FORSCHUNGSCAMPUS
FLEXIBLE ELEKTRISCHE NETZE







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Annual Report 2017

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Preface

Dear readers,

With 2017, another eventful and successful year went by for FEN Research Campus, filled with fruitful projects and research activities that gradually help us to step towards a reliable and sustainable energy system of the future.

The past year has set another important milestone in the research and development of direct current technology for electrical grids: our Medium-Voltage DC (MVDC) Research Grid, which will eventually be demonstrated and tested on the RWTH Aachen Campus. Planning has been completed and a civil engineering company has been commissioned with its construction. The MVDC Research Grid is an important instrument for validating the readiness of DC technology in public medium-voltage grids and their applications.

In the last year, two new industrial partners joined the Medium-Voltage Consortium of FEN Research Campus – Mitsubishi Electric and thyssenkrupp Electrical Steel. Together with the other partners from industry and science, they will support us in forwarding the research and development of flexible electric grids.

Our success can largely be attributed to the dedication of our university and industrial partners. We would like to express our gratitude to them for their excellent and productive collaboration. We would also like to give special thanks to our sponsors.

2017 has brought much progress and opened up new perspectives within the research activities of FEN Research Campus. We are looking forward to many more successful, innovative and exciting projects in 2018.

Sincerely yours,

Prof. Dr. ir. Dr. h. c. Rik W. De Doncker
Director FEN Research Campus
Chairman of MV Consortium

Prof. Antonello Monti, Ph.D.
Co-Director FEN Research Campus
Chairman of LV Consortium

Prof. Dr.-Ing. Albert Moser
Co-Director FEN Research Campus
Chairman of HV Consortium

Photo (from left to right):

Prof. Antonello Monti, Ph.D.; Prof. Dr.-Ing. Albert Moser; Prof. Dr. ir. Dr. h. c. Rik W. De Doncker

About us
Vision

Flexible Electrical Networks (FEN) Research Campus envisions a future energy supply that combines sustainability, reliability and affordability as its key components. Therefore, we made it our mission to research, develop and implement innovations in the field of grid technologies with a high share of fluctuating and decentralized renewable energy sources. At the same time, direct current (DC) plays a pivotal part within the framework of our research activities.

Why do we have this vision? One impulse, of course, is the prevalent and ever growing change of the electric supply system, which shows an increasing tendency towards evironmentally-friendly alternatives e.g. decentralized reneweable energy sources like solar or wind energy. Small-scale sources like solar energy, for instance, can be efficiently exploited and collected by means of photovoltaic (PV) solar systems that are attached to the roofs of private homes or public buildings. The collected energy is then distributed over the whole country and those who used to be mere consumers now become producers – or "prosumers". At the same time, large-scale power generators like offshore wind farms must be connected, sometimes over long distances.

Our existing conventional three-phase alternating current (AC) supply system was designed for a top-down transmission and distribution of electricity produced by a number of large central power stations. While this technology has served its purpose for many decades, novel electric power conversion technologies as well as the integration of renewable energies substantially change the picture of the contemporary state of the art.

Renewable and decentralized energy sources offer great potential for innovative technologies due to their high availability and sustainability – however, they also require the development of a new grid infrastructure as decentralized production of electric energy strongly affects the properties and requirements of future

About us
Organization

grids. Here, both the flexibility and efficiency in terms of transmitting, distributing and storing electricity are the primary aspects to focus on. As a result, the generation of electricity from fluctuating and decentralized sources will be managable in an easy and efficient way.

The aforementioned flexibility is a strong component of our vision and can be implemented by means of intelligent power electronics systems, thus replacing the previous 50/60HZ AC transformer technology. Consequently, an innovative electric grid, with flexible interconnections of both consumers and generators as well as unrestricted DC-based energy flow, will emerge. The development and implementation of such an innovative grid, using a high share of fluctuating decentralized energy sources, would ultimately ensure the future energy supply system.

According to our motto "Research for the grids of the future", FEN Research Campus is determined to accomplish this vision by exploring and developing innovative grid technologies. The overall aim of our scientific activities is to prepare electric grids for a high share of decentralized renewable energy sources. In this context, the research of direct current technology is a crucial and indispensible aspect.

FEN Research Campus is a cooperating association of research and industry that comprises 15 technical and non-technical partner institutes from RWTH Aachen University as well as over twenty industrial partners. It is part of the funding initiative "Research Campus – Public-Private Partnership for Innovation" by The Federal Minidstry of Eduction and Research (BMBF) which supports and facilitates long-term collaborations between academia and industry in complex research areas.

By bringing together a multitude of research fields and industrial branches, FEN Research Campus wants to lay the foundation for a holistic research and development approach that covers all required aspects of future electric utility networks.

FEN Research Campus is divided into three consortia, each of which is concerned with one of the main voltage levels of electric utility grids: low-voltage (LV), medium-voltag (MV) and high-voltage (HV). Each consortium is led by a professor of RWTH Aachen University. The staff comprises researchers from 15 institutes who are involved in R&D activities in the three consortia.
Moreover, there is a steering committee for each of the three consortia, consisting of the university as well as affiliated industrial partners. The three steering committees meet four times a year, primarily for reviewing the research activities that are presented to the industrial partners by the university partners, and for decision-making as well as discussions. Other matters discussed during the meetings include new research projects and decisions on patents or the admission of new research partners.

Besides the steering committee, there is the scientific advisory board, which includes the leading professors of the three consortia and selected industrial partners. There are also four meetings per year where recommendations regarding research projects and roadmaps as well as the acquisition of patents are given to the steering committee.

About us
Organization

FEN GmbH coordinates and organizes all activities within FEN Research Campus and its work environment, including office space, project support, IT services, marketing and communications, meetings and workshops. It is also a mediator between the university and industrial partners. FEN GmbH is controlled by the supervisory board, which consists of the Rector of RWTH Aachen University, a board member of Forschungszentrum Jülich and three professors of RWTH Aachen University.

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Members of Scientific Advisory Board

- Univ.-Prof. Antonello Monti Ph.D., Chairman of LV Consortium
- Univ.-Prof. Dr. ir. Dr. h. c. Rik W. De Doncker, Chairman of MV Consortium
- Univ.-Prof. Dr.-Ing. Albert Moser, Chairman of HV Consortium
- Univ.-Prof. Dr. phil. Eva-Maria Jakobs, Human-Computer Interaction Center (HCIC)
- Dr. Reinhold Bayerer, Infineon Technologies AG
- Robert Heiliger, E.ON SE
- Dr. Sylvio Kosse, Siemens AG
- Holger Krings, Phoenix Contact GmbH
- Dr.-Ing. Christian Haag, CEO FEN GmbH (passive)
- Dr.-Ing. Peter Lürkens, CSO FEN Research Campus (passive)

About us
Location

FEN Research Campus is located at RWTH Aachen Campus Melaten inside the “FEN Think Tank“: the building provides the team of academic researchers and industrial partners, who all work together directly, with their individual offices in a modern and spacious workplace on the fifth floor. FEN also provides all employees with e-bikes, an e-scooter and an e-car so that they can quickly move around Campus Melaten and easily reach its surrounding facilities.

RWTH Aachen Campus Melaten will also be the test site of our Medium-Voltage DC (MVDC) Research Grid. Here, several multi-megawatt test benches of different RWTH institutes will be interconnected by this specially constructed distribution grid. The construction work will begin in 2018.

Joint research activities of academia and industry under one roof at the “FEN Think Tank“ has one essential benefit: it ensures efficient knowledge exchange between the individual partners. A transdisciplinary approach is a prerequisite for successfully coping with the challenges of our future energy supply and for achieving innovation that exceeds the limits of a single competence. Yet another benefit of collaborative research in a shared environment is application-oriented research as the industrial partners can quickly transfer results into innovative products and services.

About us
Facts and Figures

15
University Partners

189
People

10 LV **14** MV
Industrial Partners

980 m^2
Office Space

About us
Facts and Figures

153
Publications

29 *Scientific Publications (FEN Research Campus P1-P4)*
20 *Further Scientific Publications*
69 *Degree Theses*
29 *Further Publications and Lectures*
02 *Patents*
04 *Seed Fund Projects*

8
Projects (publicly funded)

About us
Facts and Figures

450K€

Total Budget from FNP Medium-Voltage Consortium

35%
Staff

30%
Research

15%
Office

10%
Administration

10%
IPR*

*Intellectual Property Rights

About us
Facts and Figures

258 K€

Total Budget from FNP
Low-Voltage Consortium

0%	IPR*
10%	Office
20%	Research
20%	Administration
50%	Staff

*Intellectual Property Rights

About us
Team

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Our Research
Research Fields

Grid Planning and Operation

Cloud Platform for Smart Energy Services

Automation and Control

Power Conversion and Components

Standards and Regulations

Society, Economics and Health

Our Research
Research Fields

Grid Planning and Operation

The scientists of FEN Research Campus conduct research on procedures and methods for planning and operation of pure DC grids and hybrid AC-DC grids. Besides the identification of adapted planning criteria for DC grids, the reactions on the systems of the super- and subordinate conventional AC grids are analyzed.

For that purpose, the Medium Voltage DC Research Grid on RWTH Aachen Campus Melaten will be put into test mode at first. From this, knowledge regarding both the operation of DC grids and the cooperation of the individual components is to be gained and the further research and development requirements for DC grids shall be estimated.

Cloud Platform for Smart Energy Services

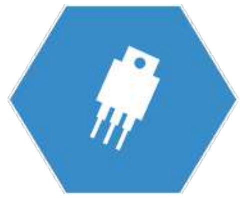
In this research field the scientists work on the implementation of a cloud platform for smart energy services. Via standardized communication links, energy profiles and projections about load and generation can be shared with a superordinate entity. This entity efficiently manages consumers and producers using a software platform. Typical examples are links to virtual power plants or services like demand response or demand side management; further energy services will be developed according to the industrial partners' requirements.

Our Research

Research Fields

Automation and Control

Grid automation and control is another essential research field. The scientists conduct research regarding grid automation concepts and technologies for DC grids with the integration of decentralized power generation and smart homes. The aim is an automated network using DC technology across several buildings in order to ensure a power supply in which decentralized generation and load cooperate in an optimal way.



Power Conversion and Components

In this research field, electrical components and systems, which are necessary for the structure and the operation of DC grids, are investigated and developed. This includes analysis of materials (e.g. semiconductor and insulation materials) and subcomponents (e.g. semiconductor devices and converters) up until the development of systems, such as DC-DC converters, circuit breakers and control technology, which will be designed, simulated, installed and tested in the Medium Voltage DC (MVDC) Research Grid on RWTH Aachen Campus Melaten. The research grid will be established primarily using standard components from the industrial partners' current portfolios so that test operations can be conducted as soon as possible; only individual subcomponents will be developed from scratch.

