In late 2019, the Flexible Electrical Networks (FEN) Research Campus, in which the institutes of E.ON ERC are involved in a leading capacity, teamed up with other institutes of RWTH Aachen University and industrial partners to commission a medium-voltage direct current (MVDC) network on the Melaten campus of RWTH Aachen University as a demonstration network (see Research & News, No. 24, 3/2019).

Just a few months after it was put into operation, in March 2020, the EnergyAgency.NRW chose this unique research grid as its “project of the month,” highlighting the project on the agency’s website, where the general public can learn about it as an outstanding example in the area of grid innovation. The detailed, highly interesting article presents a clear view of the fundamental technical and economic advantages of DC technology. It also features specific technical innovations,

Dear Readers,

The coronavirus is at the front of our minds and our activities alike. People’s health is paramount – not just worldwide, but naturally here as well. At E.ON ERC, we are rigorously following all guidelines set by policymakers and the university administration. Our buildings are eerily empty, working from home is the order of the day, physical contact is being avoided, and students are watching lectures online. At the same time, we are continuing ongoing projects and activities through close electronic contact with colleagues in the office or lab next door, at home or around the world. That is one of the reasons we can offer an interesting overview of our work with a new issue of Research & News.

Even amid all our worries and concerns, I hope you will enjoy reading this issue. Stay healthy and think positive!

Rik W. De Doncker
such as the 5-megawatt medium-frequency transformer inaugurated at FEN, which was redeveloped and redesigned for FEN, largely by the PGS Institute at E.ON ERC in tandem with industrial partners.

This DC-DC converter lends itself to various future uses, such as in large collector arrays for renewable energies, in battery storage systems, in rapid-charging stations for electric vehicles, and in industrial grids. As the next step, another DC-DC converter for power of up to 7 megawatts will be integrated into the network to enable detailed testing of this converter as well under realistic conditions. In this type of converter, the switching of the high-performance semiconductors is supported with a resonant circuit. Thanks to this new technology, energy losses are even lower here than with the 5-megawatt transformer, which is also highly efficient.

FCN: Modeling grid-friendly clean energy communities

As Germany turns away from fossil and nuclear power generation, energy communities (CECs) that switch their power supply to “clean sources” are becoming more and more important. In a working paper titled “Modeling Grid-Friendly Clean Energy Communities and Induced Intra-Community Cash Flows,” FCN researchers show how the structure of different CECs affects how they contribute to the overall grid and what intra-community flows of funding are induced as a result.

For this purpose, this publication studies three different communities – one rural, one village-based, and one suburban – as examples. The relevant load profiles are simulated, and the generation of electrical energy using solar and wind farms is calculated depending on meteorological data. Four different measures are considered: improved energy efficiency, installation of large photovoltaic systems, introduction of trading between community members (peer-to-peer trading), and installation of wind turbines.

The study shows that introducing one of these measures often reduces the community’s contribution to the overall grid, but the combination of two or more measures almost always has positive effects in this regard. With respect to contributing to the overall grid, the researchers stress the importance of combining different measures from the groups noted above. They also point out the need to support these kinds of communities in keeping with the benefits they provide.

The working paper titled “Modeling Grid-Friendly Clean Energy Communities and Induced Intra-Community Cash Flows” is available to download from the website of the FCN institute here.

Optimized technology mix reduces grid loads

Experts agree that demand for electricity will increase sharply all across Germany as a result of the German energy transition, at least in the mobility and heat sectors. However, the generation of power from renewable sources is concentrated in the north and east of the country. The expansion of the grid is not proceeding as quickly as planned, and further expansion is too difficult to achieve politically. As a result, the national transmission grid is pushing its limit.

Together with the Institute of High Voltage Equipment and Grids, Digitalization and Power Economics (IAEW) at RWTH Aachen University, FCN participated in the project titled “Regionally Optimized Energy Infrastructure and Sector Coupling,” which studied the extent to which energy transmission can be shifted to other grids, particularly the natural gas grid. The project also looked at whether the need for grid expansion can be reduced through targeted adjustments in the regional technology mix in the areas of mobility and heat. For example, it would be conceivable to rely increasingly on battery electric vehicles and heat pumps in regions with a good supply of electricity. In turn, regions with little local renewable energy generation could build more combined heat and power (CHP) plants, press ahead with methane and hydrogen mobility, and create more storage capacity to smooth the demand curve.

