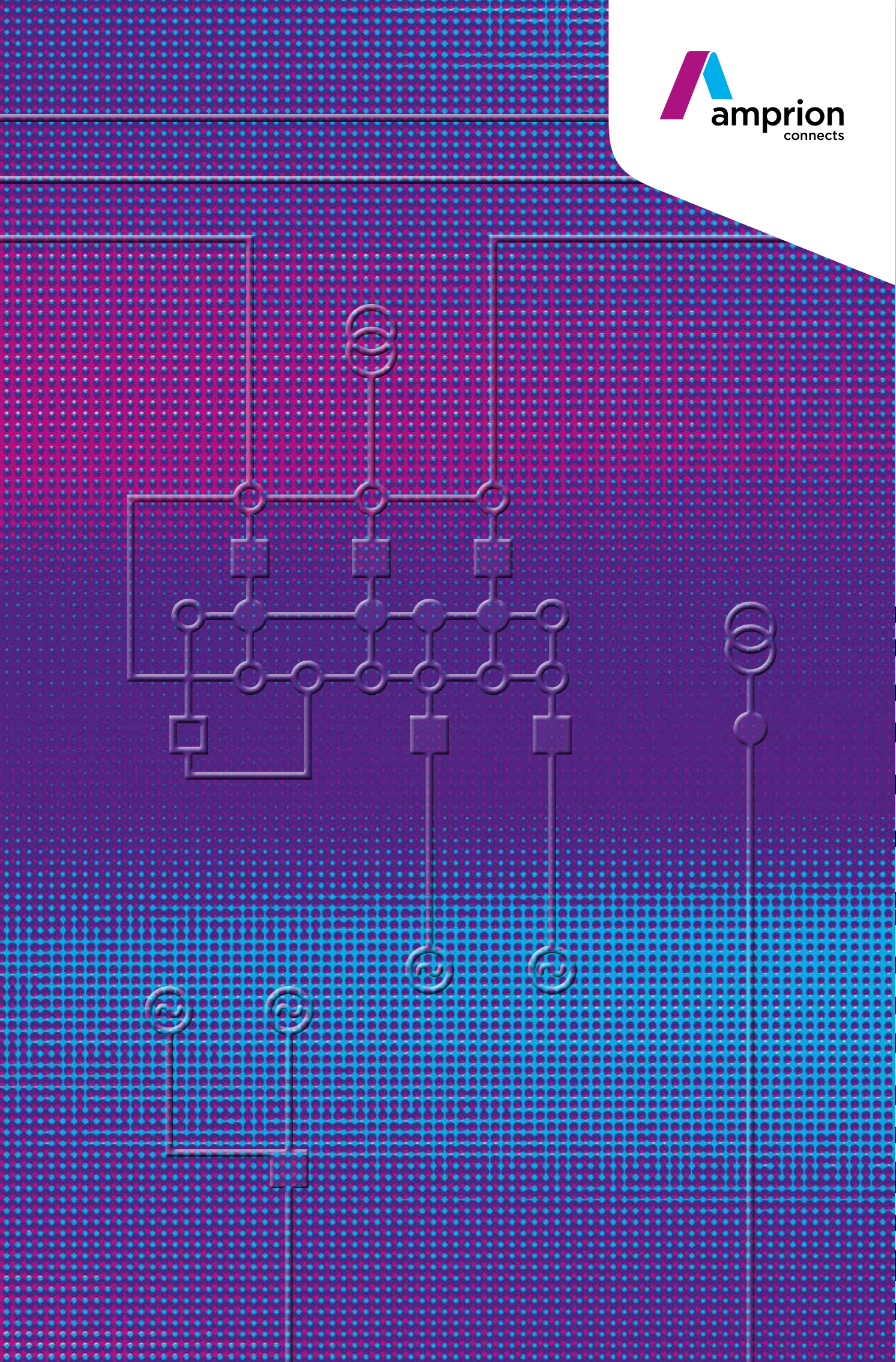
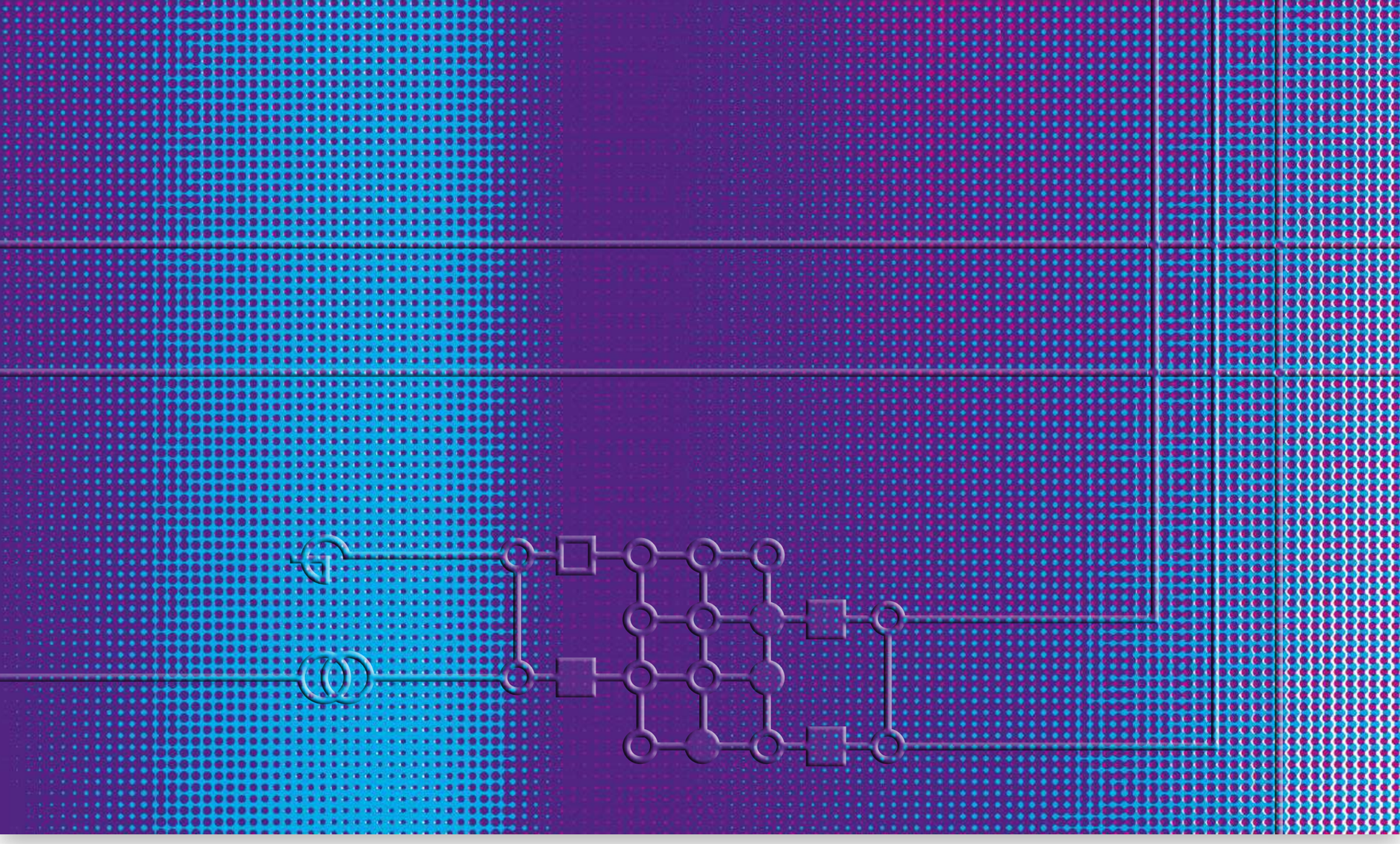
amprion
connects



INNOVATORS





AMPRION EMPLOYS NEW SOLUTIONS
FOR THE ENERGY SYSTEM OF TOMORROW.

# THE ENERGY TRANSITION DEMANDS INNOVATORS

# AMPRION IN BRIEF

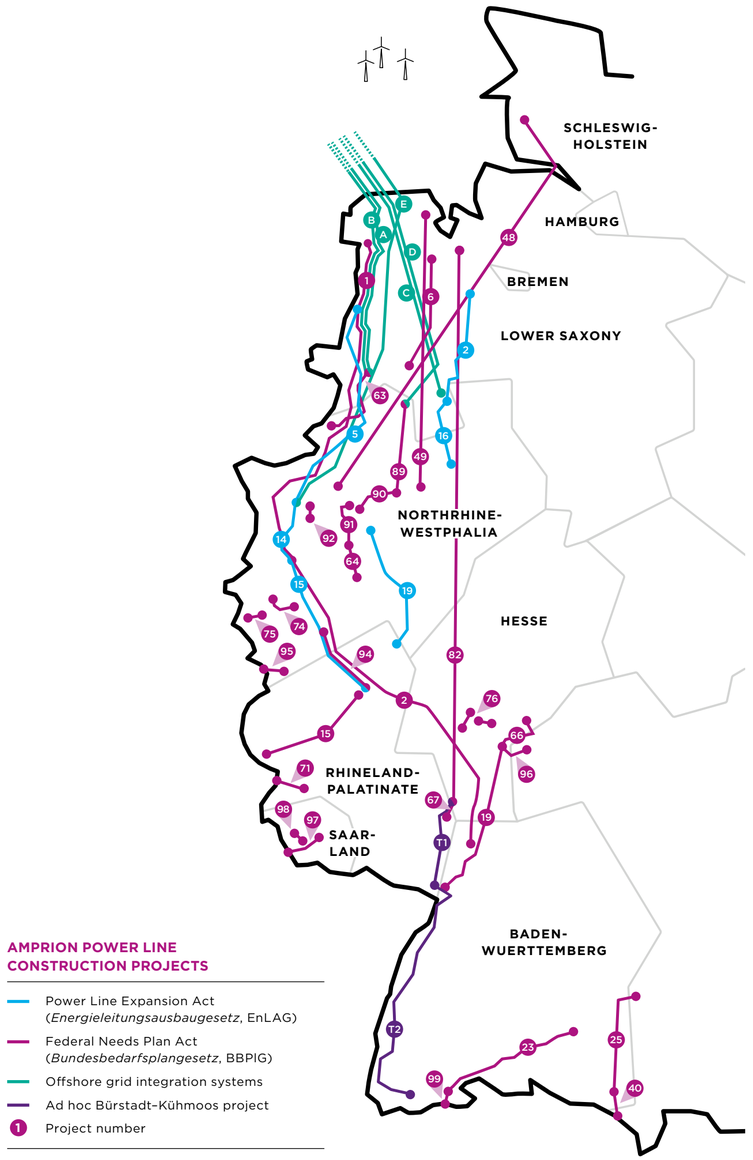
Amprion is **ONE OF FOUR TRANSMISSION SYSTEM OPERATORS** in Germany.

Our power lines are **11,000 KILOMETRES** long and extend from the North Sea to the Alps.

We ensure stable and reliable power supply for **29 MILLION PEOPLE** in our grid region.

**80 PER CENT** of Germany's power is planned to come from renewable energies by 2030. To make this happen, we are expanding and rebuilding **3,700 KILOMETRES** of transmission lines.

By 2026, our company will have invested roughly **12 BILLION EUROS** in reconstructing the energy system.






AMPRION EMPLOYS NEW SOLUTIONS FOR THE ENERGY SYSTEM OF TOMORROW.

# THE ENERGY TRANSITION DEMANDS INNOVATORS

# CONTENTS

## DEAR READERS,

Amprion is a transmission system operator paving the way for a climate-neutral energy system. Major challenges for the electrical grid's stability accompany this transformation. We will not be able to overcome them using only the solutions of today. We want to make Amprion capable of planning and coordinating the cross-sector energy system of tomorrow. To succeed, we will also require innovation, which is why Amprion is intensifying its research and development endeavours and working on new technologies, creative solutions and resource-conserving concepts.

This report will present the work we are doing on innovation, which comprises research and development projects from a wide variety of business areas. We use five main themes to present these areas, starting with "A Transforming Energy System" before providing insights into innovative "New Grid Elements". We outline innovation for "Grid Expansion 2.0", look at "Futuristic System Management and Operating Concepts" and examine the "Digitisation of Business Processes".

We report on the future-proof technologies we are developing and testing and, in some cases, already using in practice. We prioritise criteria such as sustainability, security of supply and cost-effectiveness. For many of our innovations, we work with national and international partners as well as maintain and initiate cooperative relationships with commercial and academic organisations.

Innovation arises when people take the initiative and develop ideas for how things can run better and more efficiently. We thank all our employees who engage in their work this way. We will continue to promote our power to innovate at Amprion.

**PETER RÜTH**
Chief Financial Officer (CFO)

**DR HANS-JÜRGEN BRICK**
Chief Commercial Officer (CCO) and Chief Executive Officer (CEO)

**DR HENDRIK NEUMANN**
Chief Technical Officer (CTO)

# »WE'RE A POWER-HOUSE OF IDEAS.«

**Amprion draws on innovation to help shape the future of the energy world, says CEO Dr Hans-Jürgen Brick. It's an approach that can be seen in projects from all areas of the company.**

**TRANSMISSION SYSTEM OPERATORS HAVE A REPUTATION FOR BEING CONSERVATIVE. AFTER ALL, THEY FOCUS ON THE SAFETY OF THE ELECTRICITY SYSTEM. DO THEY EVEN HAVE THE LATITUDE TO INNOVATE?**

Yes, sure we do. As a transmission system operator, we not only have responsibility for keeping the electricity system stable and secure, we also have the job of paving the way for a climate-neutral energy system. To combine both these duties, we rely on new technologies and new solutions. To put it plainly, we're not a system operator that merely manages its grid. We're helping to shape the future of the energy world – and that can only happen with a forward-looking mindset. This mindset is part of Amprion's DNA and what drives innovation.



**WHAT ARE THESE NEW TECHNOLOGIES AND NEW SOLUTIONS?**

The spectrum of our innovations ranges from new drilling methods for installing underground cables to artificial intelligence for managing systems, new equipment for stabilising the grid and digital analytics tools for helping us to model the energy system of the future. This innovation dynamic permeates all areas of our business. We're breaking new ground in so many areas for the energy transition that we've decided to comprehensively and systematically present Amprion's innovation activities. The report you're reading serves this purpose.

**WHAT FASCINATES YOU ABOUT INNOVATION?**

For us, it's a matter of adopting new approaches so we can carry out our responsibilities, which are crucial to the economy. While I'm no engineer, I'm very happy when colleagues show initiative and develop ideas for improving how things run and boosting their efficiency. Amprion has always been a powerhouse of ideas. We enjoy a heritage that stems from the engineers who invented the transmission grid in Germany 100 years ago, when the first electricity connection with the Alpine region was established. It enabled the interlinking of the coal power plants in western Germany with the hