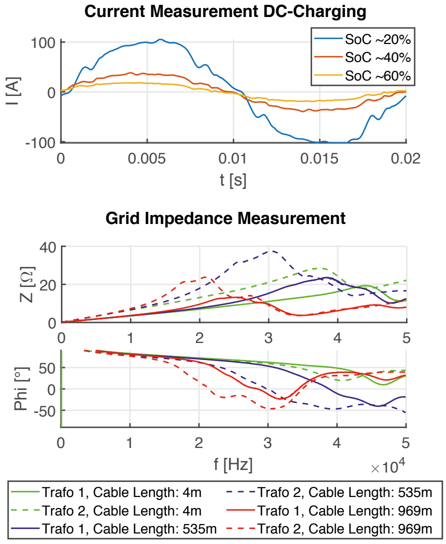


Figure: Current measurement of the charging process of an electric vehicle (top), grid impedance measurement for different grid characteristics (bottom)

modelling process. Figure 1 (top) shows the current consumption of a charging station in dependency of the state of charge (SoC). The harmonic content can be seen, which causes a distorted voltage depending on the grid impedance.

A further aspect of investigation is the grid impedance at the connection point of a component, since the resulting voltage at the network connection point depends on it. Analyses of the grid impedance for high frequency ranges, in which, for example, switching frequencies of common half-conductor circuits are located, are the subject of current research. In the low-voltage laboratory of the IAEW, the grid impedance is therefore measured up to a frequency of 50 kHz, while varying the grid characteristics.

Figure 1 (bottom) shows the frequency-dependent grid impedance for different feed-in transformers and cable lengths.

All in all, the research results will lead to laboratory-validated, simulative evaluations of voltage quality for future grid utilization cases in low-voltage networks.

i

Project Acronym
U-Quality

Project Duration
Apr 2019 – Mar 2022

Main Partners
TU Braunschweig, TU München, FGH e. V., RPT Ruhstrat Power Technology GmbH

Contact
Sandor Simon, M.Sc.
s.simon@iaew.rwth-aachen.de
+49 241 80 92946

Supported by:
Federal Ministry for Economic Affairs and Energy
on the basis of a decision by the German Bundestag

Flicker Reduction Potential of "virtual STATCOM"

Method for evaluating the dynamic behaviour of voltage controls for flicker reduction

Reinhold Bertram, M.Sc.

Perceptible changes in brightness that occur due to rapid voltage fluctuations are called flicker and can lead to health consequences for those affected. As a common countermeasure, compensation devices such as STATCOMs are used. Distributed generation systems are available in the power grid as a result of the large-scale implementation of the energy transition. As "virtual STATCOMs" (see Figure 1), they could be another solution for reducing flicker in distribution grids. Generation units coupled with a power-electronic interface already have the technical prerequisites to provide reactive power to the utility grid on short notice and could therefore compensate for flicker without hardware upgrading. A procedure must be developed to evaluate the feasibility of this solution.

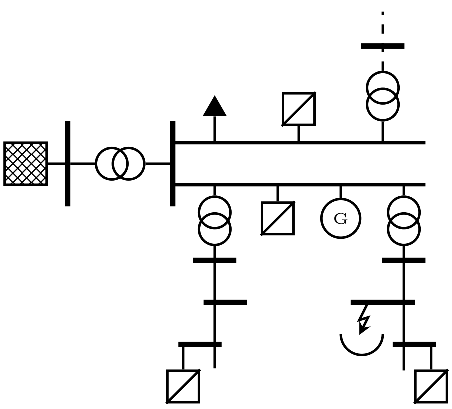


Figure 1: Concept "virtual STATCOM"

The evaluation method developed here enables a comparison of the performance of different technology portfolios and control systems with respect to their potential to reduce flicker – especially when considering distributed reactive power control systems such as "virtual STATCOMs". To this end the calculation method of the flicker reduction potential consists of the steps for calculating the steady-state, the dynamic and the simulative potential. The hosting capacity method is adapted for flicker and used in combination with non-linear optimization, an RMS flicker meter and with the time-domain simulation of reactive power control. Figure 2 shows the steady-state and dynamic flicker reduction potential.

The evaluation method determines the flicker level that can be reduced below the threshold value defined in standards by the option of a "virtual STATCOM". The results of the investigation show that the level of the steady-state potential depends on the network topology, feed-in and load. The available reactive power is the main limiting factor. The time-dependent behaviour of the reactive power control systems restricts the dynamic potential. Finally, the evaluation by means of the simulative potential shows how the potential for the control systems that can be implemented is dependent on the gradient of the characteristic curve and the controller speed.

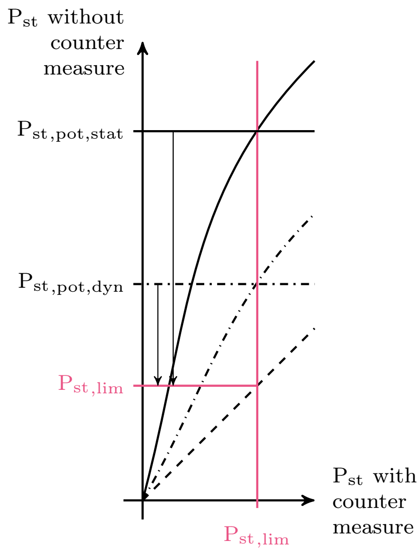


Figure 2: Schematic representation of steady-state and dynamic flicker reduction potential

Contact
Reinhold Bertram, M.Sc.
reinhold.bertram@envelio.de

Simplified Short-Circuit Current Calculation for Medium and Low Voltage Direct Current Networks

Raphael Bleilevens, M.Sc.

Background and Objectives

Medium and low voltage direct current networks (DC distribution networks) are increasingly becoming the focus of research. As in today's three-phase alternating current networks (AC networks), short-circuit currents in DC distribution networks generally cause the highest stress for current-carrying network equipment. For the safe and yet economically appropriate design of these current-carrying network equipment, knowledge of possible short-circuit currents in DC distribution networks is therefore essential. For AC systems, simplified approximation approaches or transient calculations for a short-circuit current calculation are available today. In practice, a simplified approximation approach for calculating the possible short-circuit currents is desirable, since the data requirements and the calculation time can be significantly reduced compared to transient calculations. For this reason, a simplified short-circuit current calculation based on an approximation approach is also desirable for DC distribution networks.

Due to this background, this research aims to derive a method for simplified short-circuit current calculation for DC distribution networks.

Methodical approach

For simplified short-circuit current calculation, the use of the calculation approach of superposition of approximated current courses is emphasized. In the first step of this calculation approach, the current courses of all feeding short-circuit current sources are approximated. Subsequently, the approximated current courses of the short-circuit current sources are superposed, taking into account the DC network. Finally, short-circuit current characteristics are determined.

To validate the simplified short-circuit current calculation method, a comparison of the calculated short-circuit currents with comparative data is necessary. It would be desirable to compare the calculated short-circuit currents with measured short-circuit currents. However, due to the lack of implementation of DC distribution networks, no corresponding measurement data is available. For this reason, realistic comparative data are generated by transient calculations in the form of numerical time course simulations.

Results

The simulations evaluate the simplified approximation method by varying different DC distribution networks. The network structure, the supply task, the equipment and the operating voltage are varied. The comparisons with the comparative data show that the design-relevant short-circuit current characteristics can be sufficiently estimated by the approximation method. In contrast, short-circuit currents that are not relevant to the design are often only insufficiently estimated.

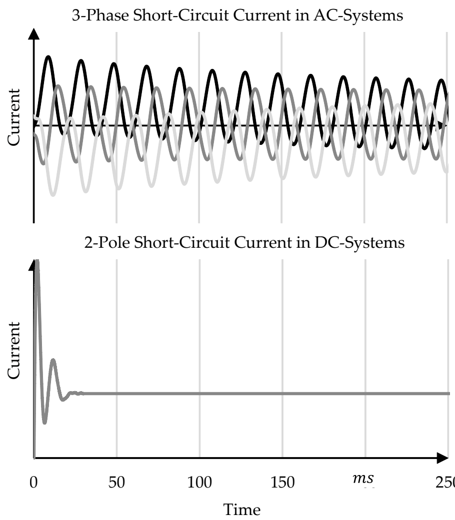


Figure: Schematic representation of short-circuit currents in AC and DC systems

Contact
Raphael Bleilevens, M.Sc.
r.bleilevens@iaew.rwth-aachen.de
+49 241 80 93049

Assessment of Different Local Energy Markets Configurations

Wilhelm Cramer, M.Sc.

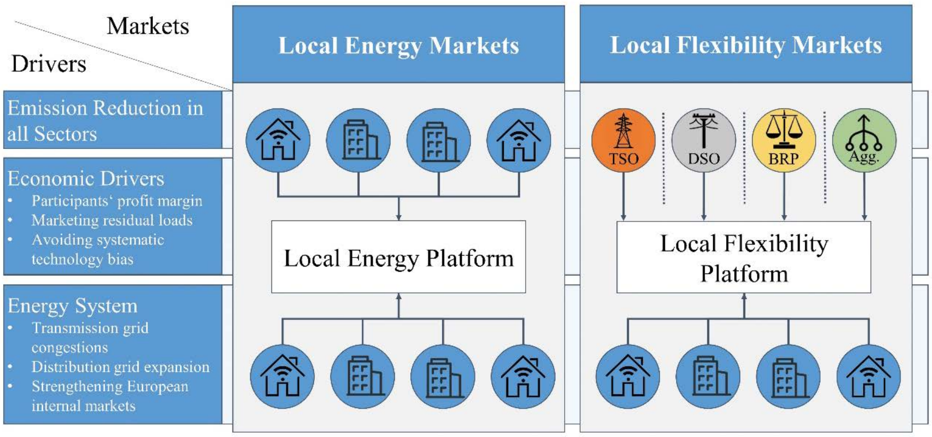


Figure: Drivers and participants of local energy and flexibility markets

Motivation and Goals

The EU's climate goals for the different sectors (energy, industry, buildings, mobility and agriculture) envisage significant decarbonization measures, which in turn lead to a structural transformation of energy systems. Besides the decentralization of power supply, the demand side will be shaped by new technologies aiming at either electrification (e.g. heat pumps or electric vehicles) or the production of synthetic gases. These developments increasingly call for an efficient coordination of the new distributed assets. As a possible approach, local energy markets (LEM) offer on the one hand the advantage of enabling a direct and potentially preference-based market participation to end consumers. On the other hand, LEM can promote a local energy allocation, which can reduce the exchange with the overlaying grid levels and thus relieve the transmission grids.

The assessment of different configurations for LEM regarding products, market design and other framework conditions (price surcharges or exemptions) is the key focus of the thesis.

Methodology

For the simulation of LEM, a bottom-up modelling approach is used that represents the scheduling of decentralized technologies and individual market participant trading decisions. For this purpose, a linear programming approach is used, where the optimization variables represent the quarter-hourly power values. Further, energy prices, taxes, levies and grid fees are included in the objectives. The constraints ensure the observance of technical restrictions of the decentralized technologies while satisfying each participant's energy demand and maintaining market energy balance.

Results

Respective KPIs for local energy markets are market efficiency and liquidity. The efficiency can be identified by calculating the social well-being, which derives from additional profits and reduced costs. The liquidity therefore represents energy exchange with the higher grid levels.

Potential factors that need to be considered when investigating LEM according to the above mentioned KPIs can be categorized into two groups. One factor is the impact of the regional circumstances of the local energy system, which contains deviations in both energy demand and technologies. The other factor involves LEM configuration options, which include energy products, the role of aggregators, uncertainties and the bidding process.

Contact
Wilhelm Cramer, M.Sc.
w.cramer@iaew.rwth-aachen.de
+49 241 80 94885

Process-aware Detection of Attacks on Intelligent Energy Supply Grids

Benedikt Klaer, M.Sc.

Background

The dependence of the power supply on information and communication technology (ICT) for electrical energy supply will increase in the future due to concepts of active grid operation management and flexibility use. The increasing expansion with modern ICT and the increased networking of facilities and actors among each other will also lead to new security risks through IT attacks on supply security.

By implementing current IT security standards, the risk potential can already be significantly reduced as a preventive measure. However, complete security against IT attacks cannot be guaranteed by purely preventive measures (e.g. zero-day exploits, internal perpetrators). Intrusion detection systems enable early detection of potential attacks and allow for situational action.

Successful attacks on cyber-physical systems (Stuxnet 2010, Ukraine 2015/2016) show that critical process states can be brought about by semantically correct process data. A threat occurs only in the process context. For classical detection methods, this context reference represents a challenge, since additional knowledge about the process is required.

Research objectives

In addition to the basic identification of process-aware indicators, a potential added value of such a system is examined in relation to the security level of the infrastructure. The information basis of the process requires a continuous up-to-date configuration of the model and additional access to process data. This requires a development and analysis of the required data model, the placement and architecture of the sensor system in the communication network and the additionally required data exchange between the sensor systems.

Methodology

The basis of the investigations is the development of a graph-based representation of the energy and ICT domain as a common data model. On this basis, co-simulations and the detection procedure can be configured automatically. For testing the procedure, normal data is generated in a co-simulation and

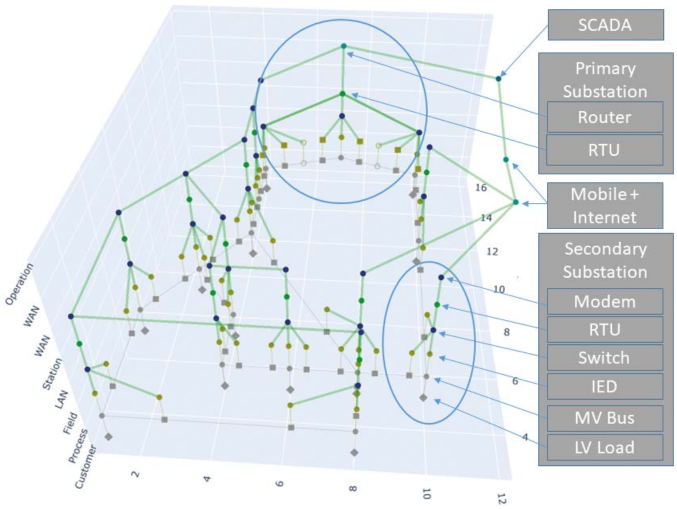


Figure: Graph-based Energy Information Model

IT attacks are generated in the infrastructure model by an expert system. To manipulate process data, a decision problem is formulated from the attacker's point of view and situationally adapted attacks on grid operation are carried out. The free placement of sensors in the simulation model allows an investigation into the influence of the available information.

This work's investigations result in a methodical procedure for investigating and evaluating the applicability of such advanced IT security procedures.

i

Contact
Benedikt Klaer, M.Sc.
benedikt.klaer@rwth-aachen.de

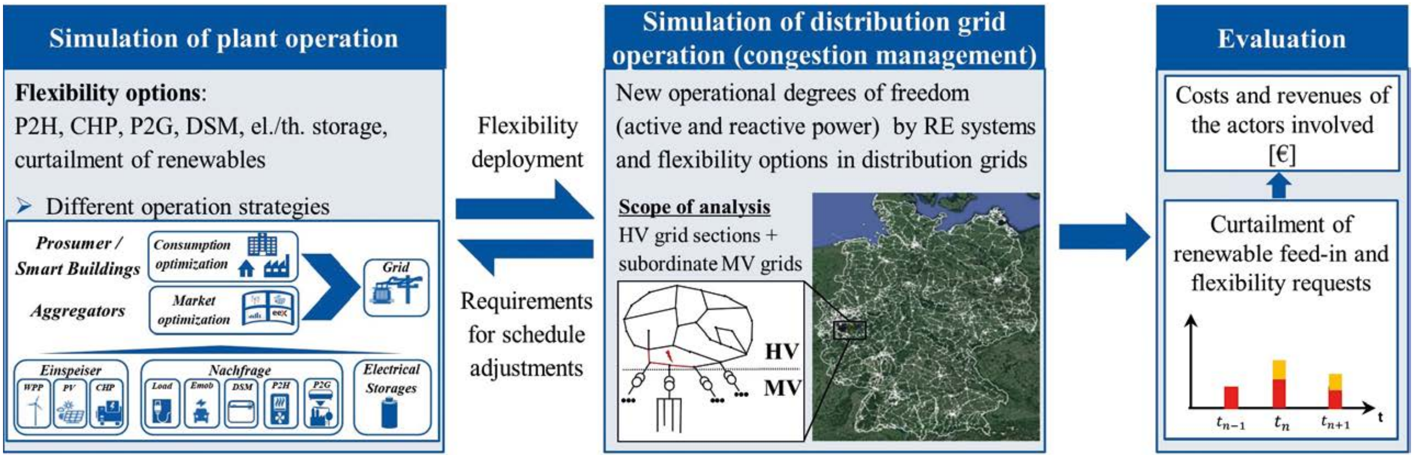


Figure: Schematic procedure of the simulation

Modelling of Congestion Management in Distribution Networks including Market-related Measures through Flexibility Options

Tom Kulms, M.Sc.

Background

As a result of increasing congestion situations caused by RE plants installed in distribution grids, enhanced coordination of grid operation along all voltage levels will be necessary in the future. At the same time, new technologies for energy storing and coupling energy sectors are establishing themselves primarily in the distribution networks. The planned reduction to 0.1 MW of the minimum plant capacity that is obligatory for participation in market-related congestion relief measures will enable the use of these technologies, also known as flexibility options, in the context of network congestion management (NCM) and authorize DSOs and TSOs to integrate previously inaccessible technologies into a planning-value based NCM. The retrieval of power adjustments must be allocated in such a way that network operation at lower voltage levels is not endangered, so that the establishment of a preventive NCM is indispensable, especially in the distribution network. In addition, the regulatory-based remuneration regime implies the compensation of opportunity costs on the part of the plant operators involved, which are, however, very case-specific due to the high diversity in the distribution grid.

Method and results

In order to assess the potential contribution of regulatory reforms and sector coupling potentials within the CM, this research work therefore develops a simulation method that models distribution grid operation, taking into account market-related degrees of freedom through RE, storage and sector coupling technologies, while at the same time reflecting their alternative benefits for plant operators. The main focus of the method is on the simulation of grid operation in the high- and medium-voltage grid levels and the supplementary integration of flexibility options in grid operation management. Based on this approach, the potential of flexibility options to reduce congestion management costs and to avoid feed-in management of renewable energy can be quantified for specific grid areas. Both the evaluation of potentials of the distribution grid internal NCM as well as conclusions on potentials in the avoidance of feed-in management and the support of voltage maintenance (reactive power provision) of the upstream TSO form the main areas of application of the procedure.

i

Contact
Tom Kulms, M.Sc.
t.kulms@iaew.rwth-aachen.de
+49 241 80 93048

Structural Design of Medium Voltage Grids based on Direct Current Technology in Consideration of Power Flow Control

Jens Priebe, M.Sc.

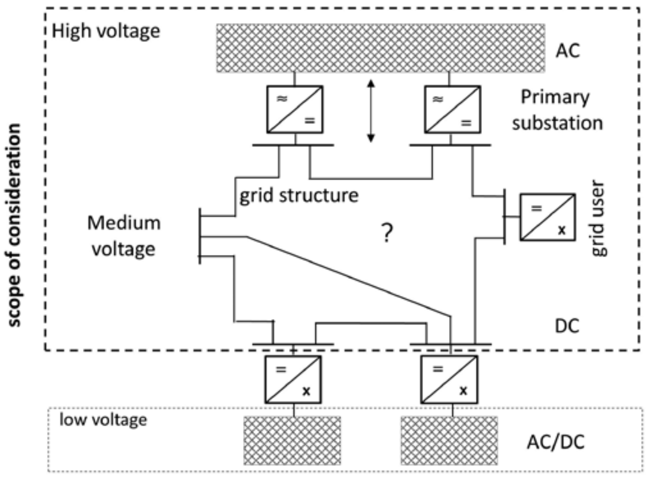


Figure: Medium voltage schematic network based on direct current technology

Background and objectives

Due to technological advances in the field of power electronics, all key components for grids based on direct current technology are now available, making it possible to realize these grids. Power flow control by controllable converters offers a flexibility on the grid side. In the future, it is to be expected that the supply task in medium voltage (MV) will continue to change, so that existing structures will have to be reconsidered and changed MV grid structures are obvious. MV grids also have a major impact on the supply reliability of end consumers. Against this background, networks based on direct current technology are of particular interest for the MV level. Consequently, the question arises as to the structural design of these grids. The main structural features of interest are routing allocation, choice of equipment for lines, transformers and converters, nominal voltage, line configuration, control of power flows, size of the switch-off areas and use of the high voltage level.

Against this background, the aim of this research project is to investigate the structural design of MV grids based on DC technology taking into account power flow control and other available degrees of freedom.

Method

The method is based on a decomposition approach and divides the overall problem into two subproblems. The optimized grid structure together with the equipment design is determined for the supply of all MV stations with controllable converters on the basis of a genetic algorithm in combination with a closed formulated power flow optimization. The choice of the nominal voltage, the line configuration and the reserve concept in primary substations are identified superimposed by variant calculations. Subsequently, for the resulting grid structure, the size of switch-off areas is determined by positioning circuit breakers using a heuristic approach.

Results

The simulation applies the method to three supply tasks. As a result of the power flow control, meshed structures result between primary substations. With increasing meshing, however, the need for power flow control is reduced. An increasingly meshed network structure at MV level reduces the use of the high voltage grid. The size of switch-off areas has a small effect on the grid structure due to comparatively low costs of additional circuit breakers. However, more meshing leads to a higher number of required circuit breakers.

Contact
Jens Priebe, M.Sc.
jens.priebe@rwth-aachen.de

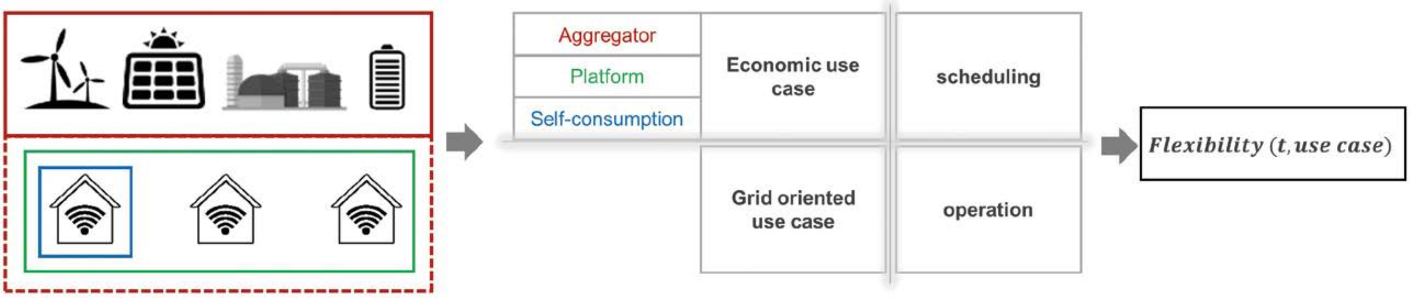


Figure: : Key influencing factors for the flexibility potential of distributed energy resources

Scheduling and Operation of Distributed Energy Systems

Maria Vasconcelos, M.Sc.

Motivation and goals

The expansion scenarios defined by climate targets for renewable and increasingly distributed energy resources (DER) require a simultaneous system integration of these assets. Corresponding requirements for the DER's operation comprise not only the fulfilment of their primary function (generation, consumption or storage) but also the coordination of their flexibility potential. Three aspects play a major role in this context:

- Economic framework home (private consumption, platform-based exchange, aggregated trading)
- Grid-oriented goals and framework
- Aggregation level of DER (requirements for modeling accuracy)

Against this background, the goal of the dissertation is the development of a method for the quantification and multi-use exploitation of DER's flexibility potential. This requires an accurate integration of the implications of the different temporal planning stages and aggregation levels in the scheduling and operation processes.

Method

The method comprises three submodels. In the economic-oriented, day-ahead and intraday scheduling process of DER, the options of private consumption, platform-based exchange and aggregated trading can be modeled. After a schedule's disaggregation, if needed, an optimal power flow is carried out, which on the one hand optimizes the reactive power feed-in of DER based on their controllability. On the other hand, in case congestions are expected, restrictions for DER scheduling are determined as a preventive measure.

The operation phase follows, during which individual DER control signals are calculated. In contrast to the scheduling phase, the method for DER operation also entails nonlinear restrictions. On this basis, the grid-oriented operation is optimized, which yields both the reactive power control signals and the operational measures needed to comply with grid restrictions.

Results

Simulated applications of the method have shown the significance of an accurate consideration of nonlinear technical restrictions for the accurate quantification of DER's flexibility potential. Furthermore, the economic use case has a considerable impact on the DER's operation and thus also on the flexibility potential. The corresponding financial implications of the selected economic use case are mainly influenced by the DER portfolio under consideration and by the assumed pricing framework.

i

Contact
Maria Vasconcelos, M.Sc.
m.vasconcelos@iaew.rwth-aachen.de
+49 241 80 93039

Effects of Flexibility in Distribution Grid Planning

Impact of controllable loads on the grid expansion planning of medium and low voltage grid

Mirko Wahl, M.Sc.

Introduction and objectives

The growth of generation units based on renewable energy sources (RES) in the distribution grids has changed the use of medium and low voltage grids (MV and LV grids) in recent years. RES are promoted on the basis of climate policy objectives. However, decarbonization of the power generation sector is not sufficient to meet these targets. Decarbonization must be extended to other sectors, such as the mobility and heat sectors. Technologies like electric vehicles (EV) and heat pumps (WP) can be used to replace technologies based on fossil fuels. Thus, MV and LV grid use will be influenced by an increasing number of EVs and WPs in the coming years. In addition, §14a of the Energy Industry Act allows distribution system operators to use controllable loads for grid-supporting purposes. This will likely lead to an active grid operation in MV and LV grids in the future.

This causes new challenges regarding the grid planning, since on the one hand the development of grid use, including the load side, is increasingly uncertain, whereas on the other hand active grid operation must be considered in the grid planning process. The research objective is therefore the development of a method to determine the impact of a grid-supporting measures on the grid expansion requirement in MV and LV grids while taking uncertainties into consideration.

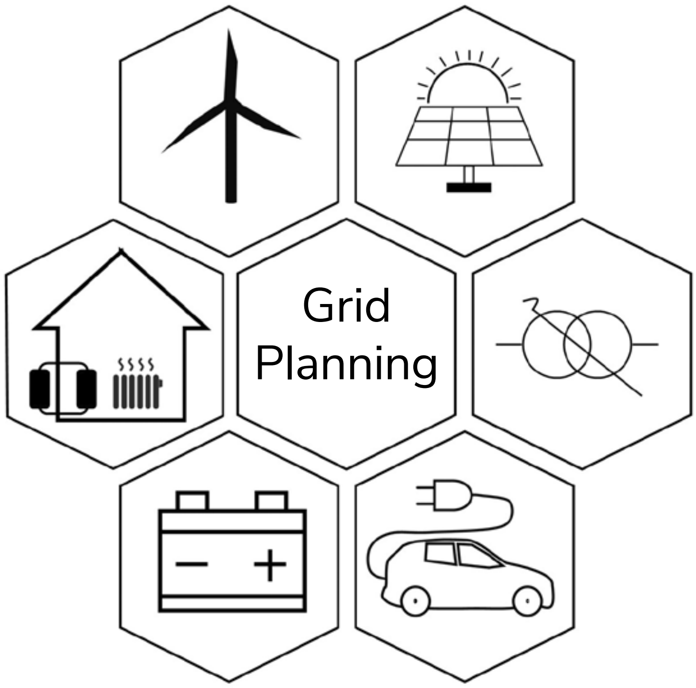


Figure: Flexibility options in the distribution grid

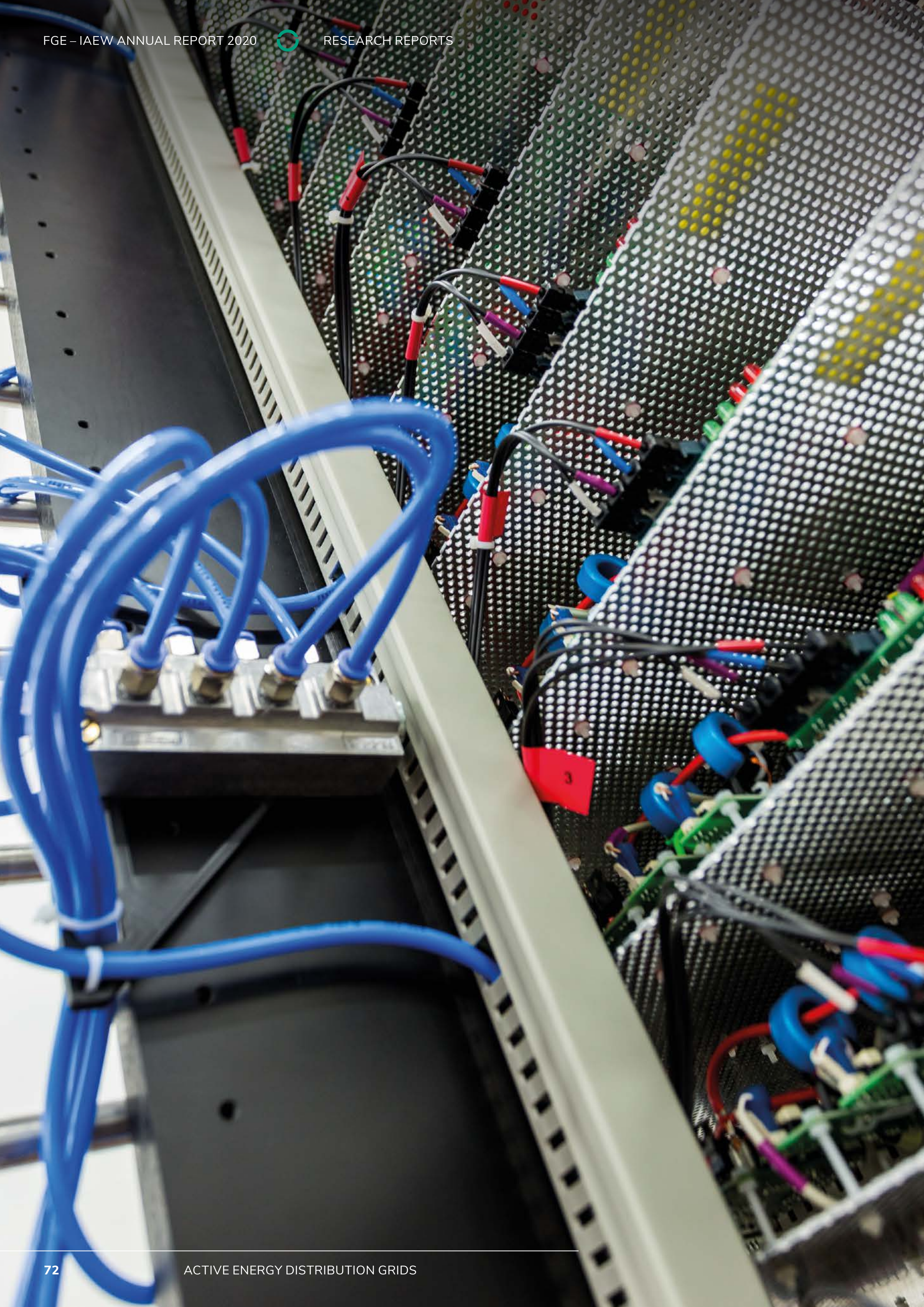
Method

The procedure consists of a grid expansion method and a simulation of an active grid operation. Within the framework of the active grid operation, the use of grid-supporting measures for voltage stabilization and temporary reduction of thermal loading is determined. The aim of the active grid operation is to maintain the operational technical limits of the grid by means of a flexible use of RES and consumers and the control of regulated distribution transformers.