Our Research
Research Fields

Standards and Regulations

FEN Research Campus actively contributes to the development and international establishment of standards and norms for DC grids and components. So far, standards and regulations fully exist solely for the current AC grid. In order to ensure high safety and reliable, legitimate and, hence, commercially efficient frameworks, it is necessary to define suitable standards for DC grids and components as well.

For this purpose, FEN Research Campus participates in the German Commission for Electrical, Electronic & Information Technologies (DKE) of DIN and VDE as well as in the International Council on Large Electrical Systems (CIGRE).

Society, Economics and Health

A prerequisite for the feasibility of comprehensive change and innovation is their relationship to political, economical, social and ecological frameworks. Therefore, besides the technical research fields, researchers of FEN Research Campus also investigate DC grids regarding non-technical factors. These include social acceptance as well as biological, ecological, urbanistic and economical aspects, amongst others.

Our Research
Low-Voltage Consortium

The **Low-Voltage (LV) Consortium** focuses on electrical energy, storage and distribution as well as the automation thereof at low-voltage level. The experts in the LV Consortium investigate power conversion units, the use of decentralized electric energy storage and the system level automation in order to integrate decentralized energy sources. Security and protection of the electrical grid as well as strategies to ensure grid stability are fundamental research aspects.

Standards and Regulations

FEN supports the identification of standards to be reviewed or newly initiated for DC grid applications. A roadmap for DC grid standards has been published, covering the standardization background and technical objectives for different cases of DC grid applications. The first review has been finalized in the beginning of 2018. However, with respect to the response and discussions of the first version, the scope of the report has been immerged. The second roadmap version will be finalized in the second quarter of 2018. The work was moderated and supported by Deutsche Kommission Elektrotechnik DKE (German Commission for Electrical Technologies).

On the global level, the International Electrotechnical Commission - Systems Committee Low-Voltage Direct Current and Low-Voltage Direct Current for Electricity Access (SyC LVDC/ WG1) has been established. The IEC SyC LVDC focuses on the standardization in the field of low-voltage direct current in order to provide system level standardization, coordination and guidance in the areas of LVDC and LVDC for Electricity Access. The IEC SyC consults within the IEC community and the broader stakeholder community to provide overall systems level value, support and guidance for the TCs and other standard development groups, both within and outside the IEC. The IEC focuses on the development of standards for Electricity Access, enabling inclusive development for all communities.

The IEC SyC/LVDC is very active to push rural and home applications, particularly 48V DC solar-powered light and television sets for private households. Although there are standards available for low-voltage DC applications, which show a high level of professionalism and trustworthiness, the placement of a new standard is intended now. Apart from this, the IEC TC 8 sets up a subcommittee with emphasis on the regulation of the low- and medium-frequency conducted emissions and disturbances in DC grid wires. The subcommittee has connections to CISPR, which specifies the emission levels in the AC grid. Here, the activities will be monitored by the DKE mirror panel of SyC LVDC.

The mirror panel focuses on the coordination of the technical committees (TCs) at IEC and DKE, with strong emphasis on protection methods. Moreover, the specification of power quality, grounding aspects and arcing will be the focus of the mirror panel.

Automation and Control

The research on low-voltage grid automation addresses architectures and technologies for the integration of distributed resources, DC technologies and smart homes. Furthermore, the research work includes the integration of communication structures and architectures. Distribution system operators are confronted with the challenges of increasing the integration of renewable energy sources such as wind and photovoltaics. A comprehensive transformation of the current energy system in terms of planning and inter-linked operation of a larger number of independent devices is crucial for the success of the energy transition. Here, DC technology will play an important role with particular attention to active distribution networks.

The research activities on low-voltage automation include the design of the automation architecture, the definition of the needed measurement and protection infrastructure and the development of new decentralized and interlinked management and control algorithms. Concepts such as load shifting by means of energy management (DSM = Demand Side Management), Power Quality Support and Voltage Control with the need for networked communication open the way for smart grids that make the increasing integration of renewables and energy storage systems possible. Smart home and related protection concepts, control elements in microgrids, as well as building technology will be increasingly linked by networked communication, to ensure the best possible integration of renewable energies and their most efficient use for the end-user.

The current research in 2017 focused on the determination of DC protection concepts and on requirements for decentralized interaction of DC related building technologies as well as on linking automation functions with cloud services.

Cloud Platform for Smart Energy Services

In order to control decentralized technologies and to allow utilizing flexibility provision from decentralized storages, compatible communication interfaces must be designed based on common communications protocols. In this context, scientists in the LV Consortium research the implementation of a cloud-based platform. Here, smart energy services with automation functions such as grid monitoring, decentralized demand response, demand side management or storage management are investigated.Within this platform, the various layers of the energy sector will be linked by standardized communication and protocols. The platform will be investigated further within the LV Consortium, which is expected to take an active part in the development of the platform itself.
The current research in 2017 included the determination of requirements for the functionality of a cloud-based service according to the industrial partners' needs and the integration of grid automation into the cloud.

Power Conversion & Components

Electric components, such as cables, fuses for the transport of electrical energy or headers and transformers for the conversion of electrical energy, are the subject of this research field.

This includes the analysis of materials (e.g. semiconductor and insulation materials) and subcomponents (e.g. semiconductor devices and converters) right up to the development of systems such as DC-DC converters, circuit breakers and control systems, which will be designed, simulated, installed and tested in the MVDC Research Grid on RWTH Aachen Campus Melaten. The MVDC Research Grid will be established primarily using standard components from the industrial partners' current portfolios so that test operations can be conducted as soon as possible; solely individual subcomponents will be newly developed. Components intended for application in the low-voltage DC grids are being investigated as well.

Our Research

Low-Voltage Consortium

Seed Fund Project:
Monitoring of dynamic distribution grids: classic and cloud

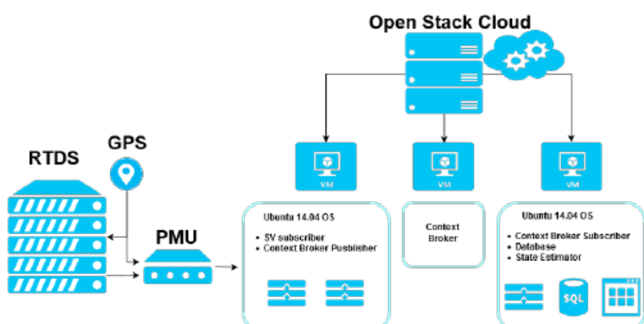
Distribution grids include the section of medium-voltage and low-voltage grids distributed in radial topologies. These sections are normally composed of transformer units, lines and passive loads. Under these assumptions, the application of monitoring strategies has been until, recently, very limited. Exceptionally, due to unexpected failures, it was only necessary to install protection units. Consequently, up to the present day, distribution automation is a synonym of protection. In recent years, however, also due to the penetration of generation in distribution grids, more advanced functionalities, such as distributed control, forecast of power consumption and generation, purchase of flexibility services from distributed generation are included in the group of distribution automation. Nevertheless, such use cases have to leverage knowledge of the status of the system's status as accurate as possible.

Therefore, the fundamental use case is monitoring. Knowing that penetration of measurement devices in distribution grid will never reach 100%, development of distribution system state estimation algorithms is required. Such algorithms can leverage a small set of real-time measurements and other statistical information on load and generation behavior to provide accurate and complete knowledge of the system's status.

The state estimation provides the voltage phasors (magnitude and the phase angle of the 50 Hz waveform) of all the nodes of the grid, starting from any measurement set (accepted measurements are active, reactive power, voltage and current magnitudes and phase angle etc.).

Our project has produced a demonstration setup for a cloud-based monitoring unit. The implemented cloud-based monitoring system exploits the Open Stack cloud infrastructure and the context broker from the open source platform FIWARE. Such a monitoring unit executes the state estimation functions of the substation automation unit, inspired by the IDE4L FP7 project. The substation automation unit is exported to the cloud, e.g. via phasor measurement units sending in real-time measurements according to IEC 61850 standard.

This monitoring system was tested in real-time digital simulation to understand the dynamic and static uncertainty of the complete monitoring chain. The results show a clear trend of reduction of total uncertainty when measurement and estimation reporting rates increase. This confirms the cloud application in monitoring of distribution grid as a feasible solution to reduce the cost for automation in distribution. However, latencies may set a boundary for cutting dynamic uncertainty and for the applications based on state estimation results, yet do not impact non-real-time applications such as grid operator visualization.



Cloud laboratory test set up

Our Research
Low-Voltage Consortium

Seed Fund Project:
Low-Voltage DC Protection Concepts

The purpose of the seed fund project was to give an overview of the current status of LVDC protection and to identify open questions for future research in this field. Three major topics have been investigated: requirements for the protection in DC grids, review of state research in protection devices and a comparison of different protection concepts.

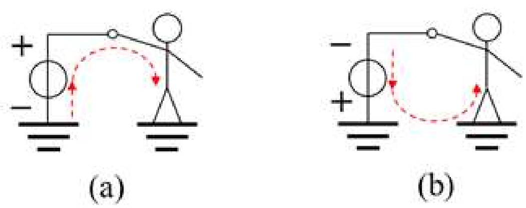
A major concern at the customer end is human safety, as the LVDC distribution network is within the daily reach of non-technical users who could be exposed to live parts in case of insulation failure. Hence, the installation of a fast and reliable system of personal protection is of top priority to ensure the safe operation of the grid and to minimize the hazard of electric shocks. Similar to the AC system, the grounding strategies in LVDC networks can be categorized in TT, IT and TN systems. Based on possible network topologies, methods for the protection against electric shock can be evaluated.

To provide personal safety in LVDC grids, the top priority is the prevention of lethal injuries by minimizing the time of exposure to dangerous body currents. Thus, protection devices have a limited time frame, depending on the touch voltage, to detect and interrupt the fault current. In mechanical breaking devices, arcs across the opening contacts sustain the fault current and inhibit a complete disconnection of the fault location from power supply. Without the support of a natural zero crossing, the extinction of these arcs is a much more challenging task in DC than in AC distribution systems, requiring increased effort and time.

This makes mechanical circuit breakers (as part of RCDs) too slow for applications where higher touch voltages may occur as they cannot meet the strict interruption time requirements in the event of human contact with live parts anymore.