As part of the project, FCN determined the maximum distribution speeds for eight heat technologies, five mobility technologies, and two storage technologies while estimating future demand for usable energy and evaluating the cost and efficiency trends associated with this kind of development.

Whether a regionally optimized distribution of the use of different technologies is feasible in political and regulatory terms and with the support of local communities, and if so, how, has not yet been studied in this project. However, plans call for researchers to study this as a next step so specific, true-to-life recommendations can be made to decision makers on what actions to take.

An assessment of the need for future infrastructure and its expansion will require not only a stocktaking of available resources and existing infrastructure, but also a regional study of the acceptance of technologies and an assessment of their expected spatial and temporal distribution. This will allow for a socioeconomic reality check of simplified techno-economic model calculations (from the viewpoint of social planners) and for a plausibility check of the results wherever possible. However, for decentralized flexibilities technologies that contribute to the
overall system to be distributed sensibly in macroeconomic terms, there is also a need for a regionally differentiated analysis of the necessary new (local) market designs and suitable incentive mechanisms. As the final step in the plausibility check, a scientifically sound assessment of political and social acceptance of the new market designs is also needed.

**FCN Electric mobility**

Study identifies new business models

The dynamic developments associated with the German energy transition definitely bring certain risks, but they also offer a large number of new possibilities. In the new "Value Pools" research project, FCN has teamed up with the E-Mobility Department at E.ON to study whether vehicle-to-grid (V2G) technology offers economic opportunities in different European countries, and if so, where. V2G uses the batteries of electric vehicles connected to the grid as spatially distributed buffer storage. Charging is shifted to times when the load on the grid is lower, for example. If demand for electricity rises, the power used for charging can be throttled, and the energy stored in the batteries can flow back into the grid at times of peak demand. Ultimately, this helps to smooth the demand curve.

With sales figures for electric vehicles rising steadily – the International Energy Agency (IEA) expects there will be 250 million electric vehicles worldwide in 2030, for example – the collective storage capacity offered by vehicle batteries has potential that should not be underestimated as an additional source to improve grid flexibility. And there are benefits for both sides: Network operators save money because they do not have to activate expensive reserve capacity as often to accommodate demand at peak times, and vehicle owners benefit from lower charging costs at certain times or may even receive compensation for the use of the vehicle battery as buffer storage.

This project is studying the electricity markets of 11 European countries, divided into four groups:
- France and Italy
- Romania, the Czech Republic, Slovakia, and Hungary
- Belgium, the Netherlands, Luxembourg, and Poland
- Norway

As the first step, the electricity markets in these countries and their particular features are being studied and mapped out in overview form. The goal of these activities is to identify possible new business models against the background of various overall legal and regulatory conditions. It is already apparent that the overall conditions that apply to the use of V2G technology vary widely. Some countries accept the use of this technology, while others at least allow pilot projects in these areas. But there are also countries that do not permit V2G in general. As the second step, the study will turn to the relevant energy markets and the possible developments over the next five years. Areas of focus here include government incentives, the market penetration of electric vehicles, and the number of charging points. The financial potential of the service offerings studied and the business models associated with them will be assessed as the final stage of the project.

**FCN Reliability of energy supply**

Shortening simulation calculations facilitates grid and capacity planning

Changes in the power plant portfolio for a country, state, or region affect the reliability of the energy supply to different degrees. As Germany shifts away from nuclear energy and coal-fired power plants, significant portions of the power plant capacity that had been in use until just a few years ago are being eliminated. Power generated from renewable energies, which is often volatile,
is taking their place. The effects of these changes on the reliability of the supply of electrical energy can be calculated using simulations, but the processes needed to do this are extremely time-consuming – or at least, they were until now.

As things currently stand, calculating the effects of interventions in the generation structure requires labor-intensive, time-consuming computer simulations due to the complexity of the energy system. For the German situation, for example, the techno-economic properties and operating modes of 750 power plants running on fossil fuels have to be modeled and simulated to achieve this. Added to this initial situation, which is already highly complex, are about 30,000 wind turbines and more than 1.7 million photovoltaic systems. All this means that simulating the reliability of the energy supply in Germany for a calendar year requires the full computing power of advanced high-performance computers for a period of about ten hours. The studies grow even more complex if they are also supposed to take into account how the Germany energy supply system is embedded into the overall European system.

