

# Research and Innovation

Report 2016–2018

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APC

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# A new future of energy

## The European energy system is undergoing significant change

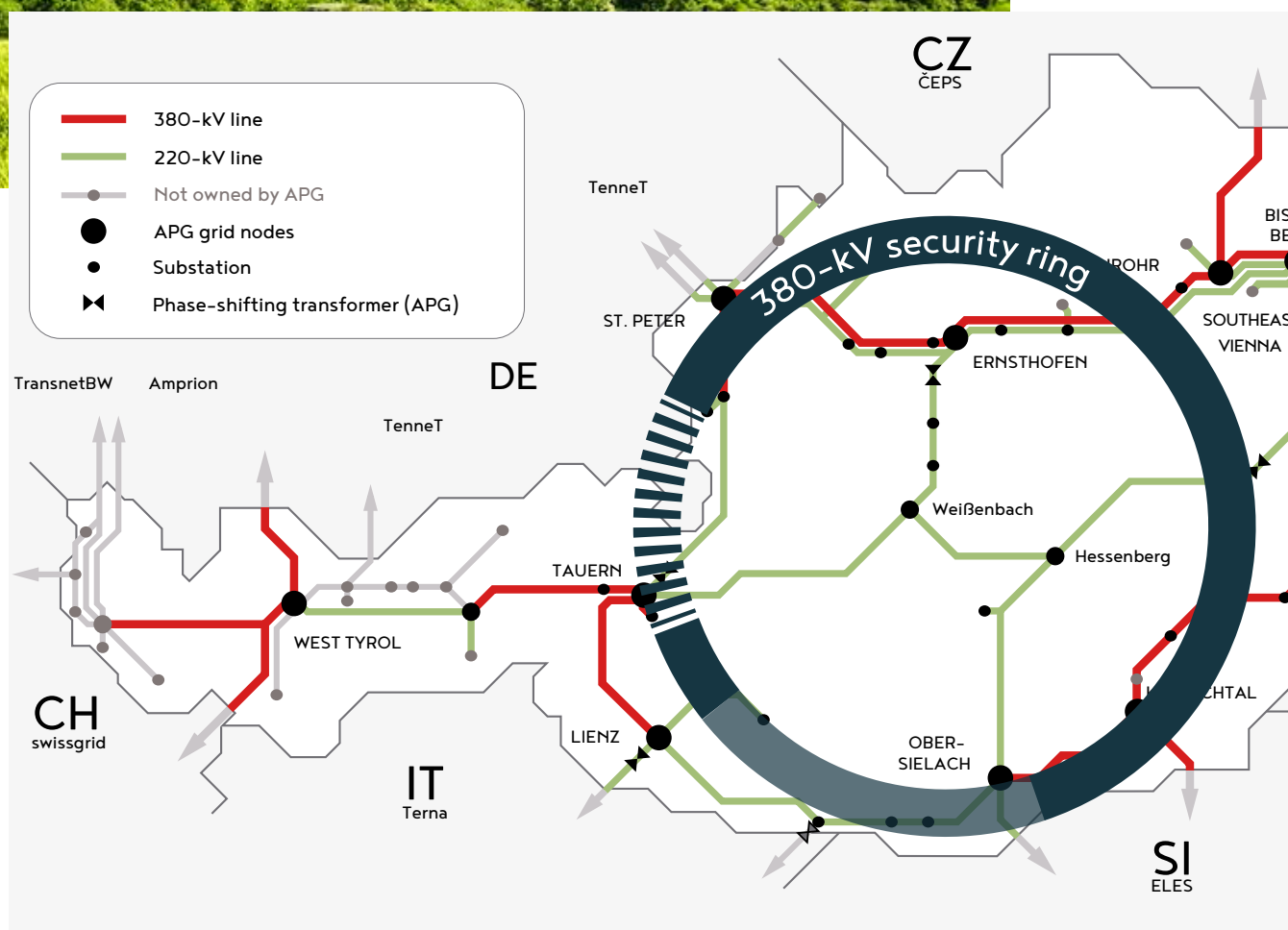
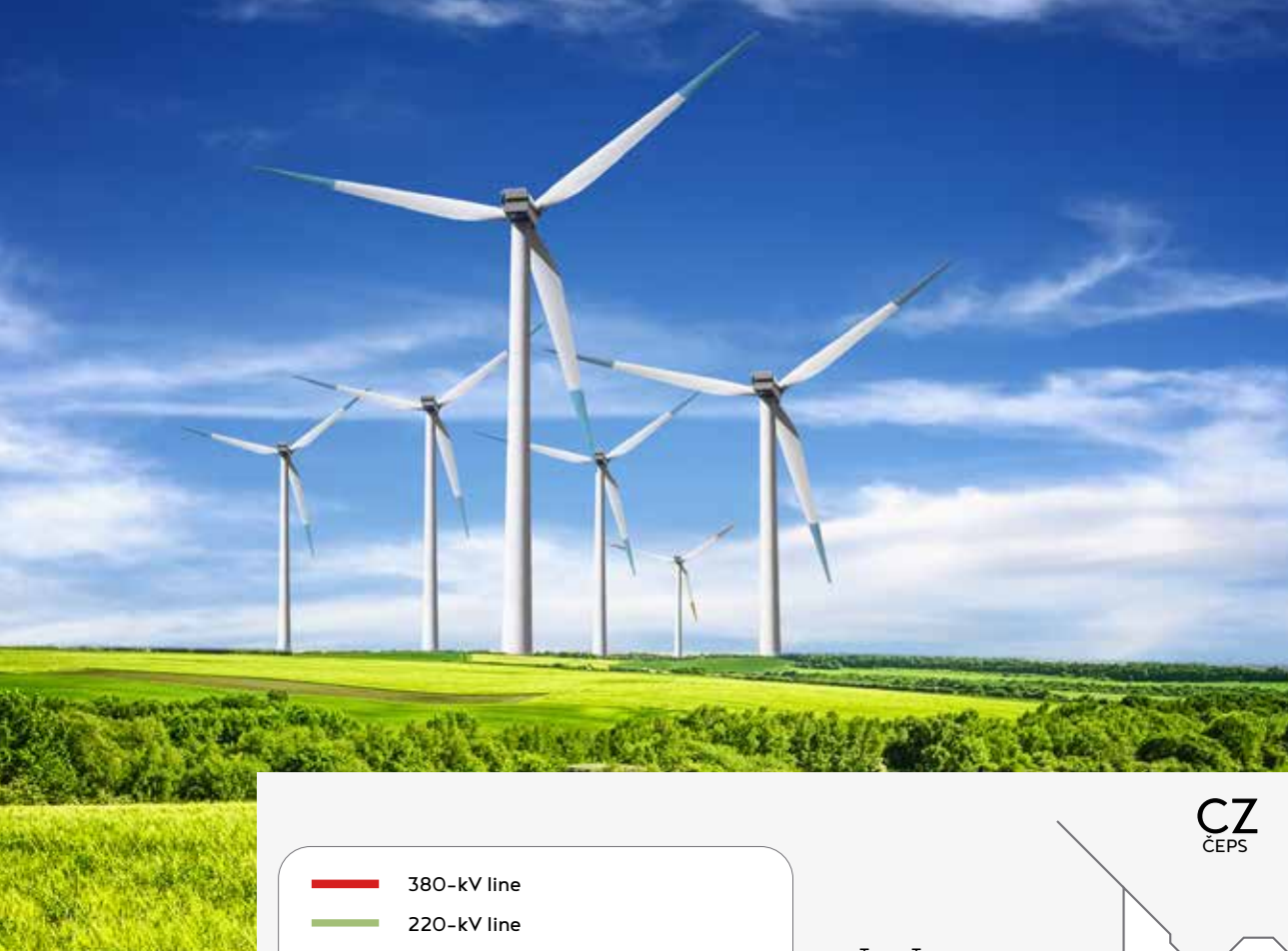
The entire European energy system is undergoing major change. In the interest of creating a liveable future for all Europeans, the European Union has defined climate and energy targets designed to achieve significant decarbonisation of the energy system. The EU targets call for an 80% reduction in carbon emissions by 2050 compared with the 1990 base year. To reach these ambitious climate and energy goals, all sectors of the economy will have to contribute accordingly. The Clean Energy Package put forth by the European Commission is intended to ensure that the targets are met.

Similarly, in 2018 the Austrian federal government established a clear framework for the future of Austrian climate and energy policy by targeting a 36% reduction in greenhouse gas emissions

by 2030 compared with 2005. The objective is to cover 100% of total national electricity consumption with power generated by renewable energy sources (RES) by 2030.

The energy system of the future is renewable, decarbonised and decentralised (because energy from wind and solar is not generated in the direct vicinity of the major load centres). It will also be more democratic: many market participants not only consume energy but also supply power back to the grid, store it for future use (e.g. in the form of local energy cooperatives) and sell/distribute power with the help of microgrids.