The definition of basic requirements for the protection against electric shock is linked to the body resistance in case of human contact with an electric wire. As the current through the human body is determined by the ratio of touch voltage and body resistance, the body current path has a major impact on the current magnitude. Another important factor with regard to the cardiac impact of a body current is its direction through the human body.

The critical touch voltage limit for proper circuit interruption using purely mechanical devices depends very much on the skin impedance (before the skin is carbonized) and, hence, on the surface area of contact. Neglecting its value, i.e. assuming a large surface area of contact, would imply any touch voltage beyond the extra-low voltage threshold of 120 V to be too high for a timely disconnection using mechanical circuit breakers.



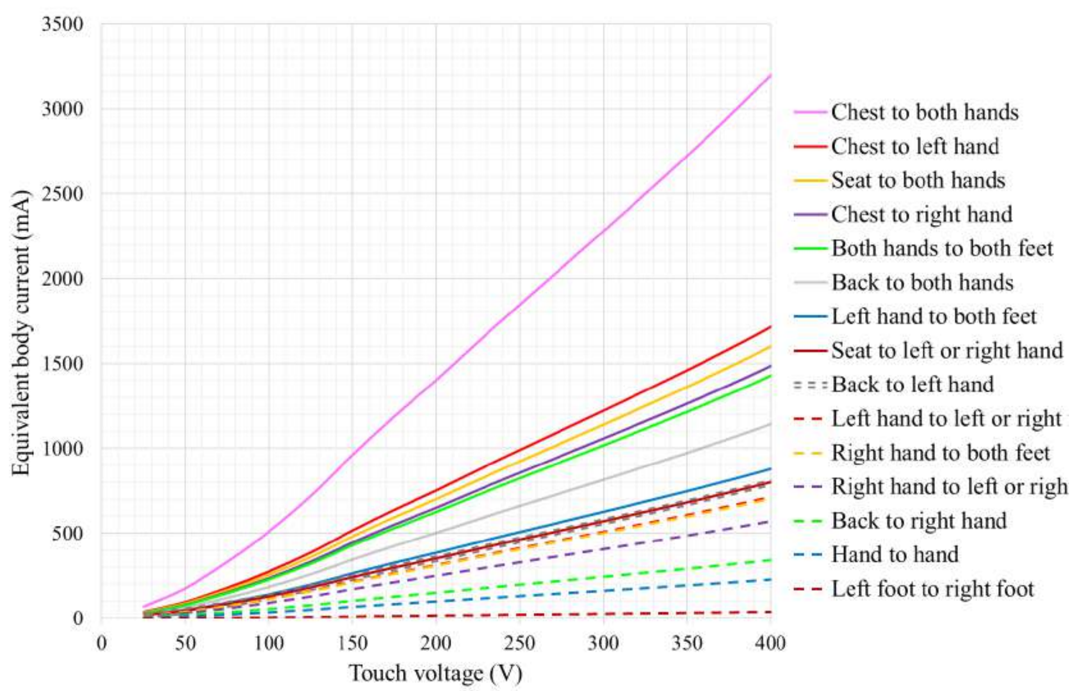
Current limits for upward and downward body currents

To enable a comparison of the personal hazard of different body currents, the current magnitude, related to different current paths, is converted to an equivalent left-hand-to-feet current and shown below as a function of the touch voltage.

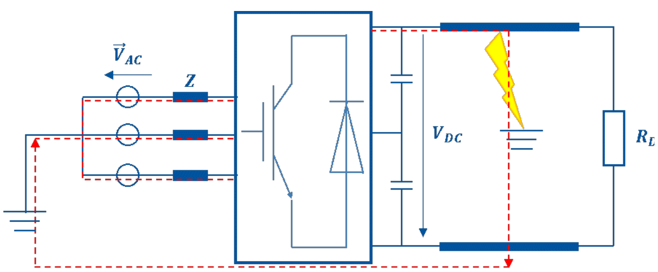
Based on the equivalent current values and the current-dependent exposure time thresholds, the required disconnection times for a reliable LVDC protection system can be estimated as a function of the touch voltage. The disconnection time requirements for the most commonly discussed DC grid voltages are listed in the table, based on the worst-case assumption of equal touch and grid voltages.

The-chest-to-hands body current path has been recognized as the worst-case scenario in terms of the physiological impact on human body. Nevertheless, other current paths, such as seat-to-hands, back-to-hands and hand-to-hand should be considered as more relevant cases.

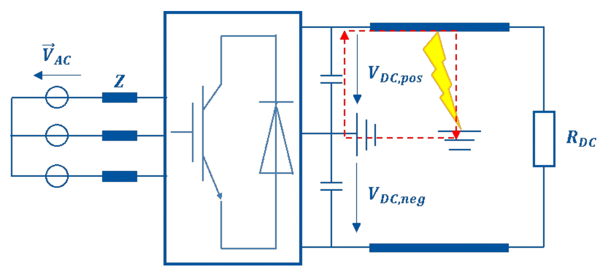
Beyond the impact of body currents, overcurrent faults in LVDC grids have been analyzed in depth. The most common fault type at LVDC distribution level or indoor installations is a short-circuit fault on the LVDC cable, as a consequence of insulation deterioration or external kinetic impact. A short-circuit fault can occur between two DC poles or from one DC pole to ground. Both fault types have been investigated. The topologies under consideration and different short-circuit scenarios are shown in the figure below.



Grid voltage (V DC)	Required disconnection time for chest-to-both-hands current path (ms)		Required disconnection time for seat-to-left-hand current path (ms)	
	Upward	Downward	Upward	Downward
120	2	100	400	>1000
190	1	2	200	1000
230	<1	1	100	400
325	<1	<1	3	200
380	<1	<1	1	100



Pole-to-ground fault when the system is earthed at AC neutral point



Pole-to-ground fault when the system is earthed at DC mid-point

The impact of short-circuit faults at system level for different fault paths and topologies is summarized here:

Fault type	Grounding Strategy	Impact	
		Overcurrent	Overvoltage
Pole-to-Pole Fault	All	On both AC and DC sides	No
Pole-to-Ground Fault	Earthed on AC neutral point, DC is unearthed	On all three phases in AC system and the faulty DC line	On the healthy pole
	AC is unearthed, DC mid-point is earthed	Only on the faulty DC line	On the healthy pole
	AC is unearthed, one of the DC poles is earthed	On both AC and DC sides	No

To avoid damage in the (naturally capacitive) DC grid, a fast interruption of the short circuit must be realized. Standard mechanical circuit breakers provide disconnection times above typically 10ms. A faster disconnection can be achieved utilizing hybrid circuit breakers (0.3ms ... 4ms) and solid-state circuit breakers (1µs … 1ms). However, while the solid-state circuit breakers enable a fast interruption of fault current, the conduction losses under normal operation are very high. Hybrid circuit breakers combine the advantages of mechanical and solid-state-based concepts and represent a good compromise between fast disconnection and low conduction losses. Within the investigation, the circuit breaker limitations have been studied.

Our Research

Low-Voltage Consortium

Strategies for fault detection have been investigated. In this context, a variety of overcurrent detection and fault location methods have been benchmarked, including di/dt-based protection, resonance-based and differential protection methods as well as the use of intelligent end devices. The results are summarized in the table, which compares the different approaches based on their ability of fault current detection and selective tripping coordination, both in the small-signal and large-signal domains.

Besides overcurrent conditions, the occurrence of arc faults has to be avoided. A fast detection of an arc fault is a necessary precondition to prevent the emergence of a fire. In AC grids, the arc detection is mandated by standards. For DC grids, the detection procedures have to be re-evaluated to avoid faulty activations. The research and validation of the right detection method should be carried out in a separate seed fund project. To ensure a reliable operation of DC grids, continuous monitoring of the grid status can be applied.

Overvoltage conditions in DC grids can be caused by several factors. Lightning strikes will cause damage to equipment in the nearby distance as well as several kilometres away from the point of strike. If multiple inverter-fed variable speed drives are connected to a common DC bus, the parallel generating and motoring operation may cause overvoltage on the bus. To prevent damage from such overvoltage conditions in the grid, overvoltage and overcurrent protection/limiting devices are applied.

The distributed inductance and capacitance of cables, filter circuits and DC links within an LVDC grid constitute a resonant tank whose frequency behavior significantly affects the system stability. A DC grid system consisting of multiple sources and loads, for example, may cause stability problems. Switching

Protection Concept	High-Speed Detection: Large Fault Current	Coordination: Large Fault Current	Detection: Small Fault Current	Coordination: Small Fault Current
Overcurrent	★	★	n/a	n/a
di/dt-based	★★★★	★	n/a	n/a
Differential protection	★★★	★★★	★★★	★★★
Resonance-based	★	n/a	★★★★	n/a
Active Impedance Estimation	★	★★★	★★★	★★★
Inductance Estimation	n/a	★★★	n/a	★★★
Use of IEDs	n/a	★★★	n/a	★★★
Voltage derivative management (for voltage weak systems)	★★	★★	★★	★★

Remarks

★ = more challenging to implement

★★★★ = less challenging to implement

★ = no communication requirement

★ = can be used with communications

★ = communication required

actions, connection of large loads, faults and disconnection of affected branches excite the system and may cause severe oscillations. This further complicates the definition of appropriate trip levels and bears the risk of cascaded system shutdown when the stability limits are exceeded. The problem is aggravated in the presence of many plug loads, where the frequency behavior can change considerably depending on the connected loads and the associated DC links, filter components and cable sections. For a proper system configuration without the need for a complete re-engineering every time a new LVDC grid is to be installed, concrete design rules and limits need to be defined to achieve a standardized system behavior. This requires a thorough characterization of transient dynamics in LVDC grids subjected to different load cases.

The proper definition of trip levels and conception of fault detection mechanisms are further non-trivial aspects of LVDC protection. The trip levels and maybe fault location delay times have to be properly set to discriminate between fault currents and switching transients during normal operation. In the event of high-impedance faults, though, the amplitude of the oscillations related to fault currents lies in the range of the normal noise level of the grid. Sophisticated detection algorithms have to be developed to distinguish between normal and fault-related transients. The uncertainty in terms of the system time constant and the frequency behavior of LVDC systems with a large number of plug loads adds to the complexity of this task. Once a fault is detected, it has to be localized to allow for selective fault isolation and fast restoration of a healthy system state. The fast proliferation of fault currents within an LVDC distribution system makes the coordination of protection devices a challenging task though. When the protection parameters are poorly designed, nuisance tripping can compromise the reliability of the system. Communication between the protection devices and a sophisticated control strategy can support the coordination for the sake of selectivity.