Researchers from the Junior Professorship of Energy Resource and Innovation Economics (EI) at FCN teamed up with colleagues from the Centre of Innovative Energy Systems at Hochschule Düsseldorf, University of Applied Sciences to develop innovative approaches to significantly accelerate studies like this.

The first results of their approaches, which are based on methods drawn from metamodeling and artificial intelligence, seem highly promising. For example, the team was able to shorten the time spent running calculations for computer simulations from about ten hours to just under two minutes in trial runs. As the next step, these new approaches will now be transitioned to robust analytical methods. If the researchers succeed in doing this, it will be possible to study and compare different energy scenarios with an eye to their impact on the reliability of the energy supply. There are also plans to apply these promising approaches to achieve consistent methods of evaluating the reliability of the European electricity supply.

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**EBC Modernization of heating**

Combined heat and power has great potential for supplying residential buildings

In cooperation with DBI Gas und Umwelttechnik Leipzig and GWI Gas- und Wärme-Institut Essen, EBC has identified potential for shifting the heating technologies used in residential buildings toward efficient, eco-friendly solutions as part of a study called “Residential CHP Switch” (Wohn-KWK-Switch). The study particularly highlights options for reducing emissions by increasing the use of combined heat and power (CHP) with high levels of electricity and heating use. The research project was supported by the German Technical and Scientific Association for Gas and Water (DVGW).

The household and residential sector accounts for a good one-quarter of energy consumption in Germany. Many heating systems used in residential buildings are more than 18 years old. That means the German federal government had good reason to set a “nearly climate-neutral building stock” as the goal for 2050. The initiative is two-pronged. First, demand for fossil fuels is to be reduced by 80 percent. Second, about half of the remaining demand for energy is to be covered by renewables. This means that extensive renovation measures will be taking place across Germany over the years to come, making this an extremely favorable time to install efficient combined heat and power (CHP) systems in residential buildings.

CHP technologies, which generate both heat and electricity, are especially interesting for residential buildings because they provide two types of usable energy, reaching very high efficiency levels of as much as 95 percent. The ecological advantages are obvious, but that’s not all. With electricity prices on the rise and attractive support mechanisms in place, households can also benefit in economic terms.

For the study, the researchers first determined the CHP potential in residential buildings throughout Germany in order to better gauge the overall conditions for the installation and operation of CHP systems, which vary by region. Both centrally supplied neighborhoods of single-family homes and larger residential and multi-unit buildings with heating networks were identified as suitable sites for using CHP.
Among other things, the study’s results suggest that for single-family homes and duplexes, simply replacing old boilers with new ones can help reduce emissions by a noteworthy amount. Installing an additional photovoltaic system brings both ecological and economic benefits, while heat pumps have even greater potential for reducing emissions than simply replacing boilers, but are also more of an investment. The researchers see fuel cell technology as holding great potential for meeting demand for electricity, but they also point out that this technology is not yet economical, despite the funding it has received. They do not recommend installing CHP systems currently available on the market in single-family homes and duplexes, chiefly because the systems take up too much space.

In almost all multi-unit buildings studied, by contrast, the use of CHP technology is beneficial in both economic and ecological terms. In principle, the study’s findings indicate that a CHP system and gas boiler delivers better results than simply replacing the existing boiler for buildings with ten residential units or more.

In the short term, the authors of the study recommend that existing multi-family buildings be shifted to CHP technologies for heating purposes. Replacing oil heating systems, which are highly inefficient, should also be a priority, along with replacing all heating systems that have been in operation for 20 years or longer.

The researchers also recommend that research and development efforts in the area of fuel cell heating for single-family homes and duplexes be intensified in the medium to long term so that these properties can be equipped with efficient heating technology now and into the future. The terms of support for CHP systems should be improved as well, they say. In terms of providing energy to meet demand, the authors believe the advantage lies with combination solutions involving cogeneration units and heat pumps. To further reduce emissions, they say, it would also be necessary to increase the proportion of biogas used in the natural gas network.

In general, the results of the study show a comparatively low CHP potential for small residential buildings. By contrast, CHP systems for multi-family properties make sense in both ecological and economic terms, as do heating networks with central generation of power and heat to supply multiple single-family homes and duplexes.