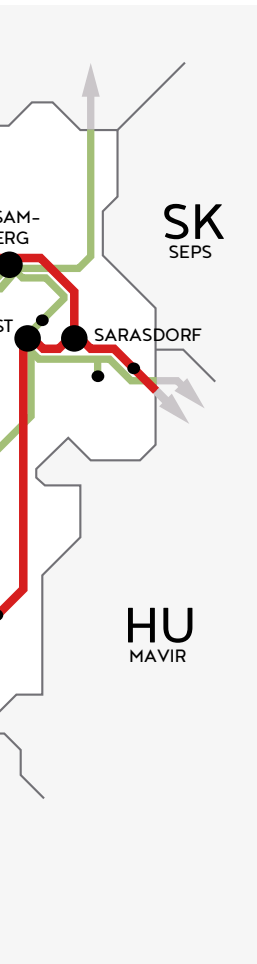


# The role of the power grid in transforming the energy system

To change the entire energy system as fundamentally as described above, all market players will have to work together seamlessly to continue to uphold security of supply in Europe.

APG already ensures security of supply in Austria by operating the high-voltage and extra-high voltage power grid. A reliable transmission grid itself is key to integrate renewable energy sources of the future. Since the volume of electricity generated from RES often exceeds local demand, the power grid is used to transport the excess energy to the Alpine pumped storage power plants in the east of Austria, from where it can be transported back to the load centres as needed. This will remain the most efficient flexibility option in the coming years, according to experts. With its 380-kV supply ring, APG has created the basis for continuing to guarantee security of supply in Austria. In this context, the Austrian power grid located in the centre of Europe plays an essential role in connecting generation and load centres.

Simply upgrading and expanding the transmission grid will not be enough to ensure that the Austrian grid is up to the task. It will also be necessary to find innovative solutions in the fields of storage technologies and sector coupling – areas in which we already expend a great deal of effort. Another important factor in the future of the energy system is digitalisation. Our entire grid is already equipped with sensors to give us a real-time overview of the status of our infrastructure that is updated every second so that we can respond accordingly. Moreover, maintenance drones and digital substations are no longer just concepts of the future, but projects we are actively working on.









## Research coordination & international partnerships

The core elements of APG's research coordination activities include internal research workshops, which are held twice per year and are attended by the APG Executive Board and all departments actively involved in research and innovation development. The workshops serve to improve the coordination of research projects within the company and serve as an information platform between departments. Project results are presented and discussed, and new projects and ideas are introduced. To enable scientific discourse with external partners, platforms and alliances are formed with representatives from the e-sector and the business and scientific communities in Austria and the rest of Europe.

APG is represented on the Research, Development and Innovation Committee (RDIC) of ENTSO-E (European Network of Transmission System Operators for Electricity), a European advocacy group. The RDIC discusses, decides on and then announces the upcoming focuses of research areas within ENTSO-E.

A Research & Development Roadmap presents the cornerstones of the fields of research that will be the most important for transmission system operators over the next ten years. Specific research topics are defined in an Implementation Plan for the forthcoming years, which is based on the Research & Development Roadmap. These two publications give the European Commission an indication of the areas in which the EU will need to provide research funding to meet upcoming challenges. The RDIC also serves to connect European TSOs when it comes to exchanging research information and forming research alliances.

# Research areas

## APG has defined four basic areas of research:

- > Network development and energy market scenarios
- > Weather, climate and the environment
- > Network monitoring and system management
- > Digitalisation

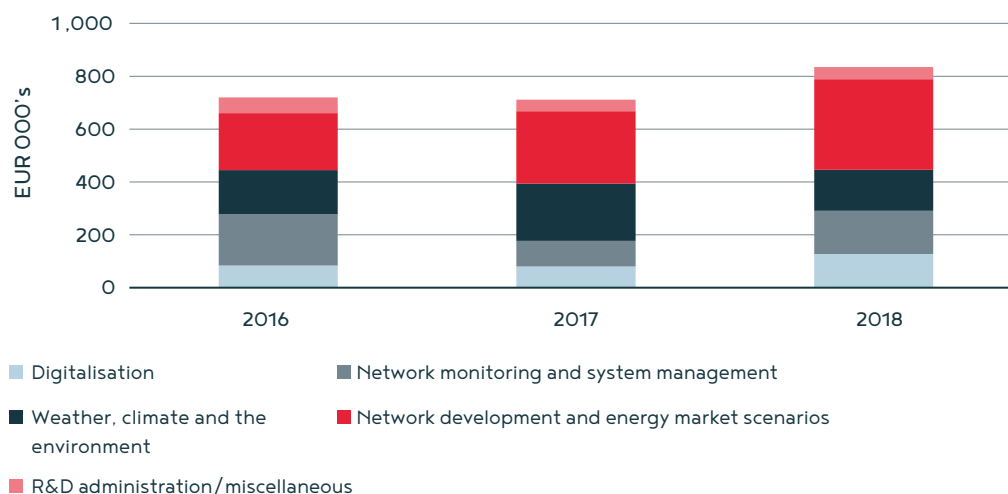
APG's research activities are based on these four areas of research, which provide a manageable framework for monitoring and documenting individual research projects. Over the past three years, APG has invested approximately EUR 750,000 in research projects. The following table presents the main figures relating to APG's research activities.

### Research expenditure 2016–2018

Year	2016	2017	2018
Total number of projects	26	24	21
Number of ongoing projects	13	12	15
Number of completed projects	13	12	6
Annual expenditure in EUR	719,362	711,737	835,186

The chart below shows the changes in research expenditure between 2016 and 2018, broken down into the four areas of research.

### Research expenditure 2016–2018





### Network development and energy market scenarios

As a transmission system operator (TSO) and control area manager, APG is required to operate, maintain and develop the Austrian transmission system safely, reliably, efficiently and with due regard to environmental protection. The energy transition and the massive expansion of renewable energies – especially wind, solar and hydropower – are creating new challenges for network integration and system stability. Coordinated development of the network infrastructure at a European level requires careful planning based on scientific considerations. In addition to developing new methodologies for analysing future scenarios, it is extremely important that relevant topics in the areas of system analysis/network planning, energy market simulation and regulatory issues be dealt with in a coordinated manner Europe-wide.

### Weather, climate and the environment

Infrastructure projects always entail an intrusion in the environment in which people live as well as in ecological systems. That's why APG works continuously to optimise the animal and plant habitats in the vicinity of its installations by creating new living environments for endangered species. Numerous projects are being implemented under that premise. APG's installations are also exposed to extreme weather conditions (severe storms and/or heavy winds), which can have a major impact on grid operation, risk management, crisis management and troubleshooting. That's why research at APG also covers extreme weather events in order to prevent possible damage to plants on the one hand and to be able to respond even more quickly in the event of malfunctions on the other. Weather also plays a major role in the context of forecasting generation from renewable energy sources.

### Network monitoring and system management

Due to developments in the area of renewable energies and changes in the market environment, power grids are increasingly being operated at the limits of their capacity. Critical load flow situations and network congestion necessitate adjustments to power plant schedules (redispatch) and disrupt intraday electricity trading. TSOs are facing increasing challenges in reconciling generation and demand patterns with time and location constraints. All options for optimising grid operation are taken advantage of to protect the system from destabilising factors. New processes are being researched and existing processes optimised in cooperation with universities, other European TSOs and commercial enterprises.

### Digitalisation

Digitalisation is one of the megatrends of our time, and one that impacts APG to a great degree. Digital innovation is opening up new possibilities for operating transmission grids such that they are both stable and efficient. Big data analytics can be used to help identify patterns hidden in large quantities of data as well as unknown correlations and other useful information. All of APG's grid elements are already equipped with sensors that enable a real-time overview of APG's infrastructure status. Along with the vast advantages arising from steadily growing data quantities, this also brings stricter requirements for information security in order to protect IT systems and operational technology systems (used to directly control physical components) from cyber attacks.

# Development of low-noise overhead line conductors

## Research area: Network development and energy market scenarios

- > Contact persons: Dipl.-Ing. Michael Leonhardsberger, Dipl.-Ing. Oskar Oberzaucher
- > Project duration: 2014–2017
- > Coordination: APG
- > Objective: to develop a low-noise conductor to reduce the noise emissions produced by corona discharge of overhead line conductors
- > Project partners: Lumpi-Berndorf Draht- und Seilwerk GmbH; Graz University of Technology - Institute of High-Voltage Engineering and System Performance; iC consulenten Ziviltechniker GesmbH
- > External funding: none

In rainy weather conditions, overhead line conductors produce corona noise when surface field strength is high, as is the case for 220-kV and 380-kV lines. The corona effect on the conductors can be reduced with a hydrophilic surface coating. Up to now, glass bead blasting technologies have been used to coat the surface of overhead line conductors to impart hydrophilic surface characteristics for noise reduction purposes. Some projects, however, may require application of a colour coating to the conductors so the overhead lines will blend into the landscape. Up to now, it has been necessary to choose between reducing corona