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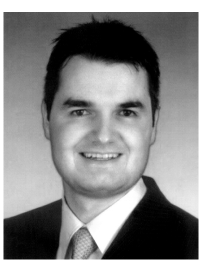

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Our Research
Medium-Voltage Consortium

In the Medium-Voltage (MV) Consortium the capabilities of DC technology of medium-voltage level, including the interfaces to AC systems as well as to high- and low-voltage levels, are analyzed. Cable connections, solutions for network automation, control and stability as well as other necessary components for a flexible energy distribution are main topics of research.

The main objective of the consortium is the construction of a Medium-Voltage DC (MVDC) Research Grid at RWTH Aachen Campus Melaten, which is near to completion now. Several test benches in the megawatt range of different institutes will be connected to this test and evaluation facility. Experts carry out field tests on electrical components, such as cables and DC-to-DC converters, but also (hybrid) switchgear. Furthermore, different control, operation and protection concepts are within the scope of investigations.

Medium-voltage distribution grids are a very important part of the electric supply system. Energy that is generated in large power stations is transmitted via high-voltage lines and then fed into medium-voltage grids to reach the customers. The grid today is meshed, i.e. interconnected, only at the transmission level, i.e. the high- and very high-voltage level (typically 220 kV and more). In contrast, medium- and low-voltage AC distribution grids are arranged radially or as open ring bus structures. A flexible energy transfer between different medium-voltage substations, e.g. between different city quarters or small towns, cannot be realized with today's three-phase AC system. This also affects the necessary infrastructure for e-mobility, which will be substantially hampered by limitations of conventional AC distribution grids.

Key problems in classical distribution grids are the fluctuating load and the reverse flow of power that occur during variable and strong feed-in situations of renewable power sources. AC grids were optimized for a top-down power flow and are subjected to voltage variations, in particular to overvoltages under reverse power flow conditions. Furthermore, coupling of separate distribution grids requires control of the grid parameters at the end points of the coupling link, due to the dependency of the power flow to frequency, phase and voltage. High peak power demands are increasingly expected in areas with growing penetration of electric vehicles.

DC grid technology does not have frequency and phase at all. Only voltage governs its behavior, thus substantially simplifying the task of connecting separated grid segments. As DC grids intrinsically use controlled converters at its substations, an additional degree of controllability becomes available allowing to

Our Research
Medium-Voltage Consortium

handle fluctuating power and reverse power flow with much higher flexibility. Also in relation to e-mobility applications, DC grid technology promises a significant improvement on fast charging capabilities in urban areas, by facilitating power flow concentration from several substations.

Another advantage of DC grid technology is its independence of the standardized AC grid frequencies (50 or 60 Hz). In an AC grid, frequency is crucial for the size, weight and eventually cost of transformers. Their equivalent in DC grids are DC-to-DC converters, performing the function of voltage transformation between different voltage levels. DC-to-DC converters still use transformers internally, which can be designed freely for operation at the best suitable frequency that is substantially higher than the standard grid frequency. This eventually results in enormous savings of copper and magnetic steel, expectedly up to 90%.

The Medium-Voltage Consortium is part of FEN Research Campus and since the end of 2014 receives support from the funding initiative “Forschungscampus – öffentlich-private Partnerschaft für Innovationen“ of Federal Ministry of Education and Research (BMBF). With this initiative, BMBF supports universities and companies that are working collaboratively on complex areas of research on a long-term basis. It is of vital importance that those areas possess high innovation potential and societal relevance.

Four connected projects (see following pages) are funded with € 10 million for an initial period of five years by BMBF with this funding initiative. There is an outlook for another grant of twenty million Euros from the Ministry for extending research in following phases after successful completion of the current phase.

FORSCHUNGS CAMPUS
öffentlich-private Partnerschaft für Innovationen

GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

Our Research

Medium-Voltage Consortium

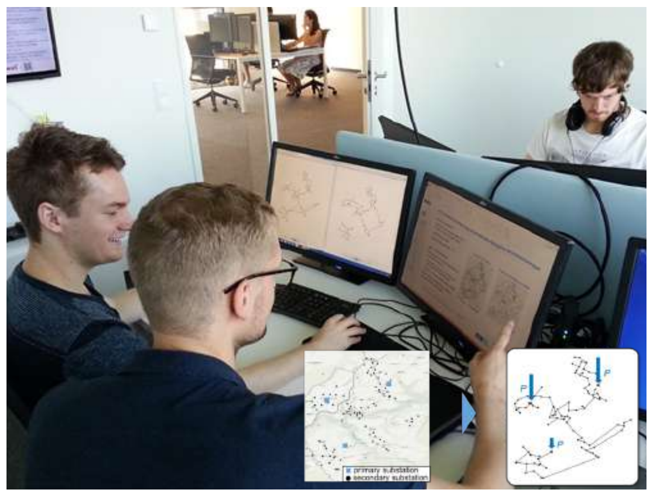
Project 1: Modelling, Planning, Conceptual Design and Assessment of Future Grids

Project 2 is led by the Institute of Power Systems and Power Economics (IAEW). In this interdisciplinary project, electro-technical as well as socio-technical aspects are addressed.

The project is organized in several larger work packages, concentrating on:

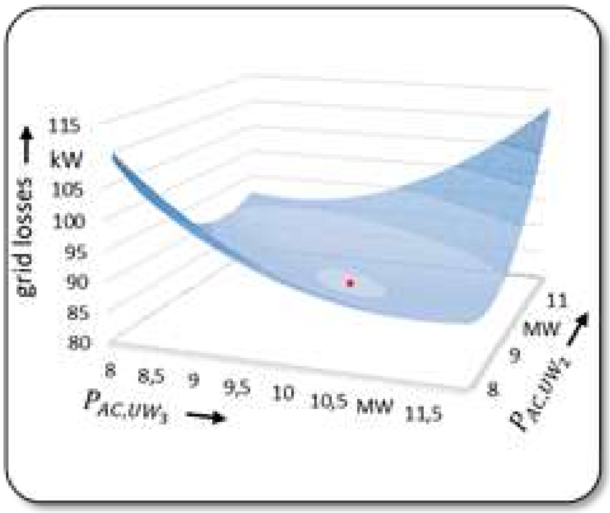
- Planning of optimized DC target grids and the migration to it, along with landscape planning, urban design and its societal dependencies
- Operational behaviors and procedures of DC grids and stability
- Protection concepts
- Interfacing medium-voltage DC grids to high- and low-voltage grid levels
- Storage integration
- Impact of communication formats on acceptance on stakeholders and on occupational profiles of typical skilled laborers and technicians
- Effects on the living environment

A new aspect in planning of optimal DC target grids is the inclusion of different degrees of freedom, which are provided by the converter-based primary substations. This brings power inflow and power outflow under control. In particular, grid-operational degrees of freedom concerning power flow controllability were considered.



Mapping of a given supply task onto an optimal MVDC grid

In the domain “Operational behaviors and procedures” the objective is the investigation and development of new procedures to find the optimal setpoint for all controlled nodes in the grid, leading to operation of all grid assets within their operational boundaries, and at the same time leading to a minimum of total losses in the entire grid. For DC grids, the type of this optimization problem is a quadratically constrained quadratic problem, for which a solution approach has been realized that differs from the established solution approach for AC grids.



Minimizing total grid losses by power flow control

Grid protection addresses fault detection, localization, isolation, clearance and restart of operation. Wavelet-based detection algorithms have been identified as the best candidates for fault detection. It could be shown that this method, proposed in literature for very long high-voltage DC transmission lines, is applicable for short medium-voltage DC lines as well. For bus bars and converters, differential protection, i.e. comparison of input and output quantities, has been found as the best-suited methodology. Protection devices as circuit breakers, fuses, DC switches and power electronics converters have been analyzed as means for selective grid shut-off of zones, allowing to limit proliferation of faults in other areas.

At the interface between MVDC grids and the high- and low-voltage domains, the influence on the powerfrequency relation (droop) of legacy AC grids becomes relevant. Due to absence of frequency DC grids may have the property of isolating load characteristics and reaction of conventional generators, leading to a loss of self-regulation, e.g. with regard to frequency. A conclusion is that DC grids should also have a droop behavior to achieve a reasonable self-regulating property.

Availability of storage systems will provide another degree of freedom for grid planning and operation. Based on operation requirements, various application strategies were determined. Large battery storage systems are aiming at flexible power in- and outflow. Small domestic storage systems should already be considered during the grid planning phase. Among battery storage technologies, LiIon-systems evolve as the best candidates in terms of operating cost per kWh throughput.

The studies on communication formats revealed the differences in perception of complex technological matters as DC grid technology at nonprofessionals, semi-experts and experts in particular about perceived risks (health, economics, technology, privacy, landscape and infrastructure). This perception is also changing over time, e.g. under influence of other regional projects such as high-voltage overhead transmission lines. An interactive exhibition concept has been developed, which communicates fundamental aspects of DC grid technologies to average citizens by different communication formats. In this setting, effectiveness of the different formats will be tested in the context of a public exhibition.

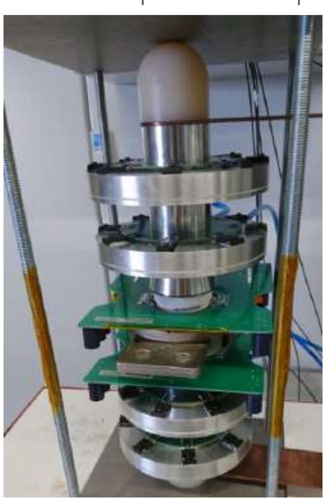
In the work package "impact on the living environment", effects of static (DC) electric and magnetic fields are investigated. Practical magnetic field strength in the proximity of humans is expected to be relatively low, similar to the natural magnetic field of the earth. Electrostatic fields are not supposed to penetrate a human body but may produce sensible effects when very strong. However, realistic practical installations for field strength are expected way below such thresholds.

Our Research
Medium-Voltage Consortium

Project 2: Electrical Equipment and Grid Technologies

Project 2, led by the Institute for Power Generation and Storage Systems (PGS), investigates new materials and components and their effects on converter and system level. The project focuses on the relevant components for medium-voltage DC (MVDC) grids. Within the project the key components for power distribution are considered: High-power high-efficient DC-DC converters, power semiconductors for medium-voltage applications, design of medium-voltage medium-frequency transformers, DC circuit breakers technologies, insulation materials for high-frequency and high voltage and medium-voltage cables in DC grids.