Results

This work investigates the required grid expansion for the integration of EV and WP on different grid structures. In this context, a need for expansion is to be identified, especially in urban and suburban grids. A grid-supporting use of flexibility can delay and partly avoid this grid expansion. In rural grids, the studies show that a flexibility use of consumption can avoid the curtailment of RES and thus improve the integration of RES. Due to the possibility of delaying expansion measures, the use of flexibility can help to avoid bad investments. Furthermore, the influence of flexibility is examined while taking uncertainties into account.

Contact
Mirko Wahl, M.Sc.
m.wahl@iaew.rwth-aachen.de
+49 241 80 94781


3

Impact of Network Control Concepts on the Evaluation of DC Applications in Distribution Grids

Niklas Wehbring M.Sc.

Background and objectives

Applications based on direct current (DC) in the distribution grid are increasingly being discussed in grid planning as a potential alternative to conventional AC grid expansion due to technological advances and cost degression in power electronics. For instance, DC short couplings and point-to-point DC connections for power flow control and reactive power supply are already technically feasible today, as well as, in the future, pure DC networks with a large number of connected stations, so-called DC multi-terminal networks.

AC/DC converters represent a new component to be actively controlled, which requires continuous setpoint updates in network operation. The setting of suitable setpoints and the reaction to failures and load changes is determined by a network control concept. The design of a control concept in turn has an effect on the benefit of the DC application and thus on network planning. Against this background, the question of evaluating DC applications in network planning cannot be answered separately from the design of the network control concept and must therefore be addressed jointly. Therefore, the aim of this research project is to investigate the effect of network control concepts on the evaluation of DC applications.

Method

The developed method is based on a two-stage approach to simulate suitable network control concepts. In the first stage, the setpoint value for controllable components is updated at regular intervals, e.g. every 15 minutes. A distinction is made between central, distributive and decentralized coordination in order to address differences in the network control concept with regard to measured value acquisition and setpoint transmission. The DC application is evaluated on the basis of the reduction potential of congestion and losses within the framework of an annual simulation.

The second stage describes the adaptation of setpoints based on local control using characteristic curves as a result of changes in the load and feed-in situation or failures. The method offers a wide range of parameterization options for the characteristic curves and evaluates them on the basis of possible equipment overloads in selected failure situations.

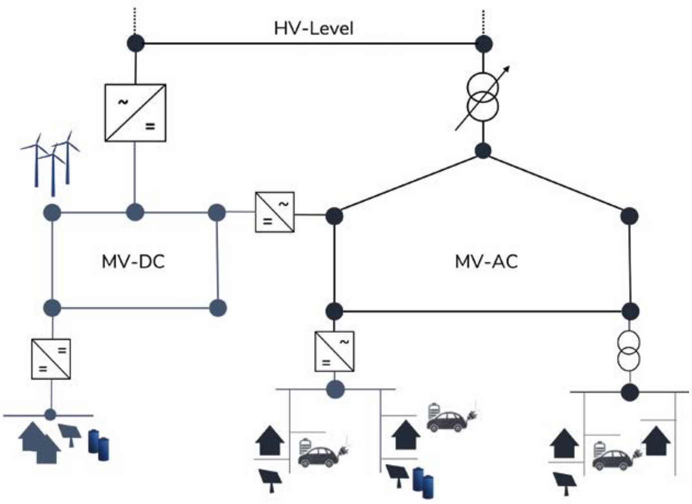


Figure: Schematical distribution grid with DC-application

Results

In the exemplary investigations, a reduction of congestion when integrating DC applications and thus a flexibility potential could be proven. In addition, it was shown that a centrally coordinated setpoint setting with complete knowledge of the network state provides a significant added value compared to a decentralized setpoint setting with limited measured value acquisition. Developed adaptive characteristic curves are also able to prevent overloads in case of failures.

Contact

Niklas Wehbring, M.Sc.
n.wehbring@iaew.rwth-aachen.de
+49 241 80 90178

Publications

Bertram, Reinhold
Flicker Mitigation by Optimization of Voltage Control
IEEE Milan PowerTech, Milan (Italy), 23 Jun 2019 - 27 Jun 2019

Bleilevens, Raphael; Jaschek, Alexander M.; Moser, Albert
Approximation of Current Contribution by Converters with DC Fault Ride-Through Capability for Short Circuit Current Calculation of DC Distribution Grids
IEEE Milan PowerTech, Milan (Italy), 23 Jun 2019 - 27 Jun 2019

Bleilevens, Raphael; Moser, Albert
Identification of Required Converter Models for a Simplified Short Circuit Current Calculation of DC Distribution Grids
54th International Universities Power Engineering Conference, Bucharest (Romania), 3 Sep 2019 - 6 Sep 2019

Bleilevens, Raphael; Priebe, Jens; Wehbring, Niklas; Moser, Albert
Identification of Relevant Fault Types for Grid Planning of DC Distribution Grids
NEIS 2018: Conference on Sustainable Energy Supply and Energy Storage Systems, Hamburg, 20-21 September 2018 / Detlef Schulz (Hrsg.), 62-67, 2019

Bleilevens, Raphael; Priebe, Jens; Wehbring, Niklas; Moser, Albert
Reliability Analysis of DC Distribution Grids
54th International Universities Power Engineering Conference, Bucharest (Romania), 3 Sep 2019 - 6 Sep 2019

Erlinghagen, Philipp
Elektromechanische Modellierung aktiver Verteilungsnetze zur Analyse der transienten Systemstabilität
Verlagshaus Mainz GmbH, Aachen, 2019

Gürses-Tran, Gonca; Mildt, Dominik; Hirst, Michael; Cupelli, Marco; Monti, Antonello
MPC based energy management optimization for a European microgrid implementation
25th International Conference on Electricity Distribution, Madrid (Spain), 3 Jun 2019 - 6 Jun 2019

Hacks, Simon; Hacks, Alexander; Katsikeas, Sotirios; Klaer, Benedikt; Lagerstrom, Robert
Creating Meta Attack Language Instances using ArchiMate: Applied to Electric Power and Energy System Cases
IEEE 23rd International Enterprise Distributed Object Computing Conference, Paris (France), 28 Oct 2019 - 31 Oct 2019

Körber, Nils; Bartolomei Viegas de Vasconcelos, Maria do Carmo
Scenario-Based Assessment of the Smart Grid Traffic Light Concept Including the Flexibility from Electric Vehicles
3rd E-Mobility Power System Integration Symposium, Dublin, Ireland, 14 Oct 2019

Linnartz, Philipp Patrick; Schulte, Nicolas Simon; Simon, Sandor
Experimental Investigation of Distribution Grid Restoration Concepts Using Neighboring Islanded LV-Microgrids
25th International Conference and Exhibition on Electricity Distribution, Madrid (Spain), 3 Jun 2019 - 6 Jun 2019

Nolting, Lars Friedrich; Schuller, Vanessa; Gaumnitz, Felix; Praktiknjo, Aaron Jonathan
Incentivizing timely investments in electrical grids: Analysis of the amendment of the German distribution grid regulation
Energy policy, 132 (September), 754-763, 2019

Offergeld, Thomas; Knittel, Markus; Bertram, Reinhold
cimpyorm – a queryable python CIM-Cache for smart grid applications
IEEE PES Innovative Smart Grid Technologies Europe, Bucharest (Romania), 29 Sep 2019 - 2 Oct 2019

Priebe, Jens; Korompili, A.; Voss, J.; Luerkens, P.; Moser, Albert; Monti, Antonello; De Doncker, R. W.
DC Grid Technology – Advances in Efficient Power Conversion, Multi-Node Control, and Medium Voltage DC Grid Design and Requirements for Planning and Operation
IEEE Innovative Smart Grid Technologies - Asia 2019

Priebe, Jens; Wehbring, Niklas; Chang, Hao; Moser, Albert; Cakmak, Huseyin K.; Kuhnapfel, Uwe; Hagenmeyer, Veit
Exploiting Unused Capacity in the Grid
IEEE Innovative Smart Grid Technologies - Asia, Chengdu (Peoples R China), 21 May 2019 - 24 May 2019

Vom Stein, Denis
Einfluss des Modelldetailgrades in Strommarktsimulationen auf die Bewertung von Flexibilitätsoptionen; 1. Auflage
Aachener Beiträge zur Energieversorgung, Band 193, printproduction M. Wolff GmbH, Aachen, 2019

Wahl, Mirko; Hein, Lukas; Moser, Albert
Fast Power Flow Calculation Method for Grid Expansion Planning
21st European Conference on Power Electronics and Applications (EPE '19 ECCE Europe), 2019

Wahl, Mirko; Tennhoff, E.; Moser, Albert
Netzausbauplanung von Mittel- und Niederspannungsnetzen unter Berücksichtigung von Unsicherheiten
11. Internationale Energiewirtschaftstagung an der TU WIEN, IEWT, 13 Feb 2019 - 15 Feb 2019, Vienna, Austria

Wehbring, Niklas; Schema, Daniel; Wahner, Falko; Moser, Albert
A Distributed Optimal Power Flow for Secondary Control of Hybrid AC/DC Networks
IEEE Milan PowerTech, Milan (Italy), 23 Jun 2019 - 27 Jun 2019

Weinhardt, Christof; Cramer, Wilhelm; Hambridge, Sarah; Hobert, Alexander; Kremers, Enrique; Otter, Wolfgang; Pinson, Pierre; Tiefenbeck, Verena; Zade, Michael
How far along are Local Energy Markets in the DACH+ Region? A Comparative Market Engineering Approach
10th ACM International Conference on Future Energy Systems (e-Energy 2019), Phoenix, AZ, USA, 25 Jun 2019 - 28 Jun 2019

Willenberg, Dominik; Mierau, Niklas; Simon, Sandor; Bertram, Reinhold
Experimental Analysis of Grid-Forming Frequency Control Strategies for Load Sharing in Low Voltage Islanded Microgrids
IEEE Milan PowerTech, Milan (Italy), 23 Jun 2019 - 27 Jun 2019

Willenberg, Dominik; Simon, Sandor; Bertram, Reinhold; Sowa, Torsten
Impact of Synchronous and Distributed Generation Unit Characteristics onto the Stable Operation of Low Voltage Islanded Microgrids
Cired, Madrid (Spain), 3 Jun 2019 - 6 Jun 2019

Doctorates


FGE
FORSCHUNGSGESELLSCHAFT
ENERGIE

Dr.-Ing. Philipp Baumanns Computation of Probabilistic Parameters for Resource Adequacy in the European Energy Turnaround

In European electricity market regulation, the term Resource Adequacy describes the adequacy of resources to meet the demand for electrical energy. Resources include primary energy sources, power generation plants, storage facilities, the grid and flexibility potential on the demand side. These must be available in adequate quantities and with adequate availability. The great importance of a secure supply of electrical energy makes Resource Adequacy a key objective of European and national energy policy. Hence, electricity market regulation requires a monitoring with probabilistic indicators, e.g. Loss of Load Expectation (LOLE) and Expected Energy not Served (EENS).

In the thesis, the properties of the resources relevant for the calculation of the parameters are investigated and then transferred to corresponding models. In the case of primary energy sources, the availability of wind, water and solar irradiation is limited by the weather, while in the case of fossil fuels, for example, by import dependency. The availability of power generation plants, storage facilities and the grid is limited by revisions and outages. Consequently, a probabilistic Monte Carlo simulation method was developed. It combines each result of a drawing of available power plant capacity and transmission capacities with feed-in time series based on historical weather data over a thirty-year period. In each of these combinations the unmet demand is minimized. The resulting distributions are used to calculate the probabilistic indicators.

This software tool is used to investigate which probabilistic indicators for resource adequacy result from anticipated developments in the European generation stack. In some countries the expected changes in the time horizon of 2020 and 2025 already result in LOLE and EENS greater than zero. France and Belgium, among others, are affected.

Dr.-Ing. Philipp Erlinghagen Electromechanical Modeling of Active Distribution Grids for the Analysis of Transient System Stability

Current energy policy goals lead to an increasing substitution of conventional power plants by distributed energy resources. The distributed systems are usually installed in the distribution grids. To prevent blackouts in the European transmission grid, analyses of transient stability, among other stability aspects, are necessary. The amount of information as well as the modelling and computational efforts for distribution grids must be kept as small as possible, using equivalent models.

This work develops a method for the dynamic modelling of reference systems that can be parameterized in a stochastic way. Using these reference systems, systemic key data can be identified which is used to parameterize the equivalent systems. For this purpose, laboratory tests are performed to identify realistic stochastic parameter spaces. The stochastic component modelling developed within this thesis is successfully tested on pure machine systems, machine systems with controllers, power electronic systems and hybrid systems. Using a variance-based sensitivity analysis, systemic key data is identified that can be used to parameterize the equivalent model of the whole system. The primary indicator is the peak power of the infeed and loads. The secondary indicator is the cumulated frequency of the plant sizes, which can be used to increase the quality of the solution.

This new dynamic parameterization approach is validated against synthetic grids and a real grid. The results show that the models themselves and the method as a whole are valid. Using simple functional dependencies, generic equivalent models can be parameterized using a small amount of systemic information on the grid. The only exceptions are the coupling impedances. They need to be modelled as impedances with an exponentially increasing dependency on the voltage.

Dr.-Ing. Bernhard Fuchs Contribution to direct methods for power system stability

The stability of electricity grids is a fundamental requirement for a productive economy. Since the liberalization of the electricity market and the EEG law in Germany, the former highly reliable power generation structure close to the consumers is evolving to a distributed structure based on small power electronic devices. As a consequence, stability issues are moving from frequency stability to transient stability aspects. The critical clearing time is an important indicator for transient stability assessment. Calculating this normally requires time consuming dynamic simulations, which limit the number of investigated cases. Thus, an increasing number of different load flow and fault scenarios require alternative methods.

This work presents extended approaches to direct methods based on the PEBS and BCU method which consider the integration of power electronic devices and improve robustness of stability assessment. For this purpose, special issues of the PEBS and BCU method are analyzed under consideration of enhanced procedures, identified and developed. Different test cases and scenarios are analyzed. The findings show that the PEBS and the BCU method are suitable for estimating critical clearing times in sufficiently damped power systems. When employing the PEBS method special extensions are recommended in order to increase robustness of estimations. In contrast to the PEBS approach, the BCU method provides conservative stability estimations. The results demonstrate that there is no negative impact on the quality of estimations by increasing the share of power electronic devices. This appears to validate the applicability of the enhanced direct methods in electric power systems with a significant share of power electronic devices.

Dr.-Ing. Felix Glinka Impact of inverter coupled distributed energy resources on protection systems in distribution grids

The increasing number of decentralized energy resources can lead to extended detection and clearing times, up to a non-tripping of the grid protection systems in the distribution systems in Germany. The fault current contribution of inverter interfaced decentralized energy resources, behaving as highly flexible, controlled current sources, is thereby highly dependent on the individual model.

Different modelling approaches for steady-state fault current calculations are derived by evaluating measurements of different inverters and by analyzing the relevant application rules. A protection-analysis method is developed based on a steady-state calculation with a current injection method. Suitable future protection solutions for low voltage grids with high inverter penetration are deduced. The impact of measured harmonic infeed of inverters during grid faults on the speed and accuracy of present overcurrent as well as distance protection relays and algorithms is evaluated using both simulations and a hardware in the loop laboratory setup.

The results show a variation of the infeed current of inverters especially during asymmetric fault occasions depending on the individual inverter. Therefore, different modelling approaches need to be considered during fault current calculations. Low voltage fuses, commonly used in Germany, are still suitable for most grid constellations, while digital protection methods can cover the remaining cases. When using the digital protection methods in combination e.g. with a triggerable fuse, the requirements regarding the speed, especially for high current faults, as well as the reliability are comparably low. This allows economically feasible solutions. Still, it needs to be considered that suitable filtering methods in combination with fitting detection algorithms need to be chosen to cope with the harmonics injected by the inverters during grid faults.


L3
1
4 5
6
7
3

Dr.-Ing. Jan Kellermann Assessment of network expansion plans in subtransmission high-voltage networks considering operational flexibility and uncertainties

In many high-voltage networks there is a need for network expansion due to the increasing number of distributed renewable energy sources and potential new consumers. Since the new network users usually offer the option of controlling their power, this flexibility can be taken into account at the network planning phase. Network operators must therefore weigh up the expansion of the network and the use of operational flexibility. The questions arise as to how network expansion plans (NEPs) can be assessed and what added value the flexibility offers for reducing costs and dealing with planning uncertainties.

Therefore, a method for the evaluation of NEP has been implemented that simulates the use of flexible network users and determines the costs for network expansion, flexibility usage and losses. Uncertainties are represented by scenarios with regional and temporal deviations from the expected development of generation and consumption. To reduce the simulation time, relevant situations are determined using time series models and cluster methods. The use of flexibility is determined by an optimal power flow, which considers generation-, storage- and load-management as well as overhead line monitoring. The assessment procedure has been integrated into a heuristic method for determining NEP in order to examine the effects of different flexibility options.

Studies show great potential for cost reduction by flexible network users, especially when flexibility offered from subordinate network levels may be used. Flexible loads and storage further reduce the costs compared to pure feed-in curtailment, when units with lower operating costs and higher sensitivity on bottlenecks can be used. In the near future, flexibility will primarily lead to a postponement of expansion measures. Long-term avoidance only occurs in later years of the simulated period.

Dr.-Ing. Ivan Marjanovic Assesment of Flow-Based Capacity Calculation Methodologies under Consideration of Uncertainties

Due to a growing share of renewable energy sources, the cross-zonal transmission capacities (CZC) available for electricity trading between bidding zones in the Europe market are steadily decreasing. In order to increase its efficiency, the CZC allocation should be performed using a flow-based method in the future. This method enables a maximization of economic prosperity while ensuring a secure and reliable transmission system operation. A vital part of the allocation process is the CZC calculation.

The future impact of a specific CZC calculation method can be assessed by performing a techno-economic analysis – which includes modeling and simulating electricity market and transmission system operation. The model should also account for the significant uncertainties that are present in the CZC calculation.

In this thesis, a methodology for probabilistic assessment of flow-based methods for CZC calculation has been developed. It simulates three processes (capacity calculation, electricity market and grid operation planning) over two time horizons. Decision making is modeled as a mixed-integer or linear optimization problem, depending on the process. A Monte-Carlo simulation is performed to quantify the possible impact of uncertainties.

The methodology developed here was used to perform exemplary assessments of the calculation aspects that are widely discussed today – such as the minimum level of CZC. The results show an increase in overall economic well-being when less restrictive calculation methods (e.g. releasing more CZC to the market) are applied. However, over-dimensioning of CZC has several drawbacks, such as increased redispatch effort, missing price signals and distorted distribution of economic well-being. Furthermore, it was shown that possible forecast errors have much higher impact when less restrictive methods are applied, and could lead to high reduction of economic well-being and even endanger secure operation of the power system.

Dr.-Ing. Janek Massmann Stability analysis of the transmission grid considering high penetration levels of renewable energies within the distribution grids

The political goal of decarbonizing the energy supply and the concomitant substitution of electrical power generation from conventional power plants by renewable energies lead to a conversion of the electrical energy supply. In contrast to conventional power plants, renewable energies are mainly located in the distribution grid levels due to their low power rating. In addition, these units are primarily connected to the grid via inverters. However, the dynamic behavior of inverters differs fundamentally from the dynamics of synchronous generators in conventional power plants. Thus, the structural and technological transition induces a fundamental change in power system dynamics.

This thesis develops a new method for analyzing transient stability in the transmission grid under consideration of the distribution grid level. The modeling approach uses grey-box models, which represent the dynamic behavior of generation units located at the high, medium and low voltage levels by means of equivalent generators. This allows a significant reduction of complexity and information demand compared to detailed dynamic distribution network models.

The modeling approach developed in this thesis is validated using synthetically generated distribution grids. In contrast to passive load models, which are classically applied for representing the distribution grid levels, the grey box models show a high accuracy both for high penetration rates of renewable energies and large voltage deviations. By applying the modeling approach to a model of the continental European power system of the year 2035, a dynamic grid model covering all voltage levels is then created and an analysis of the transient stability for three-phase short circuits in the German transmission grid is carried out. For the identified critical grid utilization cases and fault scenarios, three different options for the adaptation of the grid codes are discussed and their impact on the transient stability is evaluated.

Dr.-Ing. Andreas Moormann Determination of Robust Switching States for an Application in Transmission System Operation

Continuing developments in power supply lead to an increased need for remedial measures to avoid congestions in the transmission system. Switching measures to change the transmission system's switching state represent an almost cost-free means of grid operation, the use of which is also legally preferable to adjustments of the transport task. However, when considering switching measures in operational planning, extensive constraints must be considered:

- The occurrence of complex switching sequences and the limited reliability of switching de-vices require the testing of switching measures. Simply considering the resulting switching state is not sufficient.
- In order to be able to guarantee a smooth switching operation, the anticipatory selection of switching states is necessary.
- The coordination of switching measures requires the determination of a limited number of switching states, which can be used effectively for a longer period.

In today's transmission system operation, these constraints are considered in a simplified way. This thesis develops the concept of so-called robust switching states as a means of exploiting the potential of the switching state as efficiently as possible.

For the determination of robust switching states a method with different modules is proposed. First, a representative system use is derived on the basis of historical system use cases and modelled as a stochastic process. This allows in a next step the determination of robust switching states under simultaneous consideration of the required switching measures. Thereby an optimization is also carried out under consideration of the effect of other measures on the elimination of congestions. An application procedure is being developed for use in the operational planning of the thus determined robust switching states.

Dr.-Ing. Christoph Müller Approach for long-term planning of the energy supply structure taking into consideration of energy sector coupling

To meet climate goals, strategies are needed that address the heating and transport sectors as well as the electricity sector. Energy sector coupling could be an option to increase the share of renewable energies in all energy sectors and thus to reduce CO_2 emissions.

The goal of this work is the development of an approach for the coupled optimization of investment and operational decisions of the energy supply structure. The approach offers the opportunity to consider the coupling of energy sectors as well as the modeling of cross-sectoral flexibility options in the European energy system by taking into account energy policy requirements.

The large number of decision variables and constraints for real-size problems requires the application of mathematical decomposition methods. Lagrangian relaxation is used to relax system-coupling constraints and to split the overall problem up into unit-wise and regional subproblems. The solution approach of these sub-problems is based on a decomposition of the investment and operational decisions by using a Benders decomposition. As a result, the approach delivers cost-minimal planning and operational decisions for the energy supply structure for several coupled supply areas, which fulfills the defined energy policy requirements.

The application of this approach to the planning of the European energy system for the year 2050 illustrates its applicability to real-size problems. Up to a CO_2 reduction rate of 90 %, the most cost-effective solution in the examined scenario is a mix of an electrification of the heating and transport sector, the expansion of renewable energies and the use of low-carbon fuels and various flexibility options. In contrast, the scenario indicates that it is only possible to achieve a reduction of CO_2 emissions by 95 % by considering carbon capture in power plants.

Dr.-Ing. Stephan Raths Electricity Market Simulation in Decentralized Energy Systems

The ongoing energy transition in Germany and Europe has led to a new paradigm: Energy is increasingly provided by a huge number of distributed energy resources instead of by centralized generation. The share of cogeneration and Power-to-Heat solutions is growing. In combination with temporary electricity oversupply caused by a massive introduction of wind and photovoltaics, this leads to a stronger sector coupling, especially regarding heat and power. Electric and thermal storage devices provide additional flexibility on centralized and decentralized levels that can be used to support the market integration of renewables.

Whilst decentralization is the dominating trend in power and heat generation, on a European level electricity market coupling is evolving. These two apparently opposing effects form the main playing field for the present thesis, which develops a fundamental electricity market model that allows for the simulation of a decentralized, but pan-European electricity market.

A new decomposition approach derived from the concept of Lagrangian relaxation forms the methodical core of the model. In addition to the coordination of local load coverage within the different market areas, for the first time the international electricity exchanges are coordinated with Lagrangian multipliers in a parallel manner. This allows for an individual representation of thousands of generation units on central and decentral levels, since the system cross-plant optimization problem is decomposed into smaller sub-problems and a coordinator problem.

The model is validated against historical data. Special attention is paid to simulated spot prices, generation patterns of power plants and the simulated electricity exchange. The ability of the model to simulate centralized generation in combination with a large number of decentral energy resources on the Prosumer level is demonstrated with scenario simulations for the year 2025.

Dr.-Ing. Jens Sprey Calculation of the Frequency Restoration Reserve Taking into Account Reserve Exchange and High Shares of Renewable Energies

The progressive integration of plants based on renewable energies throughout Europe also influences the dimensioning of the control power, in particular that of the Frequency Restoration Reserve (FRR). Rising gradients and growing forecast errors of the feed-ins from renewable energy systems lead to an hourly fluctuating demand for FRR. In the future, the calculation of FRR will also be influenced by the European integration of the balancing power markets. FRR products on the balancing power market will be harmonized throughout Europe and put out to tender on a cross-border basis, with a core share of 50 % per load frequency control block (LFC-Block).

The aim of this work is to design the FRR design efficiently taking into account these emerging developments. Therefore, a probabilistic method is developed in this thesis, which determines on the basis of stochastic, transmission network node-sharp models for forecast deviations and gradients of the feed-ins of power plants based on renewable energies, for forecast deviations of loads and for power plant failures by means of a Monte Carlo simulation node-sharp balance imbalances for a seasonal series of the network use in the hourly grid.

For a given confidence interval, given product periods and taking into consideration the imbalance netting, the dimensioning of the FRR per LFC-Block can be derived and divided into manual and automatic FRR using a heuristic. Downstream, the minimum required core fraction is determined by optimization, taking into account network restrictions. Investigations show that considerable saving potentials can be realized by a dynamic design of the FRR in comparison to the static design common today. The saving potentials grow with the increasing expansion of renewable energy plants. On the other hand, further consideration of the imbalance netting, which is already practiced today, shows only low savings potentials, so that this benefit must be carefully weighed against the effort required to achieve it.

Dr.-Ing. Maximilian Stumpe Development of an Automatic Reclosing Concept for self-commutated HVDC Systems with Fault Current Controllability

The increasing use and integration of renewable energies demand energy transmission over long distances. Due to its technical advantages, high voltage direct current (HVDC) transmission with technology-dependent fault current control capability is increasingly being utilized. Energy transmission with overhead line systems is susceptible to faults due to atmospheric influences and requires reliable and rapid protection concepts for automatic reclosing (AR). In order to guarantee a highly available and stable electrical power supply, a rapid and predictable resumption of energy transmission after temporary grid faults is particularly important. For self-commutated HVDC systems, the auto-reclosing concepts based on the operating experience from grid-commutated HVDC and three-phase AC systems have thus far been used. Requirements for DC voltage recovery have not yet been specified. The existing concepts do not consider the advantages of self-commutated HVDC systems with a fast fault clearing and flexible DC voltage control.

The objective of this work is to develop an auto-reclosing concept based on the physical limits of dielectric recovery of the air insulation and an active fault clearing strategy for the fastest possible fault clearing with lowest energy input into the arc. To parameterize the concept, computational fluid dynamics (CFD) simulations are used to investigate the energy input into the arc and the subsequent cooling of the air insulation. Based on a sensitivity analysis, a fault scenario leading to a conservative estimate of the auto-reclosing is identified. To determine the dielectric strength during the cooling period a transient Leader model is implemented, verified experimentally and considered conceptually after specific validation during sensitivity studies. Subsequent to the fault clearing via the multivariable control of the converter output currents and converter voltages and a deionization delay of 40 ms, the DC voltage recovery can be initiated. Taking into account model uncertainties, an envelope curve for the DC line voltage recovery is specified. The adaptation of this curve to any HVDC system is described. The insulation arrangement investigations show that, while the complete insulation strength of the insulation path is restored after 450 ms, operating voltage stresses do not lead to reignition after approximately 250 ms. The auto-reclosing concept has a positive effect on system stability with a significant reduction of the interruption time.

Dr.-Ing. Nicolas Thie Risk Management in Direct Marketing of Renewable Energies

In conjunction with the worldwide expansion of distributed energy resources (DER), the call for stronger market integration increases. In this process, aggregators, who pool DER and control them centrally, have established themselves as service providers for the direct marketing of distributed generation. In direct marketing, aggregators are exposed to risks due to forecast uncertainties, in particular due to intermittent generation. Therefore, the quantification of risk exposure and the derivation and use of risk management measures are becoming increasingly important. However, existing market scheduling methods mostly take into account only individual uncertainties and do not permit a comprehensive assessment of risk management.

The goal of this thesis is to develop a method which can determine an optimal market scheduling under uncertainty and at the same time apply and evaluate risk management measures in a targeted manner. From the analysis of related research fields, the following measures are identified: hedging with futures, the use of flexibilities and regional diversification of DER. The method is divided into two steps: scenario generation and market scheduling under uncertainty. Within the scenario generation, the uncertainties are modelled in the form of stochastic scenarios. They represent the statistical properties of the underlying uncertainties (probability distribution, autocorrelation and cross-correlation). On the basis of the scenarios, an optimal scheduling decision is determined with the objectives of expected revenue (or return on investment) and the risk measure Conditional-Value-at-Risk (CVaR).

The combined application of the risk management measures can significantly increase profitability. The main effect of the measures is their influence on volume risks and thus on balancing energy demands.

Dr.-Ing. Denis vom Stein Influence of the level of model detail in electricity market simulations on the valuation of flexibility options

Electricity market simulations are an elementary tool for the macroeconomic evaluation of flexibility options. However, existing methods differ considerably in the level of model detail. The essential modeling dimensions are the representation of uncertainties, the different technologies with their technical and operational restrictions, the temporal granularity and the geographical scope in connection with market coupling. Due to limited computing power, a trade-off in the level of detail within and between the modeling dimensions is required. Therefore, the aim of this thesis is to develop a procedure to support modeling decisions. For this purpose, the influence of the level of model detail in electricity market simulations on the valuation of flexibility options is quantified and necessary levels of detail are identified.

The analysis includes a review of real-world uncertainties, market processes, and flexibility requirements and offers. Based on this, a selection of models with varying degrees of detail for the respective dimensions is formulated mathematically. For various model combinations, simulations can thus be used to determine the fundamental potential added value of a flexibility option on the electricity markets from a macroeconomic perspective, thus determining the influence of the model level of detail.

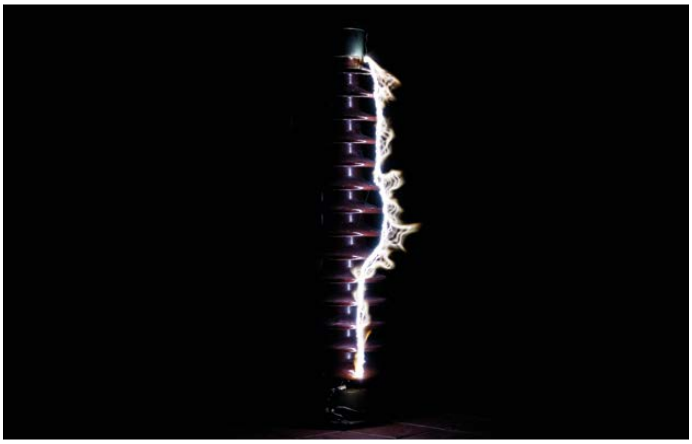
The studies show that the modeling decision in all four dimensions has a significant influence on the determined added value of a flexibility option. When compared to a defined reference calculation, the added value of an additional flexibility option quantified by the saved electricity generation costs lies between about 35 and 130 percent, depending on the model selection. The dimensions of the short-term uncertainties of residual load and market coupling are of particular importance.

Infrastructure and Tools


FGE
FORSCHUNGSGESELLSCHAFT
ENERGIE

High Voltage Equipment and Technology

Due to its extensive equipment, the Chair for High Voltage Equipment and Technology is able to deal with a wide range of problems in electrical power engineering. The focal points range from the investigation and characterization of insulating materials and systems, the development and testing of components such as switchgear or cables and overhead lines, to the investigation of protection and control strategies of future HVDC transmission systems. The infrastructure offers the possibility to perform both standardized tests, for example on surface or volume resistances or dielectric strength (AC, DC, impulse voltages) as well as customized tests. Thus, accelerated tests on the ageing behavior of insulating materials under a wide range of environmental influences (temperature, humidity) can be carried out. Extensive analytics allows the performance of non-electrical tests (e.g. light microscopy, ultrasonic diagnostics, detection of material defects or detachments, etc.). Different gas handling systems allow an extensive investigation of various quenching and insulating gases. Existing EMT models in combination with a dedicated power hardware-in-the-loop test rig for multi-terminal HVDC transmission systems allow addressing a wide range of questions regarding protection and control strategies of future DC networks. The in-house mechanical and electrical workshop enables the development and construction of individual test rigs as well as the realization of prototypes and test setups. The following test benches and tools are available:



Test Stand 1: High & Medium Voltage

For tests where high voltages are required (e.g. breakdown tests), the IAEW offers several test stations with high-voltage generators for different voltage types. AC, DC and impulse voltages (1.2 µs/50 µs, 250 µs/2500 µs) can be generated.

Technical Data:

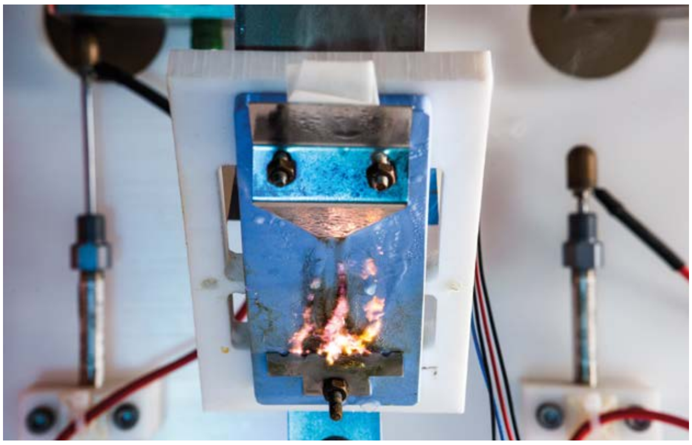
- AC voltages: up to 400 kV, 200 kVA
- DC voltages: up to 270 kV, 3,5 kVA
- Impulse voltages: up to 1 MV, 30 kJ

Test Stand 2: Climate and humidity influence

The IAEW offers a total of three climatic chambers (including a walk-in chamber), which are mainly used for the investigation of insulating materials under climatic stress. For example, contact resistances can be measured under different climatic conditions. Combined thermo-electrical investigations are also possible.

Technical Data:

- Temperature: -40 °C to 220 °C
- Relative Humidity: 10 % to 96 %
- Dew Point Range: 10 °C to 90 °C



Test Stand 3: Insulation materials
For the testing and characterization of insulating materials and insulation systems, the IAEW has a number of test stands and measuring equipment available. This includes tests of the hydrophobic properties of silicones and a comprehensive partial discharge diagnostics. Furthermore, it is possible for researchers to produce their own test specimens made of silicone (LSR) or epoxy resins (also with the addition of fillers) in the institute's material processing laboratory.

Technical Data:
- AC up to 100 kV
- DC up to 100 kV

Test Stand 4: Tesla-Transformer
At the IAEW a test bench is used to generate sinusoidal medium-frequency high voltages. The air-coupled Tesla transformer can be operated in resonance mode between 2 and 9 kHz. This allows investigations to be carried out on insulation systems, for example for use in converters or electromobility applications.

Technical Data:
- Medium frequency voltage (2 – 9 kHz) up to 100 kV

Test stand 5: Overhead lines
The overhead line laboratory enables the thermal testing of conductor cables, fittings or similar components under defined weather conditions. Mechanical and electrical parameters (current and horizontal tensile stress) as well as the influencing variables ambient temperature, wind speed and global radiation can be varied. A variable control and measuring system allows temperature recordings and the definition of load profiles.

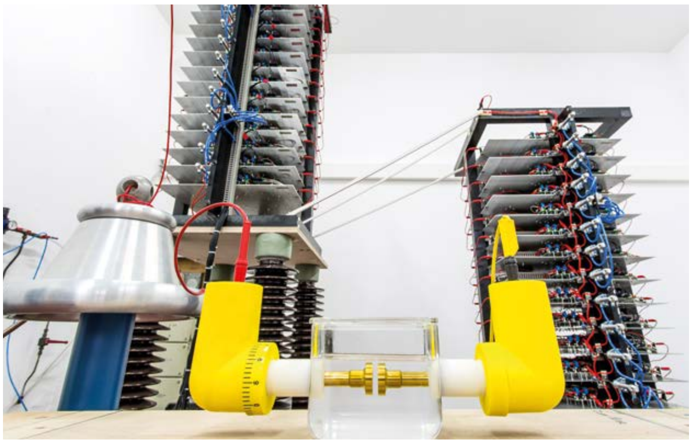
Technical Data:
- Current: max. 3 kA
- Mechanical tensile stress: max. 50 kN
- Ambient temperature: up to 40 °C
- Wind speed: 0,6 m / s – 6 m / s
- Global radiation: 0 W / m² and 500 W / m² – 900 W / m²

Test stand 6: AC high current-lab

Two synthetic test circuits according to Weil-Dobke and three separate test stations are available at the IAEW for the parallel preparation and execution of experimental investigations on AC switchgear. By means of transient recorders with up to 40 measuring channels a simultaneous acquisition of different parameters (e.g. current, voltage, pressure, etc.) is possible. A high-speed camera is available for optical arc investigations. Modern gas handling systems guarantee a safe and environmentally friendly execution of tests in different gases.

Technical Data:

- Current: up to 60 kA_{peak}
- Frequency: 50 Hz
- Recovery voltage: up to 140 kV
- Test energy: 585 kJ



Test stand 7: MFHV-Generator

The institute has a new type of medium-frequency generator at its disposal which, similar to an arbitrary voltage generator, can generate a variety of voltage forms at high output voltages and frequencies by switching different stages. For example, rectangular voltages with rising rates greater than 20 kV/µs can be generated. The test bench therefore allows the investigation of insulating materials and systems for future converters or electric mobility applications.

Technical Data:

- Medium frequency voltage (1 – 10 kHz) up to 50 kV (100 kV under construction)
- Maximum turn on and turn off time of 2 µs, Voltage rising rate > 20 kV / µs

Test stand 8: DCLab

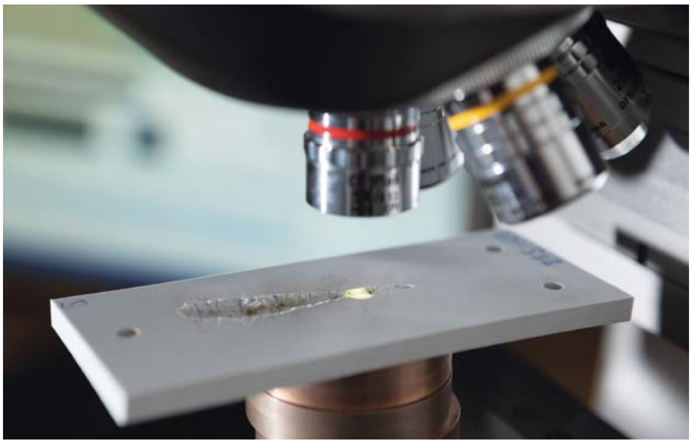
The testing and investigation of switching and protection components for DC systems is carried out in a new type of test circuit based on a parallel connection of 120 buck converter cells. The unique test circuit design allows the generation of almost any unipolar current form in an arc-fault-proof test environment. A comprehensive recording system allows the recording of relevant physical quantities.

Technical Data:

- Currents up to 30 kA
- Driving voltage of 8 kV
- Stored energy up to 2 MJ

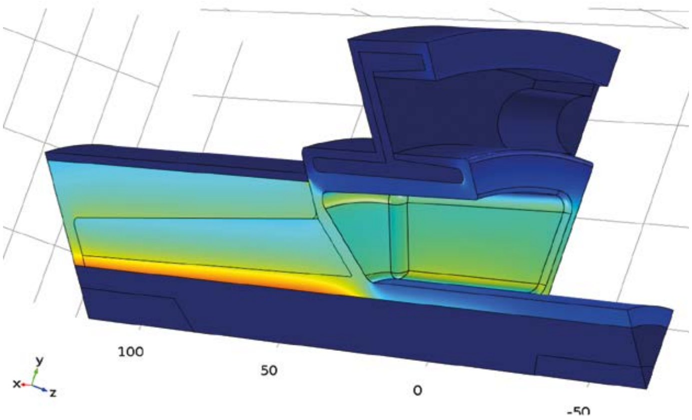
Test stand 9: MMC Test Bench
The MMC Test Bench, consisting of eight laboratory-scaled MMC converters as well as various real-time simulators, power amplifiers and pi-segments for mapping various transmission lines, enables the investigation of novel protection and control strategies for HVDC transmission systems by means of power hardware-in-the-loop and the consideration of the integration of HVDC transmission systems into existing AC structures.

Technical Data:
- 8 lab-scale MMC-converters with each 10 cells per arm
- 4 linear 4Q power amplifiers
- Transmission line emulation (cascaded Pi-segments)
- Various real time simulators



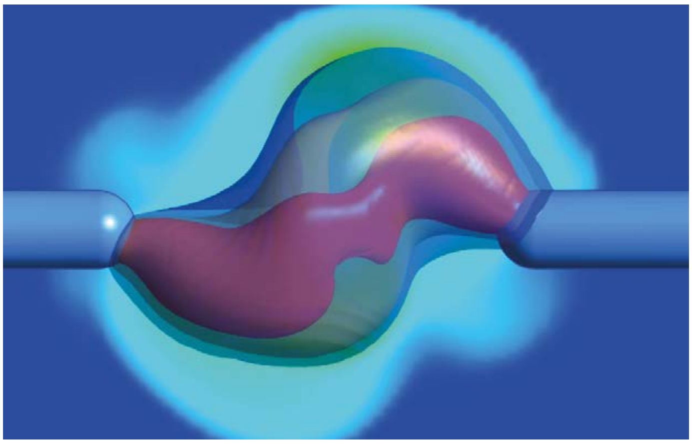
Test stand 10: Analytics
For the analysis of test specimens and components before and after test series, the IAEW has various measuring and test systems at its disposal. These allow electrical and imaging investigations of the surfaces and structure of material samples.

Technical Data:
- Laser microscope
- Partial discharge measurement
- Contact angle measurement
- Photography (Tele und Macro)
- Viscometer
- Karl-Fischer-Titration device



Tool 1: Electric field simulations
For the calculation of the distribution of the electric field in components and arrangements in 2D or 3D, the institute has various FEM solvers at its disposal. This makes it possible to identify critical field peaks and possible breakdown paths.

Used software environments:
- COMSOL Multiphysics
- ANSYS Electromagnetics

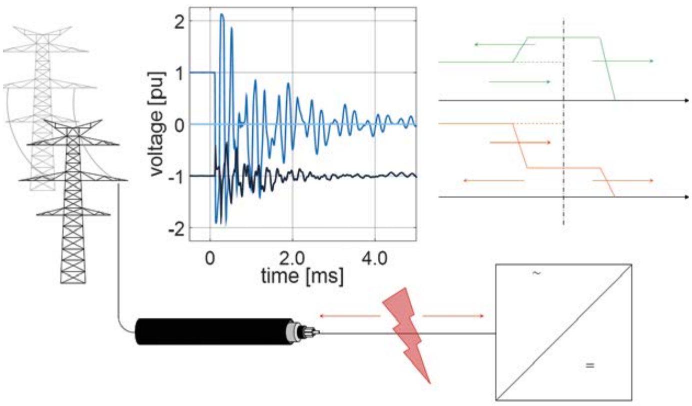


Tool 2: Electric arc simulations

The IAEW already has extensive experience in the field of FEM simulations of high-current arcs. These enable the calculation of pressure build-up in circuit breakers and a detailed investigation of the cooling properties of gas circuit breakers. Various sub-models, such as the integration of polymer ablation or the influence of metal vapor, can be used for this purpose.

Used software environments:

- Ansys CFX
- ANSYS Fluent
- ESI ACE+



Tool 3: EMT grid simulations

Various EMT simulation programs are used at the IAEW to investigate transient effects in electrical networks - for example as a result of faults. Particularly in the field of high-voltage direct current transmission (HVDC), there is a long experience, so that with the help of detailed and proven models of HVDC converters, AC and DC protection technology as well as transmission lines (cable, overhead line, hybrid lines), the phenomena occurring in present and future systems can be analyzed and loads can be quantified. Furthermore, the real-time capable EMT simulation environment HYPERSIM allows to combine this experience with hardware-in-the-loop investigation approaches (test stand 9).

Used software environments:

- PSCAD™/EMTDC™
- HYPERSIM

i

In addition to working on current research questions, the institute is available as a partner for joint research and development activities. Services can also be offered individually with the existing structure. Both tests according to standards and customized tests for special test purposes are offered.

Simulation Tools for Active Distribution Grids

ProbFlow – Grid Analysis using Probabilistic Power Flow Calculation

Due to the decentralization of the power supply with distributed, renewable generation plants, and additional loads (e.g. electric mobility, power-to-heat systems), there has been an increase in the uncertainty about future supply tasks in network planning and operation of distribution networks. This requires suitable probabilistic methods of network analysis and technology evaluation. The ProbFlow software is used to model uncertain information (for example load behavior, generator position, and weather time series) in a random process. By repeating the power flow calculation several times with identical input parameters but different random values, ProbFlow allows the simulation of a probabilistic distribution of generation units and their time series.

In ProbFlow, the repetitions are calculated and parallelized independently of each other. The software takes into account both the changing general conditions concerning the load and infeed as well as multiple innovative operating concepts, including centralized and decentralized voltage control methods. These are used today and will be used in future distribution network operation. A statistical evaluation of the resulting cluster of results is then carried out; this includes extreme values and quantiles of voltage and asset utilization. With this information, specific heuristic grid reinforcement measures can be automatically evaluated and the individual expansion requirements or integration potential for further loads and generators can be determined.

M²Q – Optimal Design of Multi-Carrier Energy Systems for City Districts

The tool "M²Q" can be used to determine optimal concepts to efficiently supply power and heat to city districts. Based on individual district data (e.g. building age and building sizes), efficiency measures are determined which minimize energy supply costs and emissions. Different energy efficiency measures and supply options are taken into account including various generation technologies (e.g. photovoltaic plants, combined heat and power plants, heat pumps, and biomass heating), electricity, and heat storage as well as the use of district heating networks. Energy-saving renovation measures are also considered. The results from the tool can be used to derive key concepts for the efficient supply of power and heat and can support decision-making in the planning of district energy systems.

Target Grid Planning for Distribution Grids

Grid usage is constantly changing due to demographic developments and changes in the generation and load structure. Against this background, regular evaluation of the existing grid and strategic planning of the distribution grids with regard to future scenarios is required. The target network planning procedure developed at the IAEW and tested in numerous studies determines a cost-minimized network structure including the necessary equipment dimensioning under the specification of a supply task and substation positions. The procedure enables the planning of radiation, ring and mesh networks and can therefore be applied flexibly for low, medium and high voltage levels. Individual structural requirements, such as a limitation of stitch connections, can be parameterized appropriately. In order to show a realistic transition from current to future networks, the existing network can be included in the optimization if required. The resulting cost-minimized target networks meet not only structural requirements but also technical constraints that are placed on the planning of distribution networks. Based on the requirements of the networks, complex load flow calculations, (N-1) outage simulations and short-circuit current calculations can be carried out as part of the technical review, taking into account joint shifts and decentralized component controls. In addition, a downstream probabilistic reliability assessment enables the determination of user unavailability in the resulting target grid as an important regulatory parameter. Based on the results, recommendations for network operators regarding the further development of their networks can be derived.

Tool for generating Synthetic, Georeferenced Distribution Grids for Energy System Studies

The IAEW has developed a comprehensive network model for the high and extra-high voltage level. For the medium and low-voltage level, on the other hand, a comparable, fully comprehensive network model can only be implemented at great expense due to the large number of networks. In order to be able to carry out nationwide system studies in addition to individual network studies based on real network data, a tool for generating synthetic, georeferenced medium and low voltage networks was therefore developed. Based on publicly available data and geo-information, characteristic medium and low voltage networks can be created. First of all, the supply task is determined on the basis of OpenStreetMap data, data from Zensus2011 and data from the Marktstammdatenregister (Core energy market data register) in a coordinate-specific or building-specific manner. This is the basis for determining the network structures. Since low-voltage networks in Germany are mainly constructed as radiation networks and medium-voltage networks are mainly constructed as open ring and string networks, they are mapped using radial network structures. The pathways at the medium-voltage level are mapped realistically by laying cables along roads. For the design of the MV and LV networks, standard equipment types are used. The use of georeferenced data to determine the current supply task and a network structure ensures that the diversity of the network structure and supply task of the distribution networks in Germany is mapped with sufficient accuracy. The grids thus developed then serve as input for system studies, such as the determination of investment requirements in German grids until 2050.

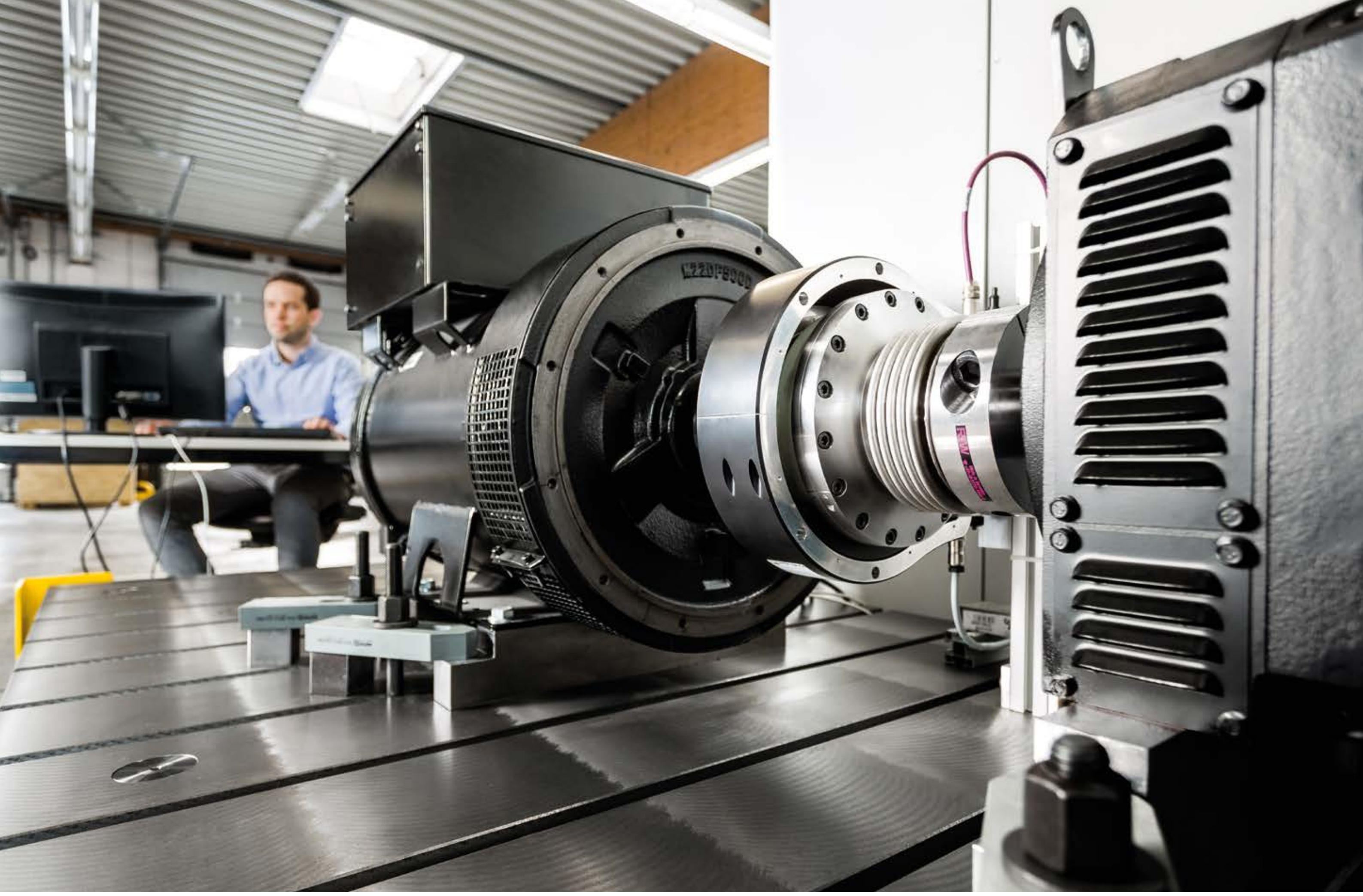


Figure: Synchronous generator

Grid Integration and Critical Infrastructure

The Testing Center ("Center for Grid Integration and Storage Technologies") is a 1:1 copy of a distribution grid in a laboratory environment, which provides the ability to test new components and modes of operation under different conditions. A medium voltage grid with different "intelligent" substations, a switchable low voltage grid, an extensive communication infrastructure with its own control system, and various different loads and energy sources allow the analysis of different grid topologies as well as load and supply profiles.

The low voltage grid has a total length of about 4.5 km cables with various cross sections allowing the reproduction of typical and special distribution grids. In addition to normal operation, specific components can also be used to analyze the effect of disturbances on network operation and the reliability of future distribution networks. Faults caused by short circuits or voltage deviations can also be generated during normal operation. One of the essential components of the lab is a 90-kVA main simulation system which generates user-defined voltage characteristics.

The main simulation system offers tests and measurements of innovative products such as Voltage-regulated Distribution Transformers, charging infrastructure, or system testing during fault conditions. To simulate different types of power plants, photovoltaic inverters with nominal power between 2.5 and 36 kVA, a synchronous generator, and an inverter for battery storage systems are available. Operation as an island network is also possible.

The existing control system offers different communication channels such as PLC, Ethernet, or mobile radio to integrate components into a smart grid. These communication channels are offered in a variety of technologies and manufacturers. Besides state-of-the-art technologies, future technologies can also be integrated. In addition to the hardware components, different software solutions are implemented to protect against cyber-attacks. This means digitalization and its influence on reliability, operation, and the security of critical infrastructure can be tested under realistic conditions.

IAEW-Toolchain

Simulation framework for cross-sectoral analysis and holistic assessment of the energy system

The IAEW-Toolchain is a simulation tool consisting of different modules for the analysis of the current and future energy system. Our scientific staff is constantly enhancing and extending our toolchain within various dissertations in order to be able to address current and future issues regarding energy supply, sector coupling and the electrical transmission grid or system stability. The economic, technical and ecological consequences of different regulatory frameworks and their interdependencies are quantified and evaluated. Possible research questions comprise the regionalisation of renewable energies, market mechanisms, power plant dispatch, transmission grid operation, the evaluation of system security as well as effects on security of supply and system stability.

With the goal of achieving the defined climate targets and pushing the decarbonisation of energy system, interactions between the energy sectors electricity, heat, gas and transport will increase. The resulting coupling of the sectors will have a significant impact on the operating modes and the requirements of thermal and hydraulic power plants, distributed energy systems as well as the electricity and gas infrastructure. The IAEW-Toolchain allows us to evaluate characteristics of different future scenarios, such as the use of power-to-heat or power-to-gas technologies, the profitability of thermal power plants or the influence of innovative congestion management concepts in the transmission grid.

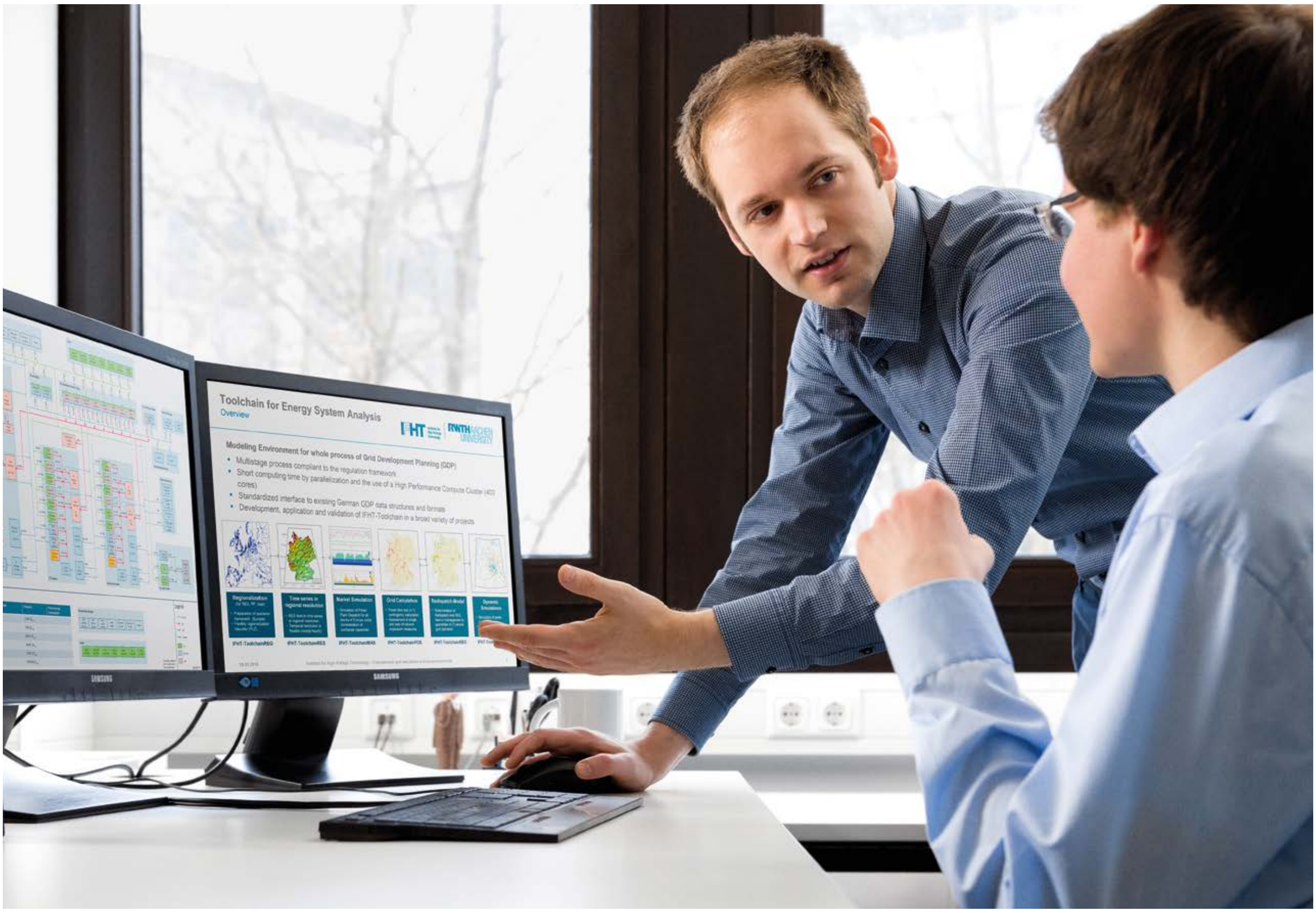


Figure: Discussion on interfaces of the IAEW-toolchain and on simulation results

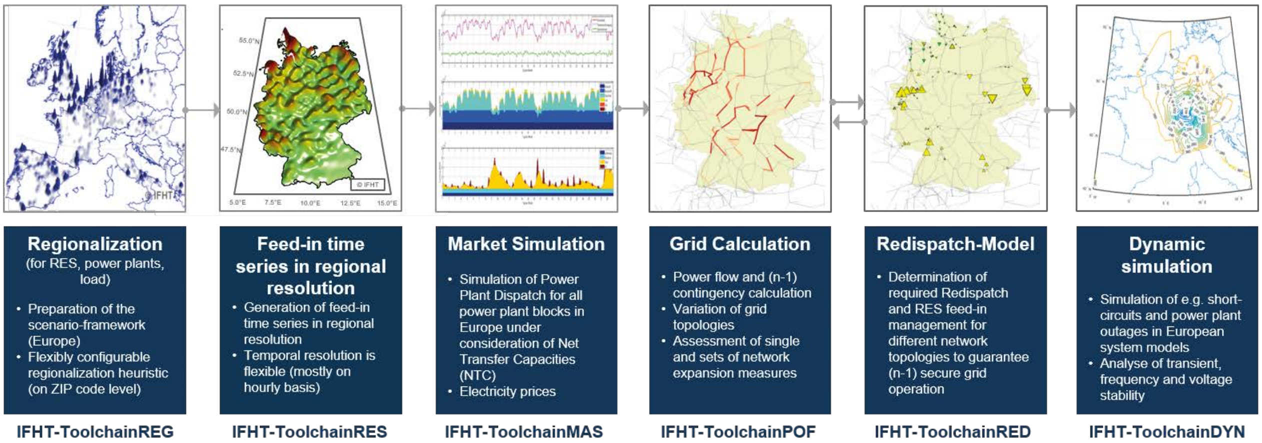


Figure: Overview oft he IAEW-Toolchain

For this purpose, market simulations are performed and feed-in time series of renewable energies generated based on European weather data with high temporal resolution. The market simulation depends on a detailed database of thermal and hydraulic power plants in Europe, which is permanently updated according to political and economical developments (e.g. coal phase-out). Power plant modelling takes various types of power plants with their specific characteristics, efficiencies, shutdown and start-up times into account. By modelling the European electricity and balancing power markets, taking into account Flow-Based Market Coupling (FBMC), it is possible to determine the dispatch of thermal, hydraulic and distributed generation, storage systems and flexible loads participating in the electricity market, as well as the effects of sector coupling. In addition, the results of the market simulations provide a quantification of future electricity prices and thus enable an assessment of the future viability of various technologies.

Changing regional load and generation patterns have an increasing influence on the transport demand and thus on the required grid expansion in the transmission system. Nevertheless, congestion management measures are required today as well as in the future to relieve bottlenecks. As part of their operational planning processes, transmission system operators forecast congestions and initiate grid-related measures (e.g. topology switching, HVDC systems, phase-shifting transformers) or redispatch measures to ensure system security. To model this process, detailed models of the high and extra-high voltage grids in Europe and various grid operation simulations of the IAEW- Toolchain are used. The tools are partly developed in close collaboration with the Research Association for Electrical Equipment and Power Economics (FGH) and are largely licensed to all German transmission system operators.

In addition to the consideration of today's operative measures, the tools enable the detailed modelling of future transmission grid operation, such as the analysis of curative or reactive system operation concepts or the analysis of coordination processes between transmission and distribution grid operators for the exchange of active and reactive power. Besides that, our toolchain enables coupled electricity and gas network simulations for the analysis and assessment of sector-coupling technologies and system operation concepts.

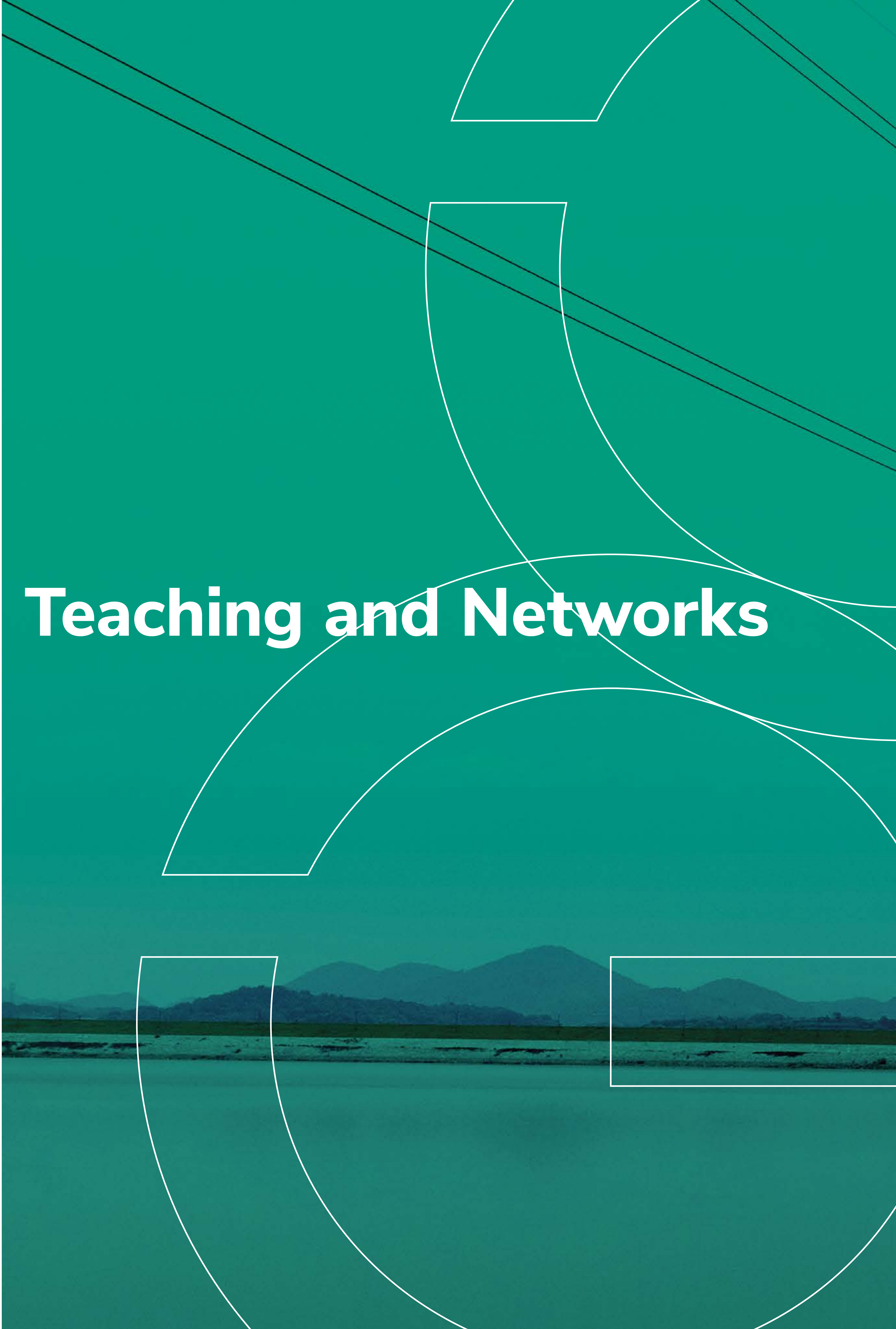
Decreasing conventional generation capacities, the increasing number of active grid components (e.g. inverters and HVDC systems) and the higher utilization of transmission lines directly affect system stability and might result in critical system states. Based on steady-state grid simulations, time-domain simulations (e.g. MatPAT) are performed to analyse the resulting system states. The methods and models enable the analysis and evaluation of harmonic, transient, frequency and voltage stability, e.g. to identify the steady-state and dynamic reactive power demand in the future transmission grid. Furthermore, the effects of short circuits, contingencies and system splits are calculated and the robustness of the system evaluated.

The simulation tool is modular designed, making it unique in this form, and is permanently modified to address current research questions. Thus, the IAEW-Toolchain allows us to perform comprehensive analysis and simulations for investigating current and future challenges in the energy system and support the realisation of the "Energiewende".

i

Contact
Dr.-Ing. Philipp Baumanns
André Hoffrichter, M.Sc.
oi-uew@iaew.rwth-aachen.de

Teaching and Networks




FGE
FORSCHUNGSGESELLSCHAFT
ENERGIE

Teaching at the IAEW

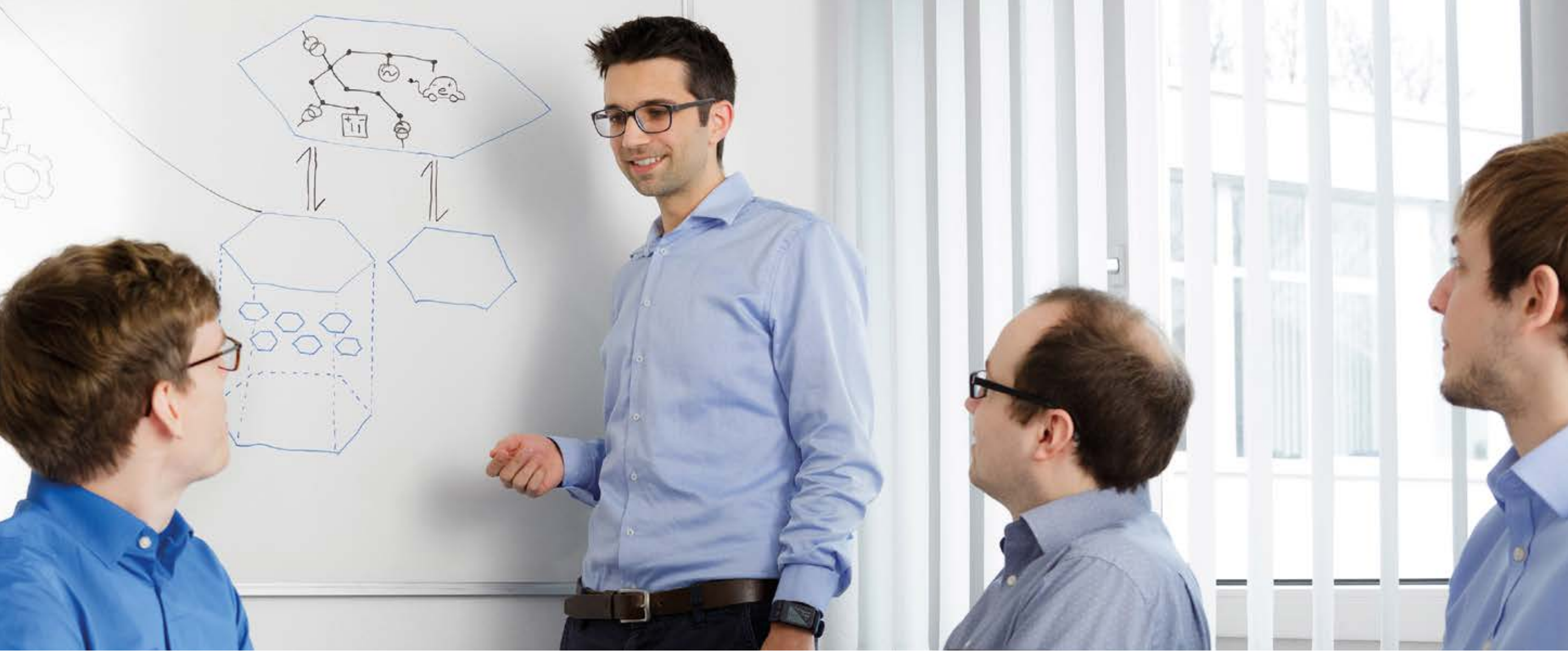
One of the main tasks of the institute is the engineering education of students. Students acquire extensive basic knowledge supplemented by subject-specific knowledge from current research and development topics in our courses from the field of electrical power engineering and energy economics. Thus, they are very well prepared for the challenges in their future professional environment.

In addition to the lectures on high-voltage engineering and electricity supply systems, practical training and project work is carried out to test and implement what has been learned. Seminars and professional excursions round off our range of courses.

With several English-language courses, the IAEW also meets the needs of the international environment.

Lectures

Course	Semester	Language
Components and Equipment of Electric Power Supply	Winter semester	German
Electrical Energy from Renewable Energy Sources	Winter semester	German
Energy Trading and Risk Management	Winter semester	German
Faults and Stability in Power Systems	Summer semester	German
High and medium voltage switching devices and systems	Summer/winter semester	German
High Voltage Direct Current Transmission	Summer semester	German
High Voltage Engineering Insulation Systems	Summer semester	English/German
High Voltage Engineering Test Systems and Diagnosis	Winter semester	English/German
Operation of Interconnected Power Systems	Winter semester	German
Overhead Lines	Winter semester	German
Planning and Operation of Power Systems	Winter semester	German
Power Economics in liberalised Electricity Markets	Summer semester	English
Power Cable Engineering	Winter semester	English
Power Generation and Trading	Winter semester	German
Power Systems	Winter semester	German
Professional Environment of Engineers	Winter semester	German
Protective Measures and Equipment in Power Supply Systems	Summer/winter semester	English/German



Seminars

Course	Semester	Language
The Future of Energy Supply	Summer/winter semester	English/German
Innovative Business Models for Energy Supplier	Winter semester	German
Economic Fundamentals for Engineers (with Corporate Planning Game)	Summer/winter semester	German
Protection and Control Technology	Summer/winter semester	German
Power Generation and Energy Trading	Summer semester	English

Laboratory Exercises

Course	Semester	Language
Electrical Engineering Labratory	Summer semester	German
Labratory in Electrical Power Engineering I & II	Summer/winter semester	English/German
Labratory Exercises on High Voltage Engineering	Summer/winter semester	English/German
Measurement Laboratory	Winter semester	German

Project Works

Course	Semester	Language
Determination of the Network Expansion to Integrate Renewable Energy Sources (4th semester B.Sc.)	Summer semester	German
Approaching the Long-Term Optimal High Voltage Grid (M.Sc.)	Summer semester	English/German
Operation of Hydropower Plants in the Electricity Market (M.Sc.)	Summer/winter semester	
Sustainable Transmission Systems	Summer/winter semester	English/German
Sustainable Distribution Systems	Summer/winter semester	German
Planning of Long-Term Optimal Medium Voltage Networks (M.Sc.)	Winter semester	English/German

High-Voltage Direct Current Transmission (HVDC)

Lecture on direct current technology in high and medium voltage networks

Figure: Excursion group during the field trip inside the HVDC converter hall

The increasing global demand for transport of electrical energy pushes conventional AC grid expansion to its economic and technical limits. One main reason is the long distance between load centers and locations with large natural resources (especially wind, water and sun) which can provide sustainable energy. On the other hand, especially in Europe, challenging geographical areas such as the North Sea or densely populated regions have to be crossed. The transmission line can basically be implemented as overhead line system or cable route, whereby socio-ecological and technical aspects can influence the choice of technology. The high volatility of renewable energy resources also requires highly flexible system solutions that combine functionalities such as load flow control, reactive power compensation, accurate fault handling, black-start capability and the coupling of asynchronous grid areas. As a result of these enormous demands on future transmission grid expansion and operation, HVDC systems have become an important supplement to conventional AC power transmission over the past two decades. Technological improvements in the field of semiconductor devices enable powerful, efficient and fully-controllable HVDC systems on the gigawatt power scale. For these reasons, HVDC systems are not only playing an increasingly central role in the German grid development plan as an alternative to conventional AC grid expansion and for connecting the steadily increasing offshore wind capacities, but are also becoming more and more system relevant. Grid connection guidelines such as VDE-AR-N 4131 (March 2019) attempt to define the necessary technical framework for this transformation. However, comparing various national requirements for HVDC systems, it turns out that many technical and regulatory questions have not yet been sufficiently agreed on and must be clarified. This alone shows that there is an immense need for research in the field of HVDC.

The master-level course “High-Voltage Direct Current Transmission” (HV-DC), which is an integral part of the IAEW’s curriculum, takes up this development trend and examines it in detail. Over two consecutive Dipl.-Ing. Wilfried Breuer, TenneT Offshore GmbH days, renowned industry experts present the relevant technical content in thematically coordinated sessions. The different perspectives of the speakers, which are based on their respective experiences, provide a comprehensive and unique insight into the subject of HVDC. Besides students of RWTH Aachen University, external parties from industry are also invited to register for the seminar. Regular breaks between the sessions provide an opportunity for discussions with the speakers, promote networking between students, industry participants and speakers, and create an excellent environment for a lively exchange.

In addition to the lecture itself, this year students had the rare opportunity to visit the onshore grid connection point of the offshore HVDC link “BorWin 3” in Emden (Germany) and, under the supervision of the engineers in charge from Siemens and TenneT, see a real converter hall on site, from inside and outside, before going into operation. Prospective graduates made great use of the opportunity to ask questions and to get detailed answers from the experienced engineers. Afterwards, the students took home to Aachen a lasting impression of a real HVDC converter site and its dimensions.

Contact
Hendrik Köhler, M.Sc.
h.koehler@iaew.rwth-aachen.de
+49 241 80 97348

Markus Kaiser, M.Sc.
m.kaiser@iaew.rwth-aachen.de
+49 241 80 97881

High and Medium Voltage Switching Devices and Systems

Block lecture

The lecture “High and Medium Voltage Switching Devices and Systems” takes place in the form of a two-day block event, in which the participants get an overview of the structure and functionality of components and systems for power transmission and distribution.

The block lecture offers a comprehensive overview of both the physical basics as well as the economic aspects of switchgear and system technology. Topics include the basics of power supply, starting with the general structure of the electrical power system, the construction of high- and medium-voltage switchgears and the functionality of circuit breakers and fuses, including the functionality of switching devices, switchgears or protective devices, as well as their design and connection to the grid. In addition, different types of SF_6 high-power circuit breakers and their functional principle when interrupting currents are explained. The structure and functionality of the components of vacuum circuit breakers are also covered. In particular, the physical processes involved in interrupting short-circuit currents are addressed and the typical application areas for SF_6 and vacuum circuit breakers are presented.

High voltage fuses are another focus of the lecture. The different types and their characteristic differences and applications are explained in detail. The structure and purpose of the individual fuse components are described using hardware fuse samples.

Fuse behavior when interrupting overload currents and short-circuit currents and the causes of current-limiting interruptions are also discussed.

Another topic of the lecture deals with the operating experience with modern plant technology from the power plant operator’s point of view. In this context, information about legal regulations and standards is presented.

Cables and overhead lines are used for the transmission and distribution of electrical power and are therefore considered in the block lecture. Their specific technical advantages and disadvantages in low, medium and high voltage applications are discussed. In addition, the purpose, the physical principle and the construction of power transformers are explained. The structure and arrangement of the individual components are presented and their functional context is explained.

Finally, the lecture gives an insight into the currently available technologies for high-voltage direct current transmission (voltage levels, converter principles, currents, cable routing). In addition, an overview of the advantages and disadvantages of different technologies in comparison to classical three-phase current technology is given.

For students, the two-day block lecture ends with a half-day tutorial, in which the main topics addressed in the block lecture are discussed and consolidated.

The central contents of the block lecture “High and Medium Voltage Switching Devices and Systems” include:

- Introduction to electrical power systems
- Substations and voltage regulation in distribution networks
- High-voltage switchgears for open air applications
- Gas-insulated high-voltage switchgears
- Medium-voltage switchgears
- Equipment for high-voltage direct current transmission
- Switching arcs and SF_6 high-voltage circuit-breakers
- Vacuum circuit breakers
- High-voltage fuses
- Power transformers and tap changers
- Surge arresters

Lecturer
Dr.-Ing. Ralf Puffer
r.puffer@iaew.rwth-aachen.de
+49 241 80 94950

Supervisor
Jannis Kahlen, M.Sc.
j.kahlen@iaew.rwth-aachen.de
+49 241 80 49353

FGE-Tagung 2019
Energy. Digital. Cross-sectoral.

On September 26 and 27, 2019, the FGE conference took place in Aachen. This conference is held every two years, alternating with the FGE seminar. The target group of the event are actors of the energy industry from different branches and areas.

The title of the conference was “Energy. Digital. Cross-sectoral.” It addressed two current and future-oriented topics of the energy industry. The socio-political discourse on a successful energy turnaround is in full swing in times of the Fridays For Future movement and the recommendations from the coal commission, the 5G frequency auctions and the strategic re-sorting of market players.

Several key issues were addressed as technical contributions to the discussions:

- How can we achieve a climate- and business-friendly and secure energy system transformation?
- How do we deal with structural grid bottlenecks?
- What influence will digitalization have on future network management?
- How can new types of consumers be integrated into the system in the best possible way?
- What role will joint planning and operation of a cross-sectoral energy supply system play in the future?

The Chairman of FGE, Dr. Joachim Schneider, Director of Technology and Operations at innogy SE, welcomed the guests and asked for a minute's silence in memory of the late, long-time director of the IAEW, Professor Dr.-Ing. Hans-Jürgen Haubrich, whose life's work he subsequently honored. Professor Moser then introduced the topic of the conference. Expert representatives from the electricity and gas industry as well as digitalization experts from the industry and academia presented their perspectives on the issues addressed at the conference and discussed them with the more than 300 guests. In addition to other high-ranking speakers from the energy industry, Dr. Rolf Martin Schmitz, CEO of RWE AG, and Dr. Leonhard Birnbaum, member of the E.ON.SE Board of Management, agreed to give the event's keynote speeches. The six sessions addressed topics such as the energy policy challenges, the digitalization of network operation and the sector coupling of electricity and gas. Participants at the conference responded positively and particularly appreciated the breadth with which the topics were treated.

The FGE Colloquia in 2019

FGE Colloquia were again offered in the summer and winter semesters of 2019. Current issues and controversial topics of the energy industry were taken up and discussed with proven experts from industry, business, associations or government. In the winter semester, a podium event, the Rogowski theme evening, was included for the first time in addition to the lectures. The target groups of the events are students of energy science, IAEW assistants and the interested public. All events were once again very well attended and guests and speakers engaged in a lively and animated dialogue.

Below is an overview of the events:

May 09, 2019: Infrastructure Outlook 2050

Tobias Frohmajer
Corporate Asset Owner TenneT TSO GmbH

Contents:
- Investigations of target visions for 2050
- Effects on the existing network infrastructure
- Identification of the main drivers in the context of sector coupling
- Message deduction

June 6, 2019: Digitalization of the energy system transformation in Germany

Prof. Dr. Michael Koch
Executive Vice President/Division Manager Smart Grid
devolo AG

Contents:
- What makes a power grid a smart grid?
- How is the legal framework technically implemented?
- With which products does devolo support the digitalization of the energy revolution?
- Outlook: The standardization strategy of the Federal Ministry of Economics and Energy

June 27, 2019: Flexibility markets – are all problems solved now?

Dr. Jens Büchner
Managing Director E-Bridge Consulting GmbH

Contents:
- What are flexibilities and who needs them?
- Do we need new market mechanisms?
- Which projects are there?
- Flex-routers and flexibility markets
- What happens next?

November 21st, 2019: Cyber Security in the energy industry

Raphael Ernst
Fraunhofer Institute for Communication, Information Processing and Ergonomics (FKIE)

Contents:
- Reality Check – From Cyber Attack to Blackout?
- False Friends – Why we say the same thing and mean something different
- Practical IT-Security – Making attacks more difficult, detecting and reacting to them
- Interdisciplinary Work – Why successful digitalization can only be achieved together

December 12, 2019: Is renewable equally sustainable?

Dr. Volker Stelzer
Institute of Technology Assessment and Systems Analysis (ITAS), Karlsruhe Institute of Technology (KIT)

Contents:
- Presentation of a tool for systematic sustainability assessment
- Sustainability assessment of energy technology options
- Sustainability assessment of the German energy system

January 16, 2020: Energy system transformation without grid expansion? Panel discussion (Rogowski theme evening)

Dr. Phillip Fest
Ministry of Economic Affairs, Innovation, Digitalization and Energy NRW

Nadine Bethge
German Environmental Aid

Dr. Klaus Kleinekorte
Amprion GmbH

Dr. Michael Ritzau
BET GmbH

Contents:
- Phasing out nuclear energy and coal-fired power generation – grid expansion as well?
- Are there alternatives to grid expansion?
- Why is acceptance of grid expansion declining?
- How can we find a social consensus and increase acceptance?

IFHT Colloquium 2019

The High Voltage Technology Colloquium of the Institute for High Voltage Technology took place on June 28th 2019. Three anniversaries were celebrated: the 80th birthday of Prof. Dr. rer. nat. Gerhard Pietsch, the 85th birthday of Prof. Dr.-Ing. Klaus Möller and the 90th anniversary of the RWTH Rogowski building.

The Anniversaries

Professor Pietsch began working at RWTH in 1975. His teaching and research activities focused on the basic areas of electrical engineering and gas discharge technology. Professor Pietsch was very involved in shaping the direction of energy technology at RWTH Aachen University – e.g. in the Senate Commission. His scientific research was primarily in the areas of fundamental studies of dielectric barrier discharges with applications in plasma chemistry and in the modeling and experimental investigation of high current arcs. Until 2008 Professor Pietsch was still active in teaching and research at the IFHT. In addition, he was a reviewer and consultant for various professional organizations and for several international journals and research funding organizations.

The second anniversary was the 85th birthday of Professor Möller. He was director of the Institute of General Electrical Engineering and High Voltage Technology at the RWTH from 1973 to 2001. In the course of his professional career, he was involved in high-ranking national and international committees in the field of electrical engineering and high-voltage engineering as well as in several professional organizations.

The two men are not only united by their passion for their scientific fields. They are also united by the joy of music and in particular of choral singing: Professor Pietsch is co-founder of the Paul Gerhardt Choir and Professor Möller directed the “Collegium Musicum” at RWTH from 1982 to 1999.

The third anniversary was in honor of the building in which the two aforementioned jubilees researched and taught – in 2019 the Rogowski Building turned 90. Built in 1929, the building was named after Walter Rogowski in 1947. Rogowksi made important inventions in the field of high-voltage technology and in 1925 he succeeded in experimentally proving the time course of a travelling wave for the first time. Rogowski received several awards for his achievements over the course of his career.

The Colloquium

The colloquium, which was attended by more than 200 guests from industry and the scientific community, was opened by Professor Moser, the acting director of the IFHT. In addition to congratulating the anniversary guests, he addressed the upcoming structural changes in energy technology at RWTH Aachen University and presented the future vision for this field. The Vice Rector for Research at the RWTH, Professor

Wessling, underlined the necessity of the RWTH internal cluster formation in central research fields in order to maintain international competitiveness. Professor Kerner, whose area of expertise is history, enthralled the audience with a humorous and entertaining lecture on the topic of old age. The first part of the event was concluded by Professor Möller with remarks on the historical development of high voltage technology since Rogowski.

The afternoon began with a top-class panel of experts on the subject of “The transformation of high-voltage technology in the context of the megatrends decarbonization, digitalization and decentralization”.

Dipl.-Ing. Michael Rohde, Managing Director of Maschinenfabrik Rheinhausen GmbH, demonstrated the potential of the classic components of high-voltage technology that can be enhanced by digitalization. Professor Stepken, CEO of TÜV SÜD AG, spoke about the important role of certification for the safe operation of our energy system. Professor Tenbohlen, head of the Institute for Power Transmission at the University of Stuttgart, emphasized that despite all the hype about decentralization and digitalization, knowledge about the components should not be neglected. Professor Schnettler took the view that power to gas will become one of the central future technologies in the context of the energy transformation.

The highlight of the event was the ceremonial presentation of the HTG Prize. The High Voltage Technology Society at the RWTH e. V. (HTG) is the alumni association of the IFHT.

HTG – The Alumni Network

Link between science and industry

The predecessor institutes for High Voltage Technology and for Power Systems and Power Economics have always maintained close contacts with their alumni. These close contacts will also be continued at the new IAEW.

The Institute of Power Systems and Power Economics maintained regular contact with its alumni at alumni events. The close cooperation with the Forschungsgesellschaft Energie also offered a constant exchange with alumni, as far as they were employed in the member companies of the FGE. At the Institute of High Voltage Technology, alumni activities were organized differently. Eleven years ago, on the initiative of two alumni, the High Voltage Technology Society at the RWTH Aachen e. V. (HTG) was founded, whose main goals were the promotion of young scientists and networking between alumni and current assistants.

HTG in 2019

2019 was an eventful year for the HTG, as the High Voltage Technology Colloquium of the Institute for High Voltage Technology in Aachen took place on June 28, 2019. There were three milestone birthdays to celebrate: Professor Pietsch turned 80 and Professor Möller 85. In addition, the venerable Rogowski building of the RWTH, location of the Institute of High Voltage Engineering, celeb rated its 90th anniversary (more about the colloquium under 108).

HTG members

At the time of its foundation, the HTG had 25 members. Today it has more than 100. Since its foundation, the association has been able to continuously expand its promotional measures and activities thanks to the commitment of its members, and has always been able to adapt them to the needs of the Institute. For some time now, the association has been accepting research assistants as guest members in order to promote networking with Institute alumni at an early stage.

HTG support instruments

Essential measures for the promotion of young scientists are financial support for patent applications and the remuneration of scientific publications that are subject to a peer-review process. It is gratifying to note that this support has been awarded frequently, which is an expression of the Institute's dynamic research environment and the high quality of its work .

The association also promotes student and social activities, such as the annual Whitsun excursion or the annual summer semester closing event.

Particularly popular is the support of the institute's sports activities, which include the weekly soccer training. Not only assistants, but also students of the Institute take part in these activities – an opportunity to start networking at an early stage of Institute membership.

Outlook

The Institute of High Voltage Technology has been transformed into the new IAEW in 2019 and the competences and potential for research and teaching cooperation have multiplied as a result. It is therefore only logical that the HTG is considering how it would like to further develop its alumni work against this background. Initial suggestions for this are currently being discussed. The corona crisis has delayed appropriate decisions in the first half of 2020, but these will be taken as soon as possible. For alliances between science and alumni working in the economy will assuredly be even more important after the crisis than before. And we want to be well prepared for this.

The HTG - Prize

The flagship of the promotion is the annual awarding of the HTG prize, which is awarded to students of the Institute of High Voltage Engineering who have written a bachelor or master thesis of outstanding quality. The prize is endowed with 500 Euro each. In 2019 the jury, a panel of experts from among the alumni, awarded the prize to the following students:

Stefanie Lösing, M.Sc.
“Analysis of Short-Term Voltage Stability in the European Transmission System”,
IFHT Department of Network Integration and Stability

Adrian Reeser, B.Sc.
“Investigation and evaluation of the applicability of machine learning methods for the detection of attacks on electrical power supply networks”,
IFHT Department of Energy System Technologies

Nils Collath, M.Sc.
“Development of a fault detection strategy for dynamic activation of faulty line segments in Multiterminal HVDC systems based on full bridge converters”,
IFHT Department of Network Integration and Stability

Imprint

Contact Information
Institute for High Voltage Equipment and Grids, Digitalization and Energy Economics
at the RWTH Aachen University
Schinkelstraße 6
52056 Aachen, Germany

Telefon: +49 241 80 97653
Fax: +49 241 80 92197
info@iaew.rwth-aachen.de
www.iaew.rwth-aachen.de

Publisher
Univ.-Prof. Dr.-Ing. Albert Moser
Institute for High Voltage Equipment and Grids, Digitalization and Energy Economics
at the RWTH Aachen University

Editorial Team
Dr. Regina Oertel
Anette Ringe

Layout
TEMA Technologie Marketing AG
www.tema.de

Images
123rf (Cover, 16 – 17, 32 – 33, 56 – 57, 76 – 77, 86 – 87, 98 –99)
Martin Braun Fotografie (3, 19, 20, 22 – 25, 34, 35, 52, 59, 72, 80, 88 – 91, 95, 96, 101)
IAEW (12, 21, 102, 105 – 107)
Angela Graumann (108 – 111)
Innovation Designs (26, 75)
Corinna Krauthausen und Innovation Designs (11)

Copy Editing
Robert Koch, Ph.D.
RWTH Aachen University Language Center

Print
sieprath GmbH
www.sieprath.de

Editorial Closing
31.12.2019

ISBN 978-3-00-066030-6

FORSCHUNGSGESELLSCHAFT ENERGIE

ISBN 978-3-00-066030-6