Researchers identify interactions and flexibilities for stable distribution networks

In the InterFlex project concluded in late 2019, five European distribution system operators teamed up with industrial players and the research sector to study interactions and areas of flexibility between participants in the energy market and the distribution network. Their aim was to find solutions for better integrating the increasingly decentralized generation of energy. The researchers also looked at ways to get the electrical system ready for new applications such as electric mobility. Special attention was paid to the aspects of energy storage, intelligent battery management in electric vehicles, demand management, island operation of local networks, network automation, and integration of different energy sources (sector coupling of gas, heat, and electricity). InterFlex is a project under the European Commission’s Horizon 2020 initiative with the aim of demonstrating smart grid storage and system integration technologies with an increasing share of renewable energies in the distribution network.

Within this project, ACS was in charge of the general work package titled “Impact and Deployment Analysis of the Innovative Solutions.”
The researchers’ activities focused on several topics:

- Interoperability and interchangeability of components and systems;
- “Interoperability by design,” taking overall cybersecurity conditions into account;
- Demonstration of the interoperability and interchangeability of systems and components in the test lab;
- Specifications for interoperable APIs (programming interfaces); and
- Scalability and reproducibility.

In addition, the ACS and EBC institutes supported energy supplier E.ON in two field trials in Sweden. In the first of these two projects, synergies between different energy sources were identified in order to tap into areas of flexibility in the storage capacity of heating networks in combination with the thermal inertia of building shells. In addition, a commercial heat pump was used to improve the energy efficiency of a local system used for air conditioning. The heat pump uses the waste heat generated by a neighboring data center while also offering cooling capacity to the data center. The pump can be switched off when demand for power is high. In these cases, buildings are heated conventionally via the district heating network, with their own cooling systems providing air conditioning. This improves overall efficiency, and the distribution network benefits from increased flexibility. The results of this field trial show that providing thermal flexibility is associated with great market opportunities.

The second Swedish demonstration project was implemented in a local island network with an exclusively renewable energy supply, where demand was controlled with control units installed specifically for this purpose in the households connected to the network. This project showed that this kind of island network can achieve stable operation by means of a specific combination of power electronics, storage capacity, and renewables. Additional elements such as targeted demand control make the grid more resilient in the face of high and volatile supplies of energy from renewable sources. The project was also able to integrate the heat pumps, photovoltaic systems, batteries or hot water reservoirs installed at customers’ facilities into the supply system. A newly created platform allows registered customers to actively contribute to stabilizing the grid with their power generation systems, storage capacity, and/or by controlling demand according to time, plus they can receive payment in return.

For detailed information on InterFlex and the five field trials, please see the summary (in English), which is available to download here.

ACS  Grid management

5G gets energy grids ready for the future

Within the scope of the NRG-5 project, a consortium has studied the influence of 5G on future energy networks and integrated, expanded, and tested a platform for various applications. The project emphasizes drone-based monitoring of critical infrastructures, electricity grid regulation for future smart power networks, and integration of smart metering into the future 5G-based mobile phone infrastructure. Significant advances have also been made in edge cloud-based electricity network regulation, drone control, image processing, and phasor calculations. The ACS Institute studied how 5G affects transmission of measurements, edge cloud-based electricity network regulation using real-time simulators, and 5G-like communication emulators in particular. The project received funding from the European Union under the Horizon 2020 framework program.

When 5G technologies are used in the area of electricity network control, there are

Knowledge and expertise for the energy transition

Two European projects, ASSET and EDDIE, are preparing content and developing tools that are essential for sharing knowledge and expertise in aspects related to the energy transition. The research sector, industry, and policymakers are working together to craft new instructional materials and update existing ones. Innovative programs to educate students, trainers, employees, and interested members of the public are under development.

ACS is working within the ASSET Horizon 2020 project, where its responsibilities include preparing instructional materials on smart, flexible energy grids. Together with the Human Technology Center and the Institute for Gender and Diversity in Engineering at RWTH Aachen University, ACS is also responsible for making sure aspects relating to the social sciences and the humanities are not neglected when programs are developed.

In the new EDDIE project funded by the Erasmus+ program, all relevant interest groups in the energy value creation chain are being combined into what is being called a “sector skill alliance,” which is to work together to develop a long-term model for the further development of the European energy sector. This, in turn, is to serve as the basis for teaching skills and abilities that are crucial to further digitization. The focus here is on the user’s perspective, and less on the traditional approach of imparting fundamental knowledge and skills first and then waiting until a later stage to develop possible applications. The cooperation among numerous different partners in this project is viewed as a key to the development of models that depict current and future global, social and technological trends and needs.
always a number of requirements that apply to critical infrastructure that must be taken into account. Thus, key indicators such as latency, transmission rates, packet losses, availability, cybersecurity, and error handling must be considered.

To support energy suppliers with a high proportion of energy generated from renewables as they move toward decentralized supply systems, it is important to study the questions that remain unresolved in terms of 5G-supported grid automation and safety, security, resilience, and scalability. The hardware and software used and developed in this research project are state-of-the-art. The development and validation activities are supported by field trials. The project integrated and expanded an edge cloud platform and implemented sample applications in software and hardware, using this as a basis for recommendations for the use of 5G in the energy sector.

**PGS I Electrical drive for aircraft**

**Direct current helps with takeoff**

In the MVDC Onboard project, medium-voltage direct current drives are being developed as components of hybrid electric drivetrains in civil passenger and cargo aircraft. This research project is part of the Aviation Research Program (LuFo) V sponsored by the German Federal Ministry for Economic Affairs and Energy (BMWi). In it, PGS is working closely with the Institute of Aerospace Systems (ILR) at RWTH Aachen University.

The development is aimed at civil transportation aircraft in the CS-25 class. This includes the ATR 72 (a turboprop regional airliner produced by French/Italian manufacturer Avions de Transport Régional, or ATR, for short-haul cargo and passenger service) and the Airbus A320-200 type airliner, which is used for short-haul and medium-haul flights.

For this project, PGS is developing electric drivetrains that work with medium-voltage direct current and onboard voltage of over 1,000 volts. The researchers are using a combination of conventional and superconducting components to achieve this. Analyzing the sensitivity of the onboard electrical and drive systems is a key part of the task. So these kinds of electric drivetrains can optimally fit into the preliminary aircraft design, a special design tool is being developed specifically for onboard electrical systems.

As the next step, the results of the PGS development work are being implemented in MICADO, which stands for “Multidisciplinary Integrated Conceptual Aircraft Design and Optimization Environment.” It was developed by ILR.

Important project goals include:
- Determining electric drive structures that are suitable for use in aviation;
- Identifying further development requirements, including those at the component level;
- Studying and evaluating various drive concepts at the flight system level; and
- Comparing various innovative aircraft designs with hybrid electric drives.

PGS is currently combining individual software modules into a design system, which can be used to quickly and reliably determine the specific optimum electric drivetrain for given aircraft data.

**GGE/EBC I Geothermal energy**

**MPC-Geothermie efficiently integrates borehole heat exchanger fields into building energy supply**

The research project MPC-Geothermal Energy (“MPC” stands for “Model Predictive Control”) focuses on an efficient and particularly on a sustainable use of existing and future borehole heat exchanger (BHE) fields. The project lead by Dr Klitzsch, in which GGE cooperates closely with EBC, Geophysica Beratungsgesellschaft, and DEOS AG, is receiving funding from the German Federal Ministry for Economic Affairs and Energy (BMWi).
The E.ON ERC BHE field is being used to study new operating strategies as part of MPC-Geothermie. The next step will be to further develop these strategies for any desired BHE field. The goal is to create a set of technical rules that can be used to optimally integrate borehole heat exchangers into different building energy concepts and operate them sustainably.

The thermal output of BHEs depends on the thermal properties of the substrate and the temperature distribution around the borehole. Since the temperature near the borehole changes during operation, inefficient and non-sustainable use of BHE fields can occur over time. For example, non-sustainable use can cause the substrate to heat up over time, which results in lower effectiveness in cooling mode.

The E.ON ERC building and its BHE field offer a unique test environment for developing MPC-based integration of the borehole field into the energy concept. On the whole, more than 5,000 sensors at E.ON ERC supply data on indoor climate, air quality, temperature, and technical systems and equipment such as the geothermal field and the building’s heat and cooling systems. The BHE field is also unique in terms of the sensors and control elements with which it is equipped.

MPC-Geothermie is ensuring maximum use of renewable geothermal energy over the entire lifespan of the building and borehole field. This will allow for energy savings of 20 to 40 percent as compared with conventional operation.

Within the PV Kraftwerk2025 research project, innovations for next-generation photovoltaic (PV) power plants are being identified and studied to see how suitable they are for real-world use through close cooperation between the research and industrial sectors. PGS is participating in this project, which is receiving funding from the Federal Ministry for Economic Affairs and Energy (BMWi). The institute is working closely with SMA Solar Technology, Infineon Technologies, and Danfoss Silicon Power on the industry side and with researchers from the University of Kassel and Fachhochschule Kiel University of Applied Sciences. The project sponsor is the Forschungszentrum Jülich research center.

As an initial area of emphasis, converter topologies and structures for large-scale PV power plants are being studied. Different power plant concepts are being considered in the process, and grid connection points for large PV power plants are being optimized. The second area of emphasis is the analysis of the transient behavior of these large PV power plants. To this end, highly dynamic models of power plant components are being developed in order to better identify interactions between them.

The objective of this project is to define and compare power plant concepts, develop an optimization methodology, identify causes and effects of interactions between power plant components, and determine effective measures to counteract undesired interactions.

Various concepts for large PV power plants with integrated battery storage systems for DC and AC grid connection points are being designed and optimized at this stage. Simulations are being used to develop evaluation models. The researchers are using dynamic models developed specifically for this purpose to identify the causes of unstable interactions. Possible countermeasures are being evaluated through simulation.
STAWAG Dissertation Awards for three PGS researchers

The PGS researchers Dr. Johannes Voss, Dr. Shenghui Cui and Dr. Jingxin Hu received jointly the STAWAG 2019 Best Dissertation Award at the “Faculty Day of Electrical Engineering and Information Technology”, which took place last Nov. 29. With this Award, STAWAG, an Aachen energy utility company, recognizes outstanding doctoral dissertations. In the frame of the BMBF Research Campus Flexible Electrical Networks (FEN), all three scientists worked on various key components that enable their vision to realize a flexible, digitally controlled and monitored cellular electrical DC network structure.

In his dissertation, Dr. Cui (in center) focuses on the cost-effective means for coupling of medium-voltage and high-voltage DC grids. Dr. Voss (2nd from left) mainly deals with high-power medium-voltage dc transformers for dc grid interconnections. Dr. Hu’s dissertation focused on the capability of distributed generation plants to ride through serious voltage sags in the dc networks without disconnecting from the network, which enables immediately grid restoration after fault clearance.

The Awardees received their awards from Dr. Christian Becker, Member-of-the-Board STAWAG (2nd from right). The Faculty of Electrical Engineering and Information Technology was represented by Dean Prof. Jens-Rainer Ohrn (left). Prof. De Doncker accepted the Award on behalf of Dr. Hu, who was not able to join the award ceremony.

E.ON ERC Workshop eGrid 2020

Researchers discuss innovation of power grids at eGrid2020

Together with the partners of the BMBF Research Campus Flexible Electrical Networks (FEN), E.ON ERC will support hosting the 5th IEEE Workshop on the Electronic Grid (eGrid2020), which takes place Nov. 2-4, 2020 at Eurogress, Aachen. eGrid is organized by the IEEE Power and Energy Society and the IEEE Power Electronics Society. The local organization is supported by the IEEE German Section, the IEEE German Joint Chapter IAS-PELS-IES and the Germany Chapter PES, as well as IEEE RWTH Student Branch & PELS Student Chapter Aachen.

For a successful energy transition towards a CO2-neutral (electrical) energy supply, the increased use of decentralize power generation, heat pumps for heating and cooling, e-mobility and the cross-sector utilization of renewable energy (Power-to-X) are indispensable. This in turn requires intelligent grid structures with a high degree of flexibility and reliability both on the transmission and the distribution grid levels.

With eGrid 2020, the organizers are aiming at presenting innovative technology options towards an efficient, sustainable and, at the same time, affordable adaptation of electrical networks with growing requirements. Discussing these topics in detail with colleagues from the international professional world is key to a successful implementation. Detailed information on the program, exhibition, and the excursions (5 MW DC PGS converter lab / 5 kV FEN campus DC grid), as well as for the registration can be found at https://egrid2020.org.

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