Significant progress has been achieved in the 7 MW dual-active bridge DC/DC converter. The components are mounted in the cabinets and further investigations on the efficiency improvements were undertaken. To reach the full soft-switching capability of the converter, the auxiliary-resonant commutated pole concept (ARCP) is implemented. The basic principle of the ARCP concept is to cause a resonance forcing a zero-voltage switching at main devices and, thus, realizing soft-switching. Hence, clamping circuits, as needed for conventional IGCT circuits, can be left out and the losses of the converter in full and in partial load as well can be reduced by up to 50 kW. To embed the concept, various switch configurations have been tested up to 1.2 kV; one example of an IGCT and SiC Diode configuration is shown in Fig. 1. As investigated, the combination of SiC diodes with active switches will improve the efficiency of the switches during reducing the losses of the auxiliary switches tremendously.



Test configuration of auxiliary switch with IGCTs and SiC-diodes

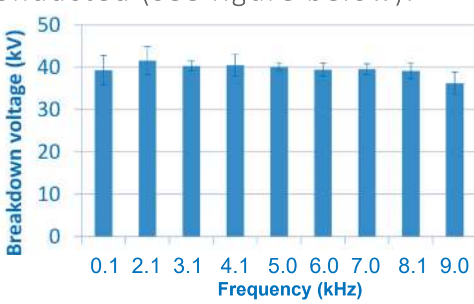
As another example from Project 2, the test benches for the insulation materials are introduced in more detail. The use of new power electronic devices, e.g. Silicon Carbide, allows much higher voltages within one step and a tremendous increase of the dV/dt during switching and thus a higher switching frequency. In case of medium voltage and high-power applications, frequencies between 1 kHz - 10 kHz are stepping into the focus of interest. Anyway, in this frequency spectrum, very little experience exists about the breakdown behavior of the insulation materials widely used in industry, e.g. in transformers now designed for medium-voltage and medium-frequency. Here, insulation materials such as isolation oil with impregnated fibers are investigated under these conditions. The breakdown voltage is measured in dependency of frequency and voltage waveforms.

Solid-State Marx Generator (SSMG)

Within the project two test-benches have been constructed and commissioned for sinusoidal and square-wave voltages settable to different frequencies and for measuring the specific losses densities. One test-bench allows stressing materials with square-wave voltage as they appear in most power electronics applications, is shown in the figure. The test bench is based on a Marx Generator.

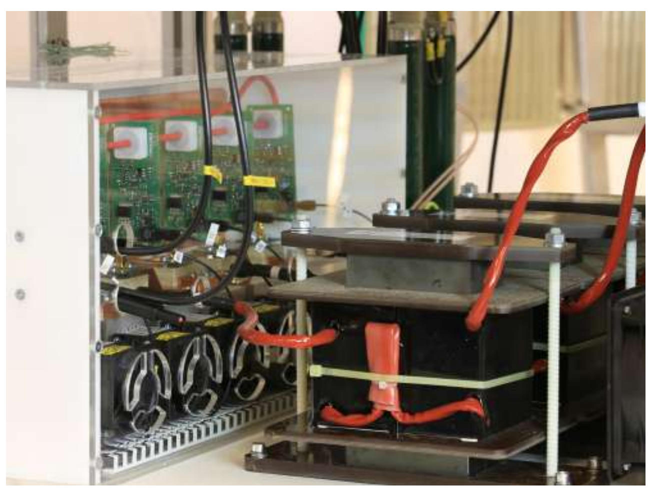
To reach the high-voltage slopes, the conventional topology has been adapted with semiconductor switches (IGBTs), hence the name Solid State Marx Generator (SSMG). Based on a galvanic isolated DC power supply, a periodic medium-frequency bipolar square-wave voltage can be generated in the frequency range 1 to 10 kHz. In total, the converter consists of 32 stages, which are connected, in series and/or parallel to reach 100 kV. To allow benchmarking, the key facts are chosen in analogy to the first test bench. On top, due to the modular design, various voltage waveforms can be programmed.

To generate sinusoidal test voltages, an air-core transformer has been constructed. The primary voltage is generated by a power electronics inverter. To reduce the power losses, resonant tanks at the primary and secondary are embedded. The excitation of the transformer is limited by the Eigen frequency up to 10 kHz. The voltage harmonics of the inverter are negligible due to the resonant design of the transformer. Depending on the frequency, up to 100 kV can be reached. Breakdown investigations of insulation oil with various impregnated fibers have been conducted (see figure below).



Breakdown Test (Shell Diala S4)

For transfer of power between several busses, a bidirectional multiport DC/DC converter has been developed. The converter is designed for a maximum output power of 150 kW and connects to a 5 kV medium voltage, a 380 V low voltage and a 760 V low voltage DC bus. The topology is a three-phase multiport dual-active bridge with three ports, called a three-phase triple-active bridge. In addition to galvanic isolation and bidirectional power flow, the triple-active bridge converter allows precise control of the power flow between the various networks, especially between the two low-voltage networks. Thus, the low-voltage part of the converter side still allows operation in island mode, even if a line failure has occurred at the medium-voltage port. By using novel 10 kV SiC MOSFETs, a switching frequency of 20 kHz and thus a compact design has been achieved (see figure below). An essential aspect of the project is the development of novel control and operating strategies for the three-phase triple-active bridge converter. The focus here is in particular on the precision of power flow control between the individual ports and the efficient soft-switching operation of the converter.



Partial view of the multiport converter: MV-SiC-inverter and transformer

Our Research
Medium-Voltage Consortium

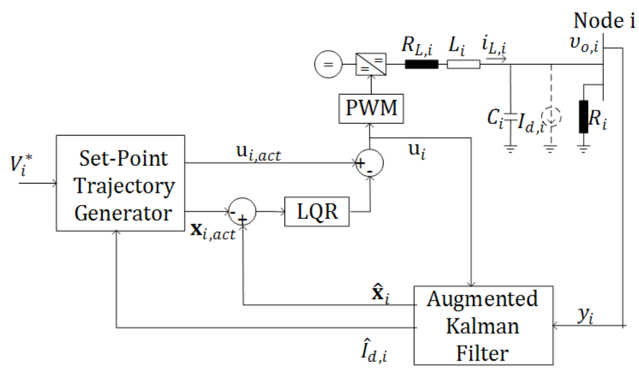
Project 3: Control, Operation and Automation

Project 3 is led by the Institute for Automation of Complex Power Systems (ACS). It focuses on the development of novel control concepts and automation architectures for pure DC and hybrid AC-DC systems.

The distributed and volatile renewable generation necessitates flexible control of the power flow, which can be achieved by connecting AC network nodes via DC grids. In this context, the project “Control, Operation and Automation of MVDC Grids” focuses on the development of novel control concepts and automation architectures for future DC and AC-DC MV distribution systems. The individual work packages of the project focus on

- Development of control concepts for hybrid AC/DC and pure DC grids
- Energy and load management
- Automation and management systems for hybrid AC/DC and pure DC grids
- Small scale demonstrator platform for (Power)-Hardware-in-the-loop testing of control (HiL)

Fully decentralized control structures for DC-DC and DC-AC converters have been developed for converter level and system level control. Proportional-integral-derivative (PID) converter level control has been combined with adaptive droop control for power sharing among parallel-operated converters. Virtual impedance-based droop controllers have been designed. The small-signal stability of droop-controlled converters in a multi-terminal DC (MTDC) system has been analyzed. In addition to conventional PID control, active disturbance rejection control (ADRC) has been proposed. Its robustness and convergence has been theoretically proven and demonstrated through simulation and Control-Hardware-in-the-Loop (CHiL) results in MTDC grids.



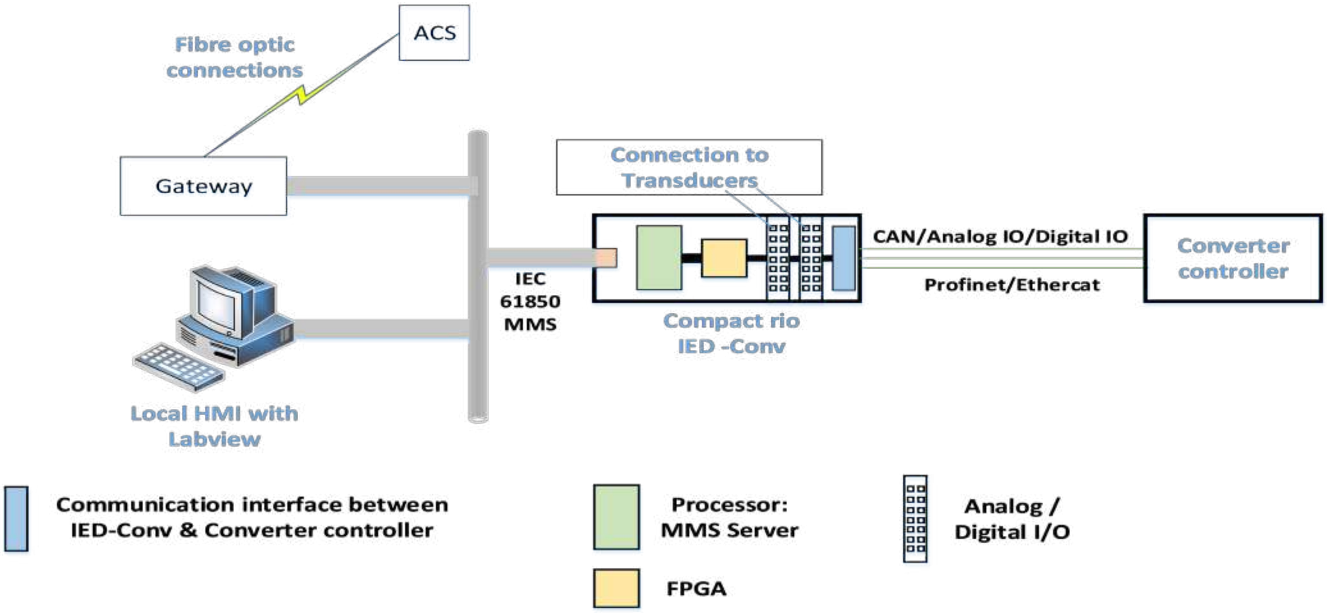
Active Disturbance Rejection Control for DC-DC Converter

As energy storage can alleviate fluctuations in the future distribution grids, an algorithm for optimal sizing and placement of energy storage has been developed. Moreover, an optimal power flow algorithm has been designed, which is computationally tractable and enables real-time system control of the distribution system. The special application case of data centers is analyzed, as they are not only large energy consumers but also flexible loads. This flexibility can be offered to the grid in terms of demand response to facilitate the integration of renewables; hence, data centers are key players in the energy transition. To enable this, a real-time control framework for data centers’ demand response has been developed.

The automation system has been implemented in an intelligent electronic device (IED) and consists of the monitoring, controlling and communication systems as well as data platforms and standardized data models. The structure of the IED is modular, allowing the easy integration of state-of-the-art automation functions. This modular feature has been achieved by using data models designed according to IEC 61850 standard. The IED has been integrated in Hardware-in-the-Loop (HiL) and Power-Hardware-in-the-Loop (PHiL) platforms.

The Hardware-in-the-Loop (HiL) platform and Power-Hardware-in-the-Loop (PHiL) platform are set up to test and validate the control concepts and the designed automation architecture. The HiL platform employs a real-time power system simulation environment and industrial measurement and control devices. The PHiL test platform is a 400V DC multi-terminal low-power lab network with PV and battery units, which can emulate the dynamics of the medium-voltage DC grid.

Hardware setup of small-scale demonstrator platform



Automation system virtualized through IED for PHiL platform

Our Research

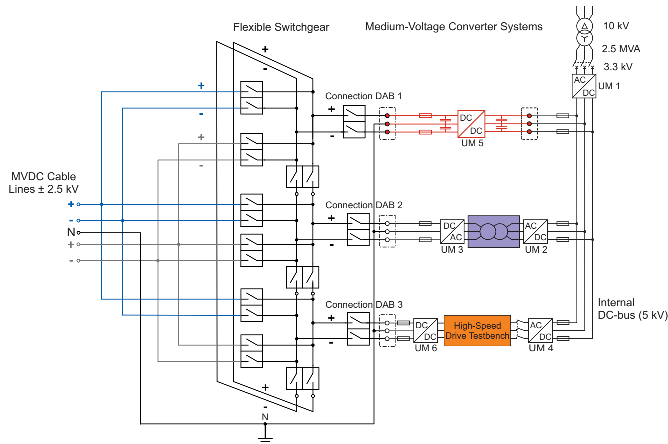
Medium-Voltage Consortium

Project 4: Design, Construction and Testing Campus FEN Research Grid

Project 4, led by the Institute Power Generation and Storage Systems (PGS), implements the design and the realization of a full-scale medium-voltage distribution grid. This infrastructure demonstrator is a 5 kV multi-terminal grid, which will be built and used for research purposes at RWTH Aachen Campus Melaten. This grid will interconnect several multi-megawatt test benches of different RWTH institutes. Since the power electronics converters allow bidirectional power flow, energy can be exchanged internally among the test benches and externally by drawing or feeding energy from or into the public electric grid.

The research grid is assembled to use converters produced by FEN industry partners and RWTH institutes. The aim is to demonstrate the feasibility of medium-voltage distribution grids using state-of-the-art technology and gain experiences from the operation and characteristics of an MVDC grid. Finally, prototype components of DC-to-DC converters, circuit breakers, DC cables or other components can be investigated by connecting them to the research grid for testing purposes. Further, additional DC-based components like fast-charging solutions can be integrated into the MVDC grid for future research.

Together with the members of the medium-voltage consortium, the budget for the construction work of the MVDC cable line was released. The detailed planning and optimization of the construction work has been finished and the necessary permissions of the involved public institutions has been obtained. Further, the connection of future buildings was prepared in the construction planning. This includes the building of the Center for Ageing and Reliability of Power Electronics and Battery Storage Systems (CARL) as well as the future FEN building which is going to be the neighbor building. For this application, a modular medium- to low-voltage DC-to-DC converter is going to be equipped. The medi-



Test Setup for first comissioning at E.ON ERC medium-voltage test hall

um-voltage cables and accessories have been selected in coordination with the involved experts from industry partners. The technical specifications have been defined in order to allow a higher DC grid voltage in the future without the need of changing the cables or accessories. The medium-voltage cable is provided by an industry partner and will be installed in the middle of 2018, as soon as the underground work is finished.

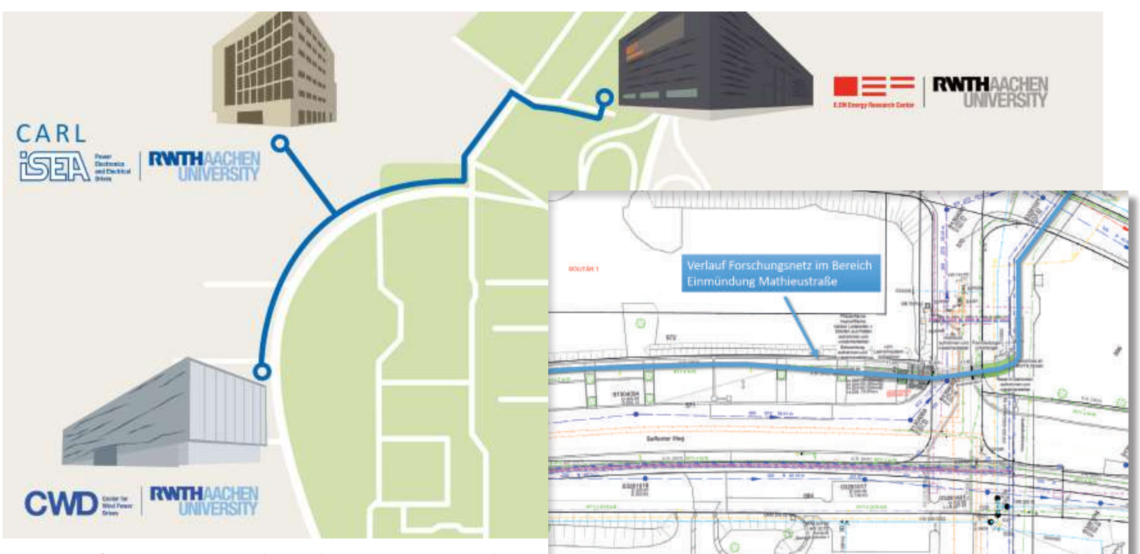
Significant work has been done on the real-time hardware-in-the-loop modeling and its optimization, which is crucial for the control evaluation of the power converters. Therefore, the real-time simulation platform of the industry partner AixControl has been used and its functionality was extended. Significant performance improvements have been obtained using an adapted modeling strategy for the converter behavior.

Our Research
Medium-Voltage Consortium

Installation of the shaft at the CWD to connect to the MVDC Research Grid

In order to control and visualize the MVDC grid status, a grid control on system level is necessary, whose implementation has started. This contains an Intelligent Electrical Device (IED), which collects all measurement signals and interfaces the converter control systems with reference values and operation commands. In order to collect and process the acquired measurement data for control and visualization, a SCADA system has been set up. This also includes a Human-Machine Interface (HMI), which shows the grid status to the operator and user and manages the grid functionalities. This also includes the control of the flexible switchgear, enabling the use of different grid configurations.

In the first phase of implementation and testing, all active components of the MVDC grid will be installed in the medium-voltage test hall of the E.ON Energy Research Center. This allows for rapid commissioning and testing of the equipment at one central location in the first stage. The external MVDC cable lines are connected to the local installation over the modular switchgear, allowing various grid configurations for testing. By connecting the two cable systems as a ring, the power can be circulated and, thus, the load performance and thermal behavior of the medium-voltage cables can be investigated under DC operation. The internal dc-bus is also connected to the 10 kV AC grid by a 50 Hz transformer and an active front end, which acts as active rectifier and links the MVDC grid to the medium-voltage AC system.



Course of MVDC research grid on Campus Melaten

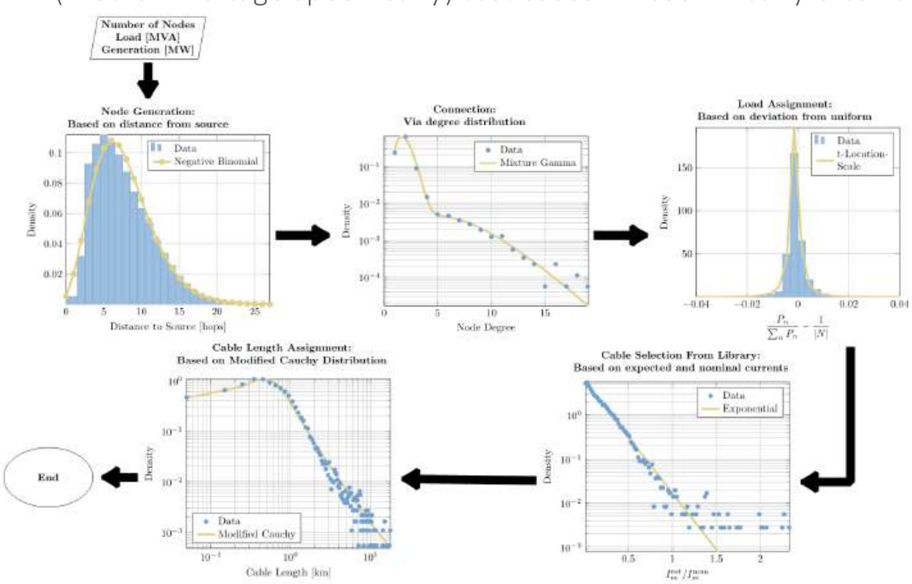
Our Research

Medium-Voltage Consortium

Seed Fund Project:
Tool Development for Distribution Grid Topology Generation

Whether introducing more automation, or investigating a switch to DC operation, the distribution system is currently the focus of very intensive investigation. All these investigations require increasingly more input data to build up the necessary test cases, which serve as the foundations of power systems simulations. Due to lack of publicly available data, as well as originating from a desire to facilitate ensemble level testing, the goal of this project was to develop an algorithm that will automatically generate the distribution systems (medium voltage specifically) test cases. These test cases are expected to aid future investigations substantially by enabling far more robust testing and verification of new applications.

Within this project, an analysis was performed on a large dataset from a Distribution System Operator in the Netherlands to understand better the structure of distribution systems. Building on the analysis, an algorithmic approach was developed to meet the same characteristics. Testing results show that the generated feeders closely agree with the statistics found in real feeders, supporting the claim of realism. The approach taken focuses on combining statistics seen in real data. A benefit of this approach is its modularity. Different statistics can be plugged in a trivial way to maintain the construction logic but drastically alter the final result. Additionally, empirical distributions could be employed in cases where particularly strict adherence to a single system is desired. In addition to the detailed algorithm development for single radial feeders, further research was performed to address the question of how these can be joined to create a full distribution system. The results demonstrate that from the perspective of the chosen verification metrics a valid, large-scale distribution system could be created.



Radial feeder generation flow

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FISMEP

Since December 2017, FEN Research Campus participates in the project FISMEP (FIWARE for Smart Energy Platform) and takes on the work package “Field Test Germany“ in close collaboration with the Institute for Automation of Complex Power Systems (ACS) at RWTH Aachen University. Moreover, FEN GmbH, on behalf of FEN Research Campus, is responsible for the work package “Dissemination and Exploitation“. The objective of the three-year project is the development and implementation of a service-oriented cloud-based open source software platform (known as FIWARE) to facilitate an efficient, automated and sustainable energy supply for single buildings as well as municipalities.

A total of seven research and industrial partners from Germany, Sweden and Romania are jointly working on a smart energy solution that will provide new capabilities in the area of distribution grid management: In addition to a modern energy system, the open source principle is supposed to enable a connection with external actors such as producers, distributors or consumers. That way, innovative energy services and business ideas can quickly be integrated into the platform for deployment.

Research conducted in FISMEP follows an interdiscinplinary approach that comprises the areas energy, information and communication technology (ICT) as well as social science. To show and exploit the platform’s impact on the energy system, three field tests will be carried out on locations in Sweden, Romania and Germany. Here, innovative use cases will be demonstrated with a particular focus on energy efficiency, performance and user-centered adaptation. Within the “Field Test Germany“, FEN Research Campus and ACS will collaboratively develop and implement a medium-voltage DC (MVDC) research grid on RWTH Aachen Campus. The objective is the automation of the research grid, also taking into account additional interfaces with alternating current (AC) grids to develop a solid automation architecture for hybrid distribution grids where DC and AC sections co-exist. Subsequently, the automation of the research grid will be virtualized in the FISMEP cloud platform and will then be put into test mode on the RWTH Aachen Campus for demonstration and evaluation.

The project has received funding in the framework of the joint programming initiative ERA-Net Smart Grids Plus, with support from the European Union’s Horizon 2020 research and innovation programme.

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ERA-Net Smart Grids Plus
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Our Research

Further Projects

RESERVE

RESERVE is a Research and Innovation Action (RIA) project of the H2020 Program aiming for the development and validation of new techniques, which can ensure a stable supply of purely renewable energy sources (RES). The objective is to enable up to 100% penetration of RES by researching concepts for new energy systems and developing new techniques and solutions based on 5G technology to assist energy providers. RESERVE will address these challenges by developing the novel research concepts of Linear Swing Dynamics (LSD) and Virtual Output Impedance (VOI), implementing them through an innovative pan-European real-time simulation infrastructure and validating them in a field test in Ireland.

As one project partner, FEN GmbH leads the work package "Creating impact with RESERVE" on behalf of the LV consortium, carrying out the communication, dissemination and exploitation activities of the project. In this role, FEN will develop the necessary communication tools and interfaces between the project participants and the different target audiences ,which include the general public, stakeholders as well as interest groups like transmission system operators, distribution system operators and standard development organizations. The overall objective of this work package is to maximize the scientific, industrial and societal impact of the project by creating awareness of the technologies and the innovative activities within the project but also by channelizing guiding feedback from the public that will be incorporated in the strategic orientation of the project.

The main achievements on this topic are summarized here:

- RESERVE has designed and implemented the necessary communication and dissemination tools and interfaces to bring about opportunities for constructive communication between the project and the public.
- RESERVE has successfully started fostering the support for ancillary services and network codes by sharing the ongoing work and achieved results as well as by collecting feedback and input from stakeholders and the Advisory Board members during the organization of associated events.
- RESERVE has created awareness of the project work and disseminated the results through the organization of and participation in numerous targeted events (workshops, conferences, trade fairs etc.) and has planned even more for the next years.
- RESERVE has developed the concept for the training programs that will be implemented in the second half of the project and that are aimed at creating impact on the educational needs of the energy sector.

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727481

FlAixEnergy

Since August 2015, FEN GmbH, on behalf of the LV Consortium, participates in the BMWi project FlAixEnergy, taking over the work packages "Conception of local production clusters" and "Conceptual design and development of solutions for power distribution". The aims of this three-year project are to develop a method for the automatic clustering of different production units, taking advantage of bundling effects as well as to determine the flexibility that can be offered on the FlAix Energy platform. One effect can be to counteract imbalances by aggregating different load and production curves. By forecasting the energy consumption, the power generation can be adjusted to optimally match supply and demand. One key aspect of the FlAix Energy project, in particular, is to support a regional match between decentralized energy generation and local energy consumption with a focus on energy-intensive industrial loads.

In 2017, FEN Research Campus participated in the development of the DIN SPEC 91366, which serves as a reference model for characterizing the energy flexibility of industrial facilities. This specification document systematically shows companies those aspects that have to be considered and investigated in the identification, assessment and utilization of energy flexibility.

The reference model supports the communication of energy information and the assessment of energy consumption behavior with regard to energy flexibility. Relevant positioning and planning values in energy and load management or production planning and control are included in the evaluation. In this context, relevant factors identified and serving for characterization include organization-, process-, technical-, cross-asset- and energy-related factors like storage capabilities.

The SPEC proposes a description model that allows a step-by-step evaluation of flexibility features identifiable in each industrial facility. Furthermore, in 2017, FEN Research Campus focused on work package VIII by investigating possible infrastructure measures that are necessary when participating in an energy flexibility platform. Here, an important aspect is to point out recommendations in the given regulatory framework.

In order to evaluate the performance of the suggested regional flexibility platform, the influence on the distribution grid needs to be quantified. Our researchers have started to apply production and load profiles into synthetic grid structures and will implement the flexibility patterns by the beginning of 2018.

In preparation of the project finalization in August 2018, FEN Research Campus intensified the activities in terms of a demonstrator.

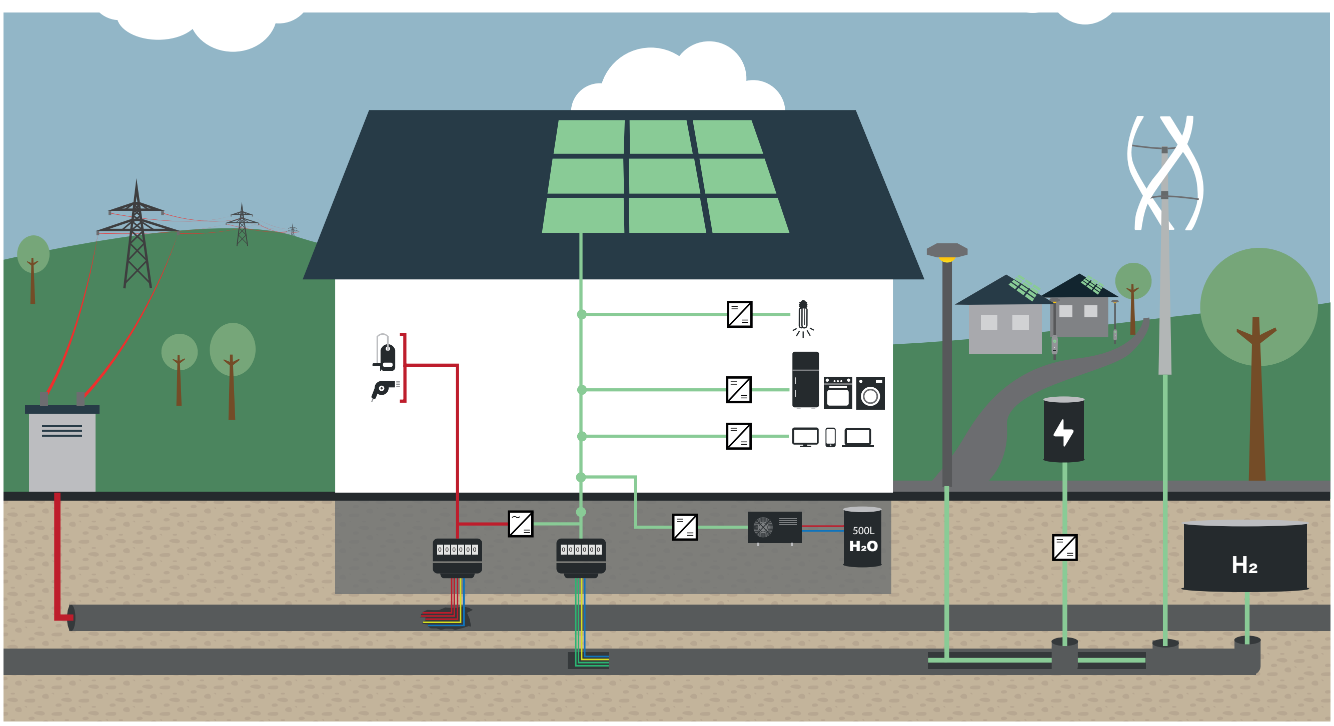
Funding Organization:
Federal Ministry of Economic Affairs and Energy (BMWi)
Duration:
August, 2016 - July, 2018
Grant total:
3.103.936 €
Grant Agreement No:
0325819D

Our Research
Further Projects

Feasibility study
In a feasibility study for Innovationsregion Rheinisches Revier (IRR) GmbH, FEN Research Campus has examined the development and implementation of a DC-based smart grid residential area, which is mostly powered by means of renewable energies (RE). An essential advantage of DC technology lies in the efficient energy supply of households where an AC/DC conversion is omitted and, hence, costs are saved. This advantage makes the business model development particularly interesting for potential stakeholders such as home owners (prosumers), service providers for RE systems, residential developers as well as grid operators.

The basis of the business model development is the “all-electric house“: By means of an integrated photovoltaic (PV) system and a local battery system, which are incorporated in a DC grid, not only the overall energy supply but also warm water heating and general heating are carried out electrically. In the business model of the DC residential area, ten of these all-electric houses are interconnected by DC street lighting. Further versions of the DC residential area include a DC mini wind turbine, a central battery, an e-car fleet and hydrogen production as additional supply and storage components.

As part of the feasibility study, FEN Research Campus considers different aspects such as regulatory requirements (no feeding into the public grid) as well as financial and economic conditions (e.g. investment and acquisition costs). Furthermore, the business model of the DC residential area and its different versions are being evaluated by means of various criteria such as economic efficiency, social acceptance or funding potential, among others. As a result, both positive and negative feedback as well as potentials and need for optimization in terms of further research and development can be shown.



Study Facing the Smart Future
FEN Research Campus participates in the consortium study “Facing the Smart Future” by analyzing smart applications and solutions which meet the needs of utilities, municipalities and industries for future cities. For this study, FEN gives expert insight into the electricity segment within the focus area “Environment and Utilities”.

In a first stage, our researchers scanned for innovative technologies and approaches, which were presented to the relevant international players of the consortium in a report meeting in February 2017. For the presentation, FEN rated each smart solution with regard to technological readiness, service potential and business potential. On this basis, the consortium voted for a subset of the presented solutions across six different focus areas. Our “Vehicle-2-Grid” and “DC Microgrid” approaches were voted into the second stage in which a detailed technical analysis and report was prepared until July 2017. Finally, in a last stage, decoupled from the “Facing the Smart Future” study, FEN started to prepare an exclusive business study for two regional partners of the smart future consortium. The finalization of the detailed report, which focuses on autonomous vehicles in the context of a DC microgrid system, is set for early 2018.

Our Partners

University Partners

HCIC, Textlinguistics and Technial Communication	Prof. Dr. phil. Eva-Maria Jakobs
Institute for Applied Geophysics and Geothermal Energy	Prof. Dr. rer. nat. Christoph Clauser
Institute for Automation of Complex Power Systems	Prof. Antonello Monti, Ph.D.
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Institute for Urban and Regional Planning	Prof. Dipl.-Ing. Kunibert Wachten


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Research for the grids of the future
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CAMPUS

Our Partners

Industrial Partners

AixControl	Dr. Jochen von Bloh
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Our Partners
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Sprint Capital	Yamada Hikaru
Thyssenkrupp	Dr. Régis Lemaître
Vacuumschmelze	Dr. Ralf Koch
Westnetz	Dr. Stefan Nykamp Mark Schocke

Our Partners

New Industrial Partners

Mitsubishi Electric Corporation

Since October 1st, 2017 ***Mitsubishi Electric*** has become a new industrial partner in the Medium-Voltage (MV) Consortium of FEN Research Campus.
With over 90 years of experience in providing reliable, high-quality products, Mitsubishi Electric Corporation (TOKYO: 6503) is a recognized world leader in the manufacture, marketing and sales of electrical and electronic equipment used in information processing and communications, space development and satellite communications, consumer electronics, industrial technology, energy, transportation and building equipment. Embracing the spirit of its corporate statement, Changes for the Better, and its environmental statement, Eco Changes, Mitsubishi Electric endeavors to be a global, leading green company, enriching society with technology. The company recorded consolidated group sales of 4,238.6 billion yen (US$ 37.8 billion*) in the fiscal year ended March 31, 2017.

*At an exchange rate of 112 yen to the US dollar, the rate given by the Tokyo Foreign Exchange Market on March 31, 2017

MITSUBISHI ELECTRIC
Changes for the Better

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thyssenkrupp Electrical Steel produce and sell powercore®, a complete range of high quality grain oriented electrical steel products. As one of the leading companies in the overall electrical steel business thyssenkrupp Electrical Steel is always in the move to expand their global market presence as well as improve the technical and market performance.
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thyssenkrupp

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Our Cooperations

ETIP SNET

Dr. Christian Haag, on behalf FEN Research Campus, was selected by the Executive Committee of the European Technology and Innovation Platform Smart Networks for Energy Transition (ETIP SNET) as expert in the work group "Innovation implementation in the business environment". This work group adopts a helicopter view of the activities carried out in the projects within the perimeter of the ETIP about the energy transition.

ETIP SNET gather actors from electricity, storage and ICT but also heating, transport and gas. The ETIP SNET will set-out a vision for research and innovation for smart networks, storage and integrated systems and engage stakeholders in this vision. It will also identify innovation barriers, notably related to regulation and financing. ETIPs have been created in the framework of the new Integrated Roadmap of the Strategic Energy Technology Plan (the SET Plan) – Europe's energy RD&I master plan.

ETIP SNET

PLAN. INNOVATE. ENGAGE.

Forschungsnetzwerk Energie

FEN Research Campus is member of the initiative "Forschungsnetzwerk Energie – Stromnetze". This initiative is part of the 6th energy research program of the Federal Ministry for Economic Affairs and Energy (BMWi). The aim is to transfer the results of energy research directly to the actors involved in the energy transition and to make the process from the development of the funding strategy to the research idea to innovation transparent and practical.

The "Forschungsnetzwerk Energie – Stromnetze" acts as an interface between politics, research and practice. For example, the members of the working groups develop proposals for the strategic orientation of research funding in the field of electrical grids, for thematic priorities of calls for proposals, funding announcements or competitions.

FORSCHUNGSNETZWERK ENERGIE STROMNETZE

Our Chronicle 2017

25/26 JAN
FEN Day @ Siemens, Erlangen

27 JAN


RWTH transparent, Aachen

07-09 FEB

E-World energy & water, Essen

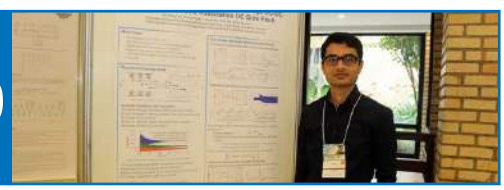
24 FEB
FEN in working group of *ETIP SNET*

21 MAR
DKE Experts forum, Mannheim

22 MAR
Kick Off Workshop for the
DIN SPEC 91366, Berlin

26-30 MAR


Applied Power Electronics Conference and Exposition 2017 (APEC), Tampa

17-20 APR

Power Electronics for Distributed Generation (PEDG2017), Florianópolis

18/19 MAY
Workshop of all BMBF Research Campuses, Aachen

Our Chronicle 2017

22-25 MAY
IEEE International Instrumentation and Measurement Technology Conference (I2MTC), Torino

23/24 MAY
BMBF "Zukunftskongress Energieoffensive 2030", Berlin

02 JUN
RWTH Campus Run, Aachen

03-07 JUN
IEEE ECCE Asia, Kaohsiung

08 JUN
International Economic Conference (INFER), Bordeaux

12 JUN
Company outing *"Phantasialand"*, Brühl

13 JUN
"Facing the Future: Smart Cities & Infrastructure"
Consortial Project Meeting, Aachen

18-22 JUN
IEEE PES PowerTech Conference, Manchester

19-21 JUN
IEEE International Symposium on Industrial Electronics (ISIE), Edinburgh

Our Chronicle 2017

19-21 JUN

RESERVE at *European Sustainable Energy Week (EUSEW 2017)*, Bruessels

23 JUN

1st RESERVE Stakeholder Meeting, Bucharest

25-28 JUN

International Conference on Amphibious Architecture, Design and Engineering, Waterloo

26/27 JUN

RESERVE at *Innogrid2020+,* Brussels

27-29 JUN

International Conference on DC Microgrids (ICDCM), Nuremberg

11 JUL

"Diskussionsforum Stromnetz", Aachen

13 JUL

FEN participates in *"Forschungsnetzwerk Energie"*

16-20 JUL

IEEE Power & Energy Society General Meeting, Chicago

11-14 SEP

EPE'17 ECCE Europe, Warsaw

Our Chronicle 2017

26-29 SEP

RESERVE Workshop at *IEEE PES ISGT* Europe, Turin

01 OCT

City festival *"Smart City"*, Heinsberg

01 OCT

Mitsubishi Electric joins FEN as a new industrial partner

03-05 OCT

RESERVE at *European Utility Week,* Amsterdam

12 OCT

DIN SPEC 91366 Meeting, Berlin

23-26 OCT

IEEE International Conference on Smart Grid Communications, Dresden

29-31 OCT

Annual Conference of the IEEE Industrial Electronics Society (IECON), Beijing

01 NOV

thyssenkrupp Electrical Steel joins FEN as a new industrial partner

09 NOV

GRAPES meeting, Fayetteville

Our Chronicle 2017

15 NOV

Regional Energy Conference South-West Thuringia, Suhl

17 NOV

JARA-ENERGY Talks, Aachen

27 NOV

FEN Workshop Protection in LVDC Grids, Aachen

01 DEC

Official start of EU project *FISMEP*

12-15 DEC

IEEE International Conference on Power Electronics and Drive Systems (PEDS), Honolulu

13/14 DEC

FISMEP Kick Off Meeting, Aachen

Our Future 2018

11 JAN — Company Outing, Cologne

30 JAN — *“Diskussionsforum Stromnetze”,* Aachen

30 JAN — Final Report Meeting *“DC Microgrids Business Case Study”,* Aachen

06-08 FEB — *E-world energy & water,* Essen

07 FEB — Adoption and enactment of *DIN Spec 91366*

08 FEB — *Applied Research on Charging Infrastructure (ARCHI),* Delft

14 FEB — *Workshop Standardization LVDC,* Frankfurt

15 FEB — *JARA-ENERGY Talks,* Aachen

06 MAR — FEN is honored by KlimaExpo.NRW for its project *FlAixEnergy*

Our Future 2018

12-15 MAR — *International Conference on Developments in Power System Protection (DPSP)*, Belfast

16 MAR — *DKE Standardization Meeting*, Frankfurt

19 MAR — *Groundbreaking ceremony of MVDC Research Grid*, Aachen

20/21 MAR — *Annual Meeting of Electrical Winding & Insulation Systems (EWIS) and “Transformatoren & Stromversorgungen” (TuS)*, Hamburg

04-06 APR — *International Public Communication of Science and Technology Conference (PCST)*, Dunedin

12 APR — *Mobility2Grid Conference*, Berlin

17-18 APR — *ECPE Workshop: “DC Grids, Technologies and Applications"*, Aachen

19/20 APR — *Aachen DC Grid Summit (aDCgs)*, Aachen

Our Future 2018

04 MAY — Opening Exhibition *“Mission Energiewende – mit Gleichstrom in die Zukunft”*, Alsdorf

15/16 MAY — RESERVE at *Innogrid2020+*, Brussels

20-24 MAY — *International Power Electronics Conference (IPEC),* Niigata

25 MAY — *European PhD School Power Electronics, Electrical Machines, Energy Control and Power Systems,* Gaeta

04-08 JUN — *RESERVE at European Sustainable Energy Week (EUSEW 2018),* Brussels

11 JUN — *"Diskussionsforum Stromnetze",* Aachen

16 SEP — *European Conference on Power Electronics and Applications (ECCE),* Riga

18 SEP — *FlAixEnergy Project Completion with Final Presentation Event,* Aachen

Imprint

EDITORIAL
Dr. Christian Haag, Dr. Peter Lürkens, Bettina Schäfer, Christoph Loef, Gonca Gürses,
Dr. Marina Maicu, Sascha Falkner, Laura May

LAYOUT
Ann-Caroline Volkmann, Laura May

PICTURES
© Andrea Boldizsar: street with wind turbine
© Arne Hinz: Installation of the shaft at the CWD to connect to the MVDC Research Grid
© Asimenia Korompili: Hardware setup of small-scale demonstrator platform
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