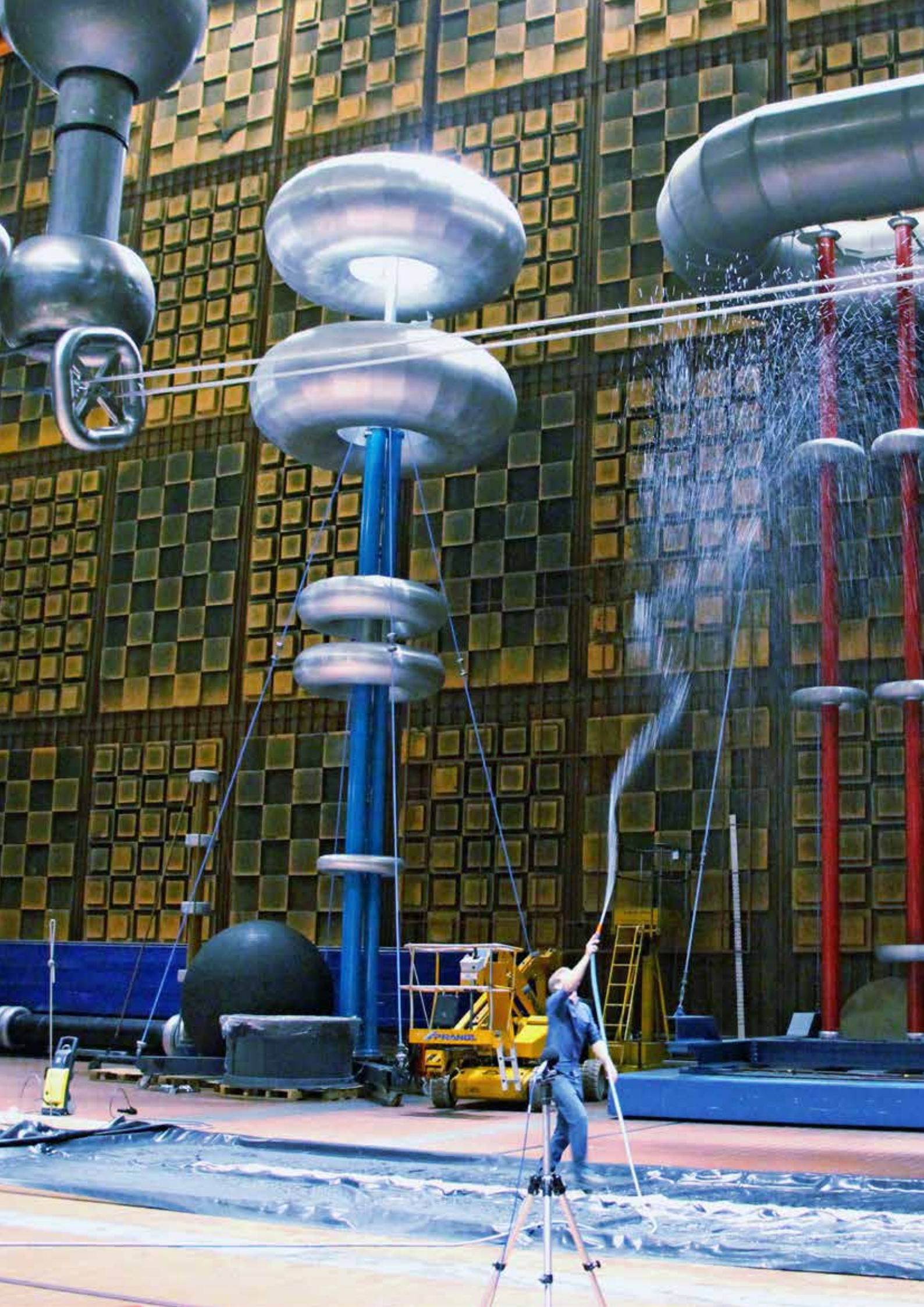
noise by bead blasting the conductors or reducing their visual impact by treating them with a colour coating. Hydrophilic coating solutions enable these two advantages to be combined.

To further reduce noise emissions, plastic fillings were used to increase the diameter of a conductor without significantly increasing the weight in addition to the coating of the conductors with a hydrophilic film. Increasing the diameter of a conductor reduces the surface field strength and thus corona noise emissions.

The project to reduce noise emissions from overhead line conductors (by combining a hydrophilic coating with the enlarged conductor diameter) resulted in development of a conductor capable of reducing noise emissions arising from corona discharge. The project was part of a research alliance with Lumpi-Berndorf Draht- und Seilwerk GmbH, Graz University of Technology - Institute of High Voltage Engineering and System Performance, and iC consulenten Ziviltechniker GesmbH. Empirical evidence of the effectiveness of the conductors in reducing noise emissions was gathered in tests carried out at the high-voltage laboratory of the Graz University of Technology's Institute of High Voltage Engineering and System Performance.











More information:



EnInnov2018



EnInnov2016



The conductors were also tested in practical trials by replacing the existing conductor on a 1.2 km-long line section with the low-noise conductor.

The project findings have been included in several publications and presented at industry conferences (publication for CIGRE's 2016 and 2018 sessions; 2016 CIGRE SEERC Conference; 14th and 15th Energy Innovation Symposiums of the Graz University of Technology).

In the future, it will be possible to use low-noise overhead line conductors in new build projects and when replacing lines (conductors) in environmentally sensitive areas.

## Research results

- > Evidence and quantification of the ability of hydrophilic coated conductors with an enlarged diameter to reduce corona noise in both laboratory testing and field trials
- > Evidence of the potential for industrial production of conductors that use plastic cored wire to increase conductor diameter and for application of the conductors in standard fittings of overhead line structures
- > Definition of quality criteria for hydrophilic coatings for overhead line conductors
- > Test of durability of the coatings and the conductor structure (both during assembly and long-term behaviour)
- > Publication of the research results
- > Findings concerning the use of conductors equipped with a hydrophilic surface coating in new build projects and when replacing lines (conductors)

# Analysis of energy market scenarios

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## Research area: Network development and energy market scenarios

- > Contact persons: Dipl.-Ing. Klemens Reich, Dipl.-Ing. Stefan Führer
- > Project duration: 2010–2016
- > Coordination: APG
- > Objective: to develop long-term scenarios for the Austrian energy market
- > Project partners: TU Vienna and TU Graz
- > External funding: none

APG's long-term strategic planning, its 2030 Master Plan and its Network Development Plan are all based on detailed analyses of the energy market environment and the scenarios building on those analyses, with a time frame until 2030 and an outlook for 2050. The analyses and scenarios were developed by APG in cooperation with the Vienna University of Technology (TU Vienna)

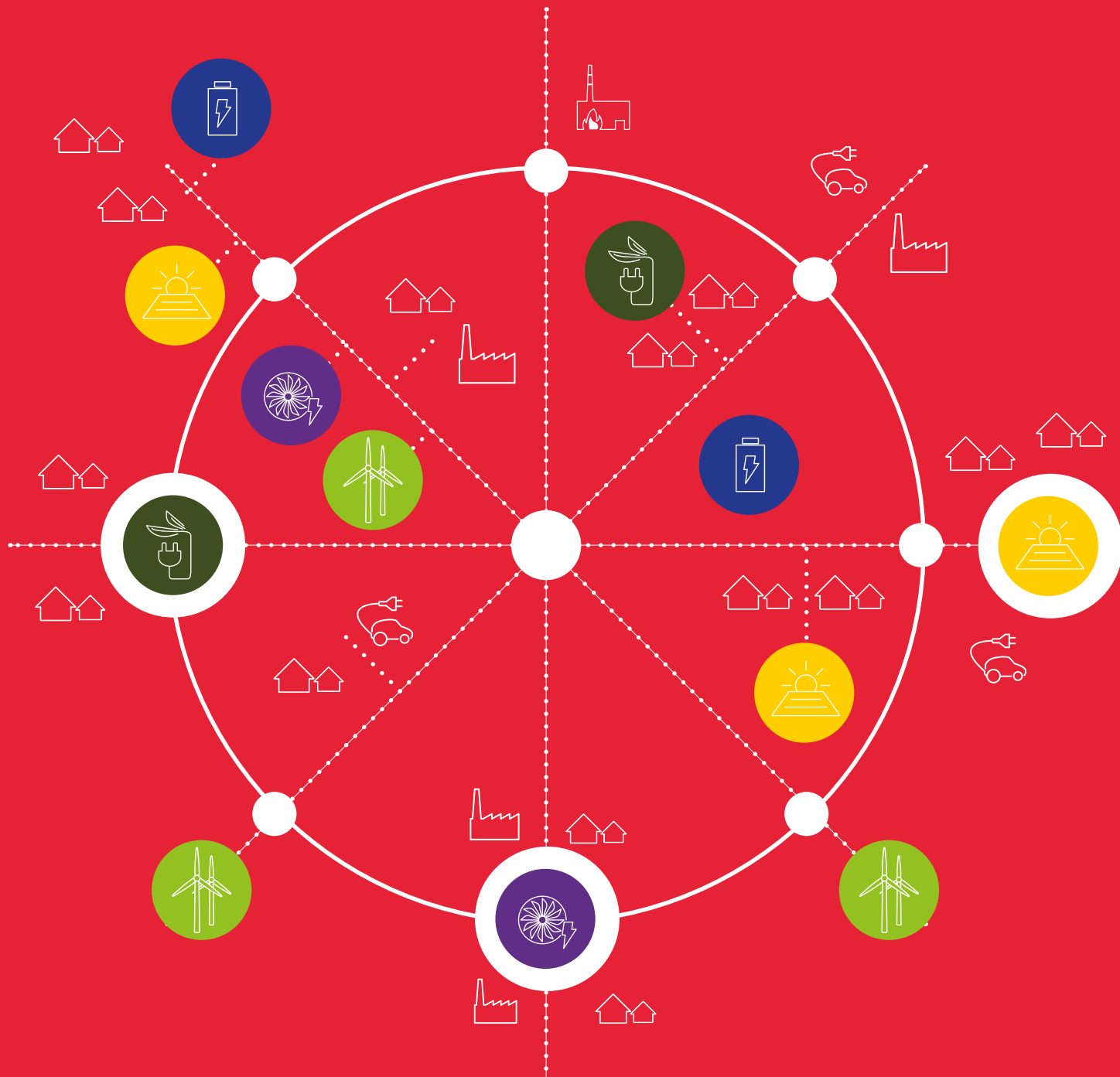
and the Graz University of Technology (TU Graz). The findings enabled an assessment of future developments in the energy market based on a variety of parameters, such as the degree of renewable energy development in Austria and the neighbouring countries, the cost of primary energy, the capacity of the European transmission grid, etc. The assessments were made in cooperation with the aforementioned universities on the basis of current scientific and technological advances. TU Vienna, for example, incorporated the latest findings in the area of photovoltaics (new developments in efficiency, building integration, etc.). The simulations were carried out using a state-of-the-art simulation model developed by TU Graz to model the behaviour of individual market participants.

## Research results

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The results of the simulations supplied detailed information on future grid utilisation and identified where improvements to the network infrastructure were necessary, which were then analysed to determine their effects on security of supply and the electricity market. Along with the Master Plan and APG's 2013–2015 Network Development Plans, the results of the research alliance were used as supporting documentation on the energy market when seeking official approval for line construction projects (e.g. in the EIA approval process for the Salzburg line). The project findings also represent a significant advance in expertise, which can be applied to ongoing optimisation and improvement of network simulation processes at both Austrian and European level (joint working group with other European TSOs via ENTSO-E, including for ENTSO-E's Ten-Year Network Development Plan – TYNDP). A sound assessment of future developments is the basis for many types of energy market projections. The long-term alliance with TU Vienna and TU Graz has enabled the scenarios developed to be constantly improved and adapted to reflect current developments.





WIND POWER  
GENERATION



FUEL CELL



SOLAR POWER  
GENERATION



BIOMASS  
WITH CHP



MICRO GAS TURBINE  
WITH CHP



PRIVATE  
HOUSEHOLDS



INDUSTRY



CONVENTIONAL  
POWER PLANTS



E-MOBILITY

More information:



EnInnov2018

# The impact of solar winds on Austria's high-voltage power grid

## Research area: Weather, climate and the environment

- > Contact person: Dipl.-Ing. Dr. Georg Achleitner
- > Project duration: 2014–2017
- > Coordination: APG
- > Objective: to research the correlation between the Earth's magnetic field and the occurrence of geomagnetically induced currents in Austria's high-voltage transmission system
- > Project partners: the Central Institute for Meteorology and Geodynamics (ZAMG – Zentralanstalt für Meteorologie und Geodynamik) in Vienna; TU Graz – Institute of Electrical Power Systems; the VRVis virtual computing research centre (Zentrum für Virtual Reality und Visualisierung); the Geodetic and Geophysical Institute – Research Centre for Astronomy and Earth Sciences; the Hungarian Academy of Sciences; the Geological Survey of Austria (GBA – Geologische Bundesanstalt) in Vienna; the British Geological Survey; the Geological Survey of Norway
- > External funding: Austrian Research Promotion Agency (FFG – Österreichische Forschungsförderungsgesellschaft mbH)/Austrian Space Applications Programme (Project Geomagica)

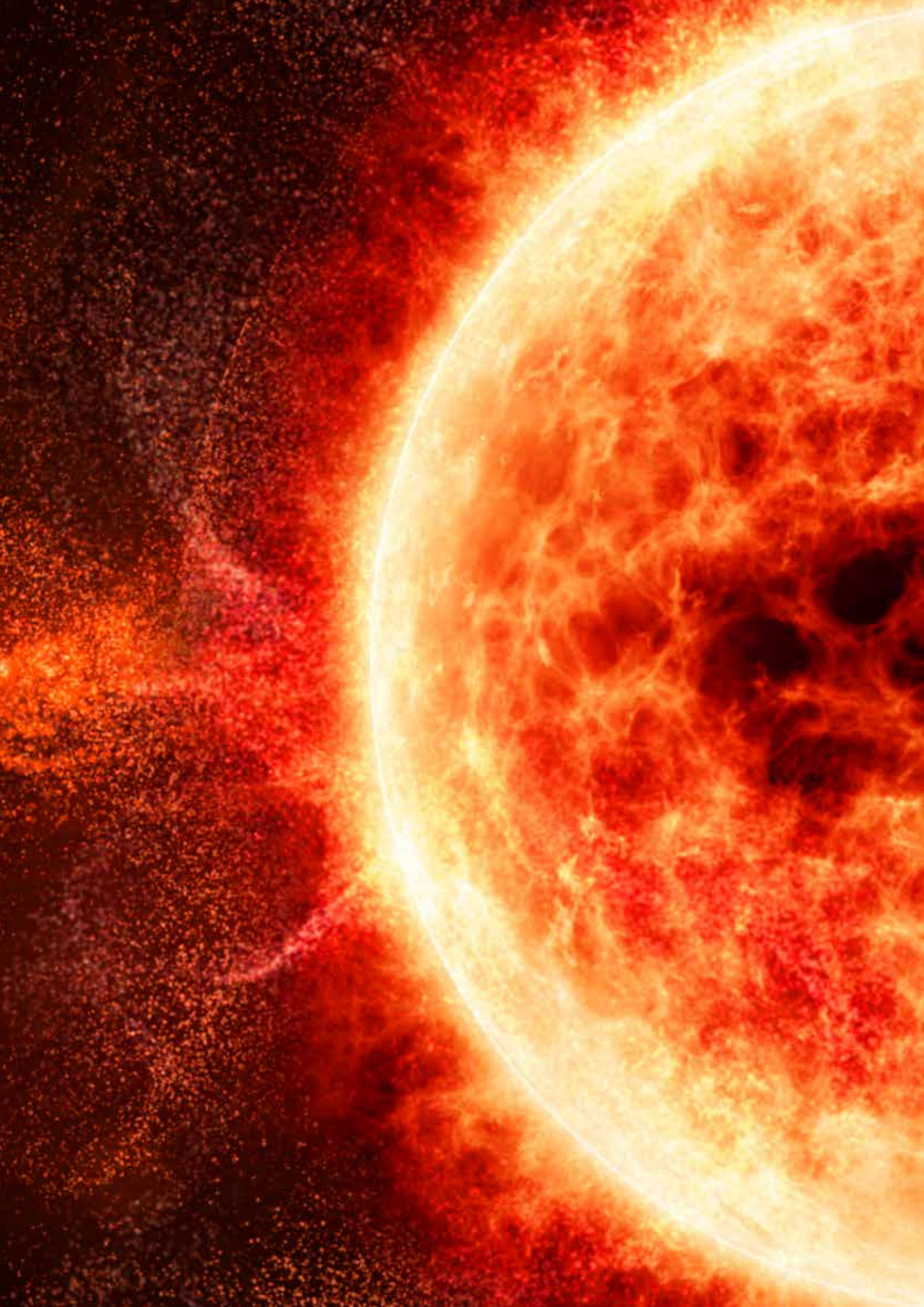
In cooperation with various research organisations (ZAMG, TU Graz, etc.),

APG conducted extensive investigations which found that direct currents (DC) were flowing through APG's high-voltage and extra-high voltage transmission grid. Direct currents can cause transformers to malfunction. The direct current voltages were discovered to be caused by disturbances in Earth's magnetic field. Solar winds, for example, are known to cause major geomagnetic disturbances. It was determined that the direct current voltages occurred most frequently when solar winds were present. Over the course of several years, a number of projects were initiated to research the correlation between Earth's magnetic field and the occurrence of direct currents (primarily at transformer neutral points). The projects resulted in two dissertations, among other things.

### Preliminary projects: investigating DC in transformers (Transformer DC I and Transformer DC II)

Neutral point currents occur in high and extra-high voltage systems, especially in the case of low-resistance grounded networks in normal operation. The direct current/very low frequency component of neutral point currents can in some cases overload the magnetic circuit of the transformer and negatively impact operations (corona loss, noise emissions, etc.). This project involved a scientific investigation and analysis of the occurrence and characteristics of neutral point currents.







Based on the results of the Transformer DC I project, the Transformer DC II project focused on the installation of a system to measure direct current in transformers for analysis and evaluation purposes. The objective was to install an Austria-wide system for measuring direct current – the only one of this magnitude in Central Europe. The measurement results were input into Project Geomagica, which analysed the correlation between the geomagnetic field and direct current in high and extra-high voltage transmission systems. The measurement system is constantly updated to improve the accuracy of the results.

#### **Calculation of geomagnetically induced currents: Geomagica – Geomagnetically induced currents in Austria**

Led by the Central Institute for Meteorology and Geodynamics and funded by the Austrian Research Promotion Agency, the project involved computing geomagnetically induced currents (GICs) in APG's high-voltage power grid. An investigation of geological conditions in Austria was conducted up to great depths, where GICs normally occur. The results were used to develop a model of the ground, which also incorporated existing lines, and to compute the currents. A major factor in the success of the project was that it was possible to use the measurement results gathered Austria-wide in the Transformer DC II project as reference points and as a basis for modelling.

#### **Measurement, analysis and evaluation of geomagnetically induced currents**

The Central Institute for Meteorology and Geodynamics carried out magnetotelluric measurements able to detect GICs at the Southeast Vienna substation. This was the first time such measurements had been conducted in Austria. In connection with Project Geomagica, the intention was to improve understanding of direct currents in the high-voltage transmission system in order to better comprehend the occurrence of geomagnetically induced currents at substations and thus enable preventative stabilisation measures to be taken.

The project showed that it is possible in principle to measure geomagnetic fields. However, it is preferable to do so outside of heavily populated areas due to the sensitivity of the measurement setup.

#### **Introduction of a solar wind early warning system**

Based on the results of Project Geomagica, which confirmed the correlation between direct currents flowing through high-voltage transmission lines and solar winds, a solar wind early warning system was developed especially for APG in the context of the project. The system issues an early warning on the basis of satellite data in combination with theoretical considerations. The only one of its kind in the world to date, the solar wind early warning system is crucial for APG in terms of allowing measures to be taken promptly in the event of severe space weather events.



## Research results

- > The investigations succeeded in proving the existence of geomagnetically induced direct current in APG's extra-high voltage transmission system.
- > A solar wind early warning system was implemented by the Central Institute for Meteorology and Geodynamics and is already in trial operation.
- > The research results will be used as the basis for conducting additional investigations aimed at deriving new information relevant to the operation of transmission grids and developing a targeted action plan to be implemented in the event of very high levels of direct current voltages.
- > The project findings will flow into the descriptions of tenders for new transformers in the high-voltage network and thus serve to increase network stability.

APG has published a number of international papers in this field together with the cooperating research institutes.

## More information:

- > Halbedl, T.; Renner, H.; Achleitner, G. (2018). Geomagnetically induced currents modelling and monitoring transformer neutral currents in Austria. *e&i – Elektrotechnik und Informationstechnik*, 135(8), pp. 602–608. <https://doi.org/10.1007/s00502-018-0665-9>
- > Bailey, R.; Leonhardt, R. (2017). Predicting the root-mean-square of expected GIC from satellite data with recurrent neural networks
- > Bailey, R. L.; Halbedl, T. S.; Schattauer, I.; Achleitner, G.; Leonhardt, R. (2018). Validating GIC Models With Measurements in Austria: Evaluation of Accuracy and Sensitivity to Input Parameters.



Conrad Observatorium



Space weather



# Forecasting photovoltaic output using weather-driven supply and demand analyses

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## Research area: Weather, climate and the environment

- > Contact person: Dipl.-Ing. Christoph Karner
- > Project duration: 2015–2017
- > Coordination: APG
- > Objective: to develop a forecasting tool that uses high spatial resolution to forecast the output of photovoltaic installations in the APG control area
- > Project partner: JOANNEUM RESEARCH Forschungsgesellschaft mbH
- > External funding: none

APG cooperated with Joanneum Research to improve output forecasts for photovoltaic (PV) installations in Austria as part of a research project entitled “Weather-Driven Demand and Supply Analysis-Based PV Output Forecasts”, or PVWeddas for short.

The project objective was to assess the potential for improving forecast quality by using high spatial resolution to forecast photovoltaic output in Austria for local areas or individual plants rather than across widespread geographical regions.

### Methods and procedures

The PV forecasting models were calibrated using satellite data on global radiation and temperature forecasts from AROME. The models were validated using AROME forecasts of global radiation and temperature based on a high spatial resolution (2.8 km x 2.8 km). Spatial aggregation was also optimised, which significantly improved the forecast results. A spatial resolution of 170 km x 170 km was found to be the most efficient.





## Research results

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The investigations showed that implementing high spatial resolution forecasting resulted in an annual NRMSE of 5.84%. This represents an improvement of 1.54% compared with the previous forecasting error rate of 7.38%. The values specified apply to the period from February 2015 to January 2016, to all PV installations where load profile meters are used to measure output and to the day-ahead forecast horizon (+24 to +48 hours). This corresponds to APG's own basis for forecasting PV output.

The project was expanded in 2017 to examine whether temporal aggregation of global radiation data would further improve forecast quality. However, this did not prove to significantly reduce forecasting errors.



# Electric fields induced in the human body, part II

## Research area: Weather, climate and the environment

- > **Contact persons:** Dipl.-Ing. Dr. Katrin Friedl, Dipl.-Ing. Klemens Reich
- > **Project duration:** 2017–2018
- > **Coordination:** APG
- > **Objective:** to simulate and analyse the effects of interference from electric and magnetic fields in the assessment of exposure based on exposure thresholds
- > **Project partner:** Seibersdorf Labor GmbH
- > **External funding:** none

The impact of electric and magnetic fields on the human body varies depending on the intensity of the field, for which reason Guideline R 23–1 issued by the Austrian Electrotechnical Association (OVE-Richtlinie R 23–1) requires that thresholds be adhered to for the general population. Exposure to both types of fields often occurs in the vicinity of overhead lines.

Guideline R 23–1 requires the total exposure quotient (TEQ, equal to the sum of the quotients for the electric field and the magnetic field) to be taken into

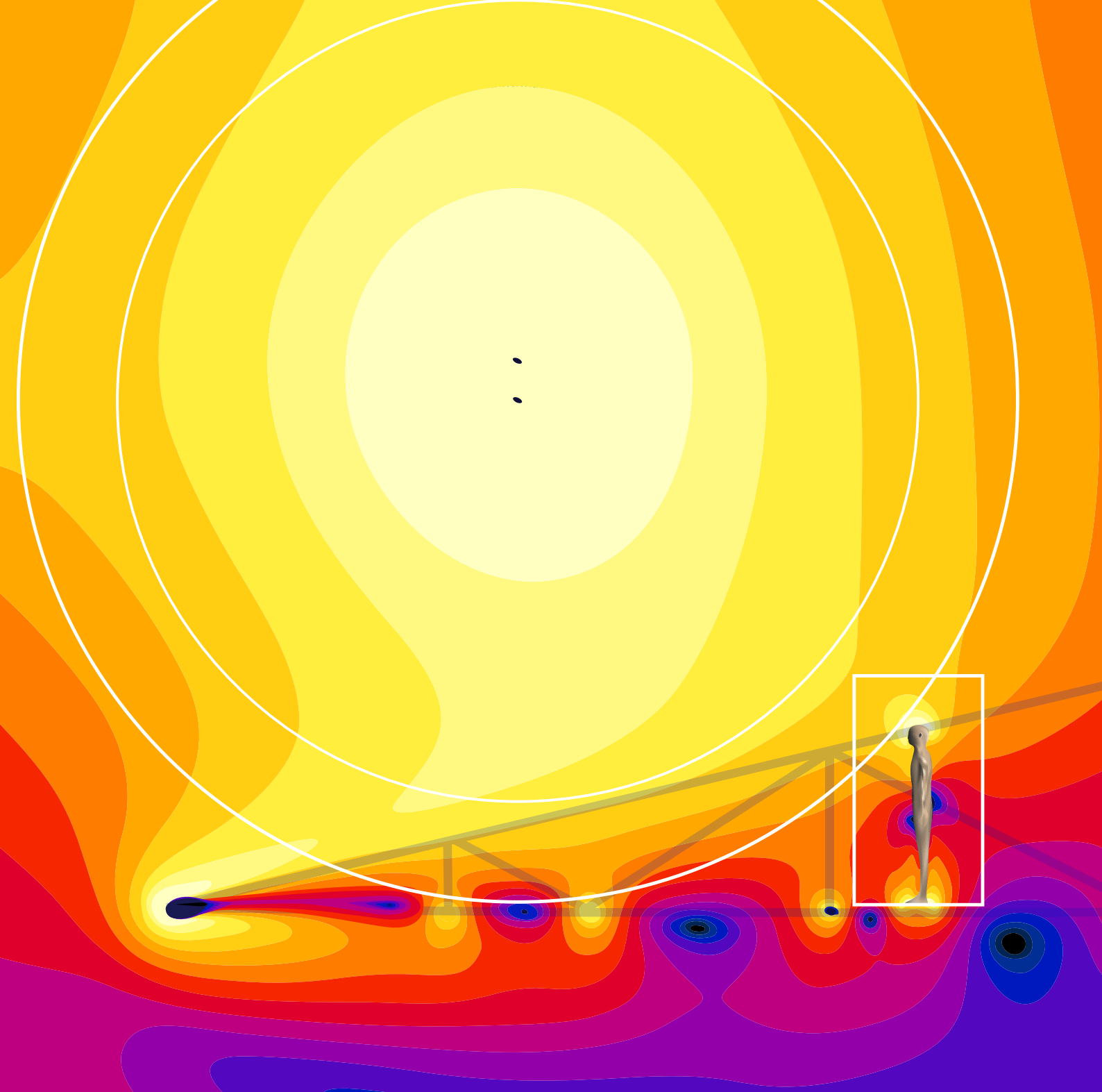
account when both electric and magnetic fields are simultaneously present. Alternatively, calculations can be provided to show that the thresholds from which the reference values for the strength of fields outside the human body were originally derived have not been exceeded. The research project dealt with the complex calculations for arriving at such reference values.

The numerical calculations were based on a complex, medical model of the human body in a resolution of 1x1x1 mm that models all human organs and tissue types. The extensive simulations involved exposing various parts of the human body to electric and magnetic fields and evaluating the results in terms of thresholds for the human body, which are likewise specified in Guideline R 23–1. The simulations also took different field/body alignments into account and therefore covered a number of real-life exposure scenarios.

## Research results

As an alternative to the TEQ, the aforementioned R 23–1 guideline permits the use of simulations to collect evidence of complex exposure situations. Current models of the human body and simulation methodologies were used to prove that exposure threshold limits for the general populations were being adhered to in the vicinity of transmission lines, even when electric and magnetic fields occur simultaneously.





## More information:

- > Hirtl, R.; Schmid, G.; Friedl, K. Expositionsbewertung in Hochspannungsanlagen – Numerische Berechnungen der im Körper induzierten elektrischen Feldstärke für unterschiedliche praxisrelevante Expositionsszenarien;
- > Presentation: NIR 2018: Wellen – Strahlung – Felder, 50th anniversary of Fachverband für Strahlenschutz e. V., Dresden; 3 September 2018 – 6 September 2018; in: NIR 2018: Wellen – Strahlung – Felder, (2018), ISSN: 1013-4506; pp. 585-599.



Annual Meeting  
2018 of the German-  
Swiss Association for  
Radiation Protection,  
Dresden (German only)



# Improved modelling and measuring techniques in the Austrian high-voltage power grid

## Research area: Network monitoring and system management

- > Contact person: Dipl.-Ing. Dr. Georg Achleitner
- > Project duration: 2012–2017
- > Coordination: APG
- > Objective: to develop improved modelling and measurement techniques for analysing the behaviour of substations in the case of transient events
- > Project partner: TU Graz – Institute of High-Voltage Engineering and System Performance
- > External funding: none

One of the challenges of dealing with high-voltage technology is gathering information on transient events. Due to the increase in the number of switching operations in the transmission grid in recent years, the recording and analysis of transient events has come to play a greater role. Modern measurement techniques are often accompanied by theoretical analyses. To this end, a number of projects were initiated in cooperation with TU Graz for the purpose of developing improved modelling and evaluation techniques and using measurement data to evaluate those techniques.

### Using capacitive voltage dividers to measure transient events

Special equipment is needed to measure transient events. For instance, ohmic-capacitive voltage dividers are used to record transient voltages. When using the dividers for measurement purposes, it proved to be extremely tricky to connect a measurement system to the ohmic-capacitive voltage dividers. No interfering signals can be present when conducting the delicate measurements needed to record very short-lived transient events. The project led to the development of a system that enables measurement devices from different manufacturers to be securely connected to the capacitive dividers. The system was designed on the basis of theoretical considerations and tested using real-world measurements.

No such measurement system was available on the market at the time the system was conceived.

The project also extended to various measurements that are already carried out in practice. This involved measuring, analysing and evaluating transient events at substations. Synchronous but







spatially separated measurements were conducted to gain unique information on transient events such as line switches, transformer on/off switching processes, atmospheric discharges across all of Austria, and short circuits.

At the Kainachtal substation, the measurements were conducted with a special focus on atmospheric discharge near Koralm. The project data enabled unique research advances to be made in the “Alpine Lightning” research project in subsequent years. At the Vienna South-east substation, the transient behaviour of a transformer was investigated. At the Tauern and Obersielach substations, the measurements were used to check suspected incidents of switching overvoltages.

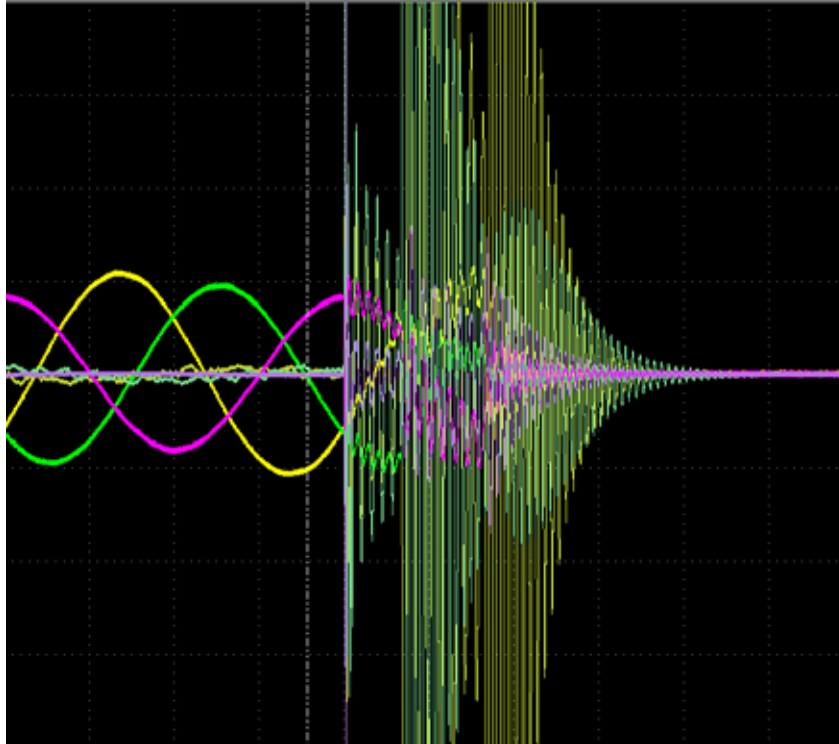
#### **Ferroresonances – modelling and calculating resonance phenomena in high-voltage networks**

Network configuration processes and switching operations in high-voltage networks can have resonance effects,

which can cause transient overvoltages in power system components. Resonant overvoltages are a particularly common occurrence when unloaded transformers are connected to a busbar idle.

The causes of resonant overvoltage were investigated with the help of modern numerical calculation tools. The project therefore dealt with the fundamental causes of resonant overvoltages in transmission grids, defining and calculating resonance effects and coming up with suggestions to alleviate the problem. Investigations were limited to 110-kV and 220-kV substations.

It was found that the resonance phenomena were primarily attributable to ferroresonances, and that experimental measurements of such resonances could be conducted using high resolution techniques.



## Research results

- > Valuable information about the transient behaviour of switching stations was gained and is already being used in the design of new systems.
- > Several capacitive dividers were purchased to improve overall understanding of transient behaviour.
- > The project findings were used to validate and improve the calculation models.

## More information:



High-Voltage Institute  
of TU Graz

# Short-circuit testing at the Hessenberg and Rosenau substations

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## Research area: Network monitoring and system management

- > Contact person: Dipl.-Ing. Dr. Georg Achleitner
- > Project duration: 2010–2018
- > Coordination: APG
- > Objective: to develop techniques for earth faults localisation when earth faults or short circuits occur in the network
- > Project partners: TU Graz, Energienetze Steiermark, Ennskraft, Artemes, Innovation Consult Dr. Hauer, Omicron, Energie AG
- > External funding: none

Line-to-ground or multiple phase-to-phase faults occur frequently in high-voltage and extra-high voltage networks. These faults can be caused by a variety of issues, including simple earth faults or high-voltage short circuits. In resonant grounded networks earth faults do not disrupt the power supply, whereas short circuits result in outages. The first part of the project series

focused on testing earth fault localisation and hence the various measurements involved in testing for earth faults.

Due to the various measures being carried out in 2018 to upgrade the transmission grid, APG's research activities that year focused on short circuit testing. Outdoor substations that had already been decommissioned were used as "real-life" testing laboratories for the trial configurations carried out at the Hessenberg and Rosenau substations in autumn/winter 2018.

### Earth fault localisation, earth fault testing and measurements in earth fault testing

Resonant grounding is used in the operation of 110-kV networks. Due to the manner in which such networks function, it is possible that they will continue to operate even after the occurrence of single line-to-ground faults. Normally,



around 90% of all faults extinguish by themselves. The rest remain in the network as stationary earth faults and must be localised via switching operations.

The earth fault localisation project aimed to accelerate fault localisation to enable key information on how to correct the fault to be quickly supplied to operating personnel and the line team. The research project was based on a dissertation by Dipl.-Ing. Dr. Georg Achleitner, an APG employee, which showed that it is possible in principle to adapt existing distance protection equipment for use in earth fault localisation.

In the course of the project, prototypes from three manufacturers were installed on a line for test purposes. All of the tests conducted confirmed the applicability of distance protection equipment to fault localisation. The manufacturers will now develop units for mass production for use by APG and, presumably, worldwide.





### Short-circuit testing at the Hessenberg and Rosenau substations

From 1 to 3 October 2018, short circuit testing was performed on the 110-kV system of the Hessenberg substation. The objective of the tests was to validate the results of short circuit current calculations and short circuit force calculations and to expand on those calculations.

This was the first time that APG was able to test short circuit currents in a real system rather than in a laboratory setting. The idea was to model short circuit current forces and impacts and to conduct high-resolution, precise measurements of those forces and impacts. The testing

was possible because Energienetze Steiermark GmbH, to which the system was handed over, had completed its rebuild of the substation with conversion to gas-insulated switchgear (GIS).

Renowned manufacturers of busbar protection devices (Andritz, Schneider Electric, Siemens) were involved in the testing. They tested new protection devices under real-world conditions with high-voltage short circuit currents. The tests clearly indicated how important it is to use the protection devices to quickly locate faults and showed the benefits busbar protection devices offer in terms of rapid fault detection. It was moreover proven that high-voltage short circuit currents have a major impact

on instrument transformer saturation, which, however, was detected by all protection devices. Despite the high level of saturation, all of the protection devices tested were able to detect all faults without error. The Technical University of Graz additionally tested the internal arc quenching behaviour of line switches.

stress testing was performed on the high-voltage system to supplement the electrical tests conducted in Hessenburg. The mechanical stress tests delivered interesting and informative findings regarding the design of substations.

At the Rosenau substation, mechanical

## Research results

The tests delivered valuable input regarding the design of new systems and protection concepts as well as information on temporary measures for improving short circuit resistance. The findings will also flow into training programmes for new employees since it is now possible to impart knowledge based on real-world experience.

### Mechanical testing results:

- > Correct dimensioning of the system is essential.
- > Even old systems can be improved (e.g. semiconductor spacers).

### Electrical test results:

- > Illustrated the importance of rapid emergency shutdown to minimise fault impact.
- > Residual currents only amounted to 3 kA in testing. Although residual currents can reach much higher levels in actual operations, APG's substations are already designed to handle currents of up to 80 kA.
- > Tests of real fault incidents confirmed the calculations of simulated currents.

## More information:



Localising earth faults  
now easier with new  
measuring device  
(German only)



Video: Research  
under high voltage



# DC fault localisation

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## Research area: Network monitoring and system management

- > Contact person: Dipl.-Ing. Dr. Georg Achleitner
- > Project duration: 2015–2017
- > Coordination: APG
- > Objective: to develop a circuit assembly for locating insulation faults in battery systems
- > Project partners: TU Graz, Sprecher Automation
- > External funding: none

Substations have battery systems to ensure security of supply. Such systems are susceptible to earth faults, also known as insulation faults. At present, insulation faults in battery systems are usually

located by systematically shutting down individual branches one by one. However, this method puts a great deal of stress on the systems' DC switches and creates potential risks for APG's operating personnel. Frequent on/off switching can also lead to malfunctions in control units. The aim of this research project was to create a circuit assembly for locating insulation faults that is simple, reliable, precise and cost-effective and that can be implemented as independently as possible.

## Research results

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In cooperation with TU Graz, a circuit assembly was developed that uses differential measurement to enable precise identification of branches. This permits high-impedance insulation faults to be detected, which was not possible in the past. The process was developed as a passive system, meaning that the battery system is not actively impacted.

The concept was developed in cooperation with TU Graz and has been successfully patented in the meantime. Sprecher Automation, an innovative company domiciled in Linz, acquired the licencing rights and developed a product that is now distributed worldwide.

This project is a very successful example of cooperation between transmission system operators, universities and industry.

Research results: patent EP2796886 (A1)

Outlook: In addition to using a stationary assembly to locate faults, a mobile version of the measurement system is planned.



## More information:



Isolation monitoring &  
earth fault detection



Circuit assembly for  
locating insulation faults







# Drones at work for APG

## Research area: Network monitoring and system management

- > Contact persons: Ing. Paul Zachoval, Ing. Rainer Wagenhofer (B.A.)
- > Project duration: 2012–2019
- > Coordination: APG
- > Objective: to operate and evaluate unmanned aerial systems (UASs) to support APG's business processes
- > Project partners: Smart Digital Concepts – SDC; Austro Control

Unmanned aerial systems, or UASs for short, are pilotless flight systems (drones) used to collect and evaluate data. APG has used such systems in the maintenance of its power grid since 2012. The systems undergo constant assessment and development, which in combination with the contributions from employees based on their experience in the development process has enabled two concrete use cases to be specified for APG's current operations:

### 1) Spot inspections of system components used in high-voltage overhead lines

APG's power lines are electronically monitored at all times. In addition, the route corridors through which the overhead lines run are inspected twice per year by a team responsible for ongoing monitoring. In some cases, the exposed position of the transmission towers makes it extremely difficult for the specialists on APG's line team to take a close look at every component. That's why a total of four quadcopters were purchased in 2019 to support employees in this task. Each copter is equipped with a high-resolution camera that transmits a

live feed directly to the personnel on the ground, thus permitting them to make an immediate assessment of the condition of the tower component in question. The use of drones therefore improves the quality and efficiency of the condition assessment process and especially improves employee safety.

### 2) Beyond visual line of sight (BVLOS) flights in the transmission grid

With a route length of approximately 3,800 kilometres, APG's transmission grid forms the backbone of the Austrian power supply. The BVLOS project aims to test unmanned drones beyond the line of sight for the first time in Austria. Lightweight, propeller-driven fixed-wing drones manufactured by SDC with a wingspan of 3–4 metres are used to undertake flights of up to 100 km without landing. The flight path is determined by the GPS coordinates of the transmission towers and is programmed in before initiating the flight. Once the drone is in the air, it follows the programmed flight path and makes course corrections and altitude adjustment automatically. A high-resolution ground-facing camera automatically photographs the power lines as it flies over them and sends the images back to the ground station for evaluation. Development of the system is expected to assist in reducing the time needed to put systems back online after malfunctions caused by severe weather in particular.

## More information:



Video: Game of Drones



Video: Flying assistants

# ABS for the Power Grid: ABS4TSO

## Research area: Network monitoring and system management

- > **Contact person:** Michaela Leonhardt, Ph.D.
- > **Project duration:** 2018–2021
- > **Project coordinator:** APG
- > **Objective:** to examine how battery storage and other fast-response systems can contribute to maintaining security of supply by balancing out fluctuations in grid frequency with highly dynamic services
- > **Project partners:** Austrian Institute of Technology (AIT), Technical University Vienna, VERBUND
- > **External funding:** EUR 1.8 million has been provided by the Austrian Climate and Energy Fund under its Energy Research Programme

The growing share of renewable energy in Europe's power supply in combination with the decreasing use of thermal power plants is fundamentally transforming the dynamic behaviour of the entire power supply system. Fluctuations in power grid frequency arise more often due to decreasing system inertia, rising volatility and geographical concentrations of energy suppliers – trends that will continue in the future. However, these trends can be counteracted by suitable activation of highly dynamic balancing services.

This is where the ABS4TSO project comes in. The project focuses on examining both demand for and the requirements placed on new, highly dynamic system services to ensure

frequency stability. That's also why the project bears the name ABS4TSO, which stands for Advanced Balancing Services for Transmission System Operators.

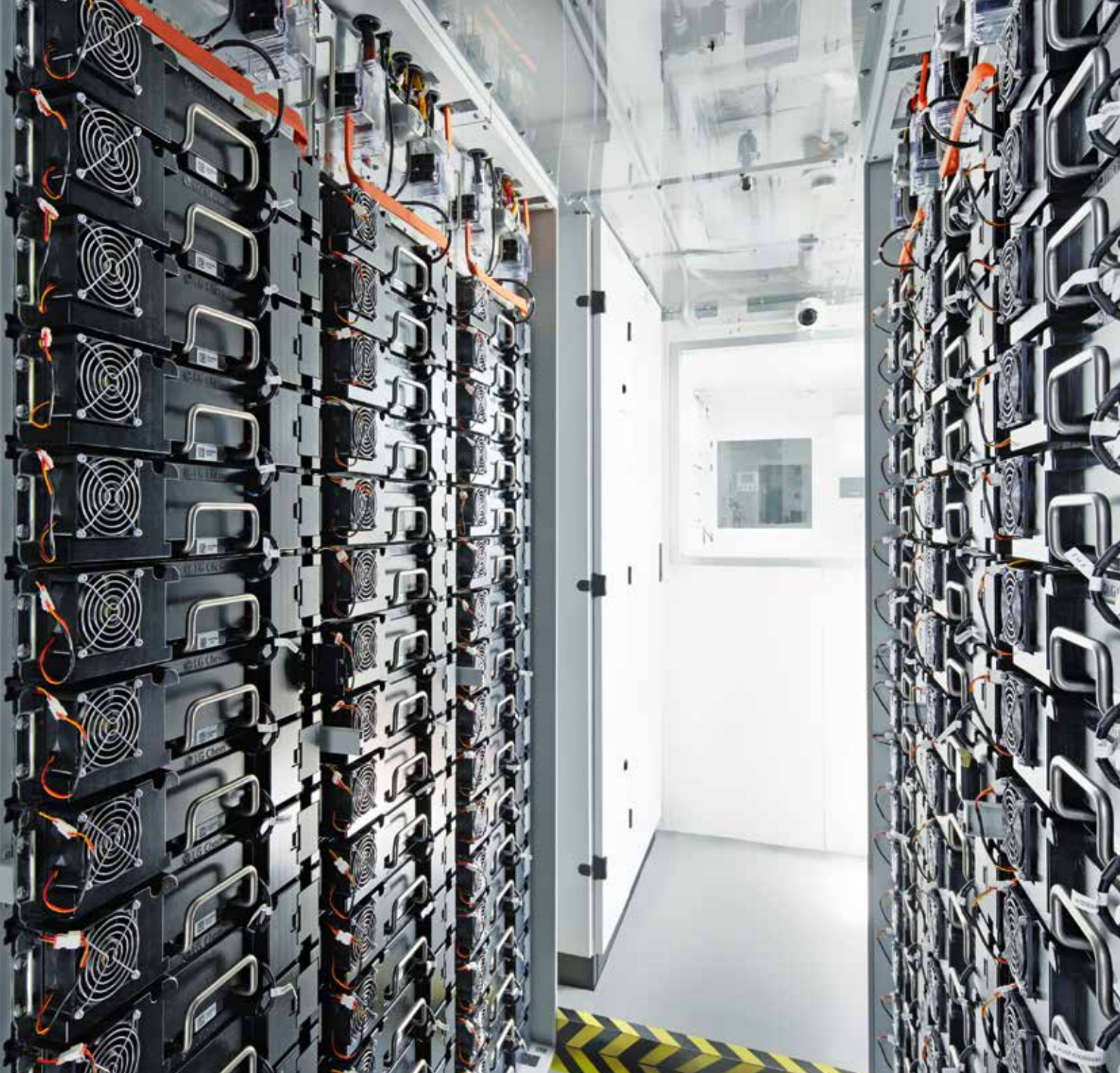
It's already clear: fast-response systems will be much more relevant going forward. The ABS4TSO research project examines – using an innovative battery storage system at a test installation – just how such systems can be used to balance out fluctuations in grid frequency very quickly. Highly dynamic response times of just a few milliseconds are being tested, and an “ABS for the power grid” is being developed – similar to the ABS anti-blocking assistance systems in modern vehicles.

The core element of the project is a battery storage system with a capacity of 1 MW/500 kWh. The system is powered by lithium ion batteries, a proven standard in battery cell technology. By contrast, the inverter had to be custom made as it has to offer sufficient flexibility for testing highly dynamic control response and an option to adjust the parameters. The installation and commissioning of this test system at APG's Southeast Vienna substation will be completed by the end of 2019.

At the end of the project, the research results will be assessed using a technology-neutral approach and then extrapolated to the transmission grid. ABS4TSO is a national project of significance for all of Europe!







## The benefit for society

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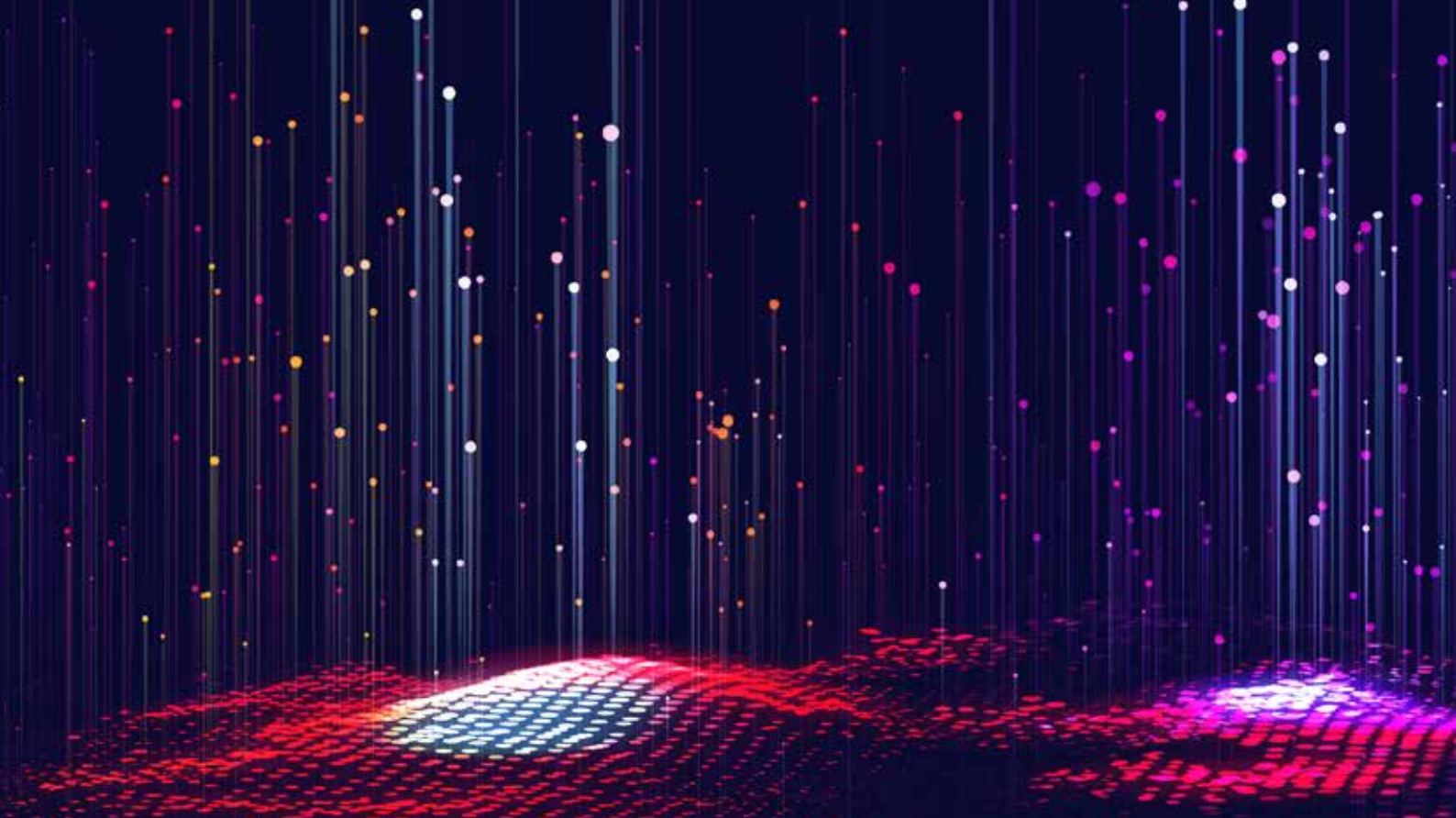
The ABS4TSO project came into being due to the immediate need to ensure the future viability of the transmission grid in terms of frequency stability and security of supply. The project involves research on the part of APG and its project partners into innovative methods for stabilising the power system, ensuring system reliability and integrating renewable energy sources. These are issues that are relevant to the whole of society, since both the economy and society require a reliable supply of electricity in order to function.

## More information



ABS for the Power Grid





# TOHIVA: using big data analytics to assess complex correlations

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## Research area: Digitalisation

- > Contact person: Hermann Mehl-Weiss
- > Project duration: 2014–2016
- > Project coordination: VRVis Research Center
- > Objective: to visually analyse extensive sets of time-series data relevant to the energy market and the correlations between them
- > Project partners: VRVis Research Center, AVL List GmbH, Plasmio GmbH, HAKOM GmbH
- > External funding: provided through the Austrian Research Promotion Agency's COMET K1 centre (Area 3: “visual analysis”)

APG deals with enormous quantities of data in a variety of areas (operations, forecasts, analytics, etc.). The project

TOHIVA used big data analytics to deliver key findings in the areas of control power usage and wind and solar forecasting. Other areas of application involved analyses of correlations between network conditions upon equipment failure, auto-reclosure of lines and even market simulations for ENTSO-E's Ten-Year Network Development Plan (TYNDP). TOHIVA stands for Task-Oriented Visual Analysis of High-Dimensional Data and is based on the application and continuous development of Visplore software.

The multi-company project took APG's big data requirements as the basis for researching options for new IT solutions, which were provided to APG for testing. Therefore, the software was continuously developed in the course of the



project and adapted to meet the needs of the project partners. This interactive approach resulted in a build-up of expertise within the companies participating. APG gained access to customised solutions and also advanced its expertise in using big data analytics to evaluate highly complex sets of data.

on an increased use of sensors but also on a greater level of interaction with market participants. Big data analytics techniques will therefore be indispensable going forward to allow the correct conclusions to be drawn from the large quantities of available data.

APG has access to a steadily growing data pool in many areas, based not only

## Research results

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Quick, interactive and, above all, visual analyses of large sets of data make it possible to rapidly gain a basic overview of the analysis results, to develop new findings based on those results and to present them in a comprehensible manner. One of the questions dealt with, for example, is which parameters affect forecasts of output from renewable energy sources. Does the impact of the parameters change based on the time of year? Does the input data show any structural discontinuity (for example due to a change in measurement technique) that should be rectified before utilising the data further? By building up internal expertise in the area of big data analytics, APG is making a valuable investment in its future.

Following the TOHIVA project phase, an additional period of cooperation known as En2VA (Visual Analytics for Energy and Engineering Applications) was initiated with funding from the Austrian Research Promotion Agency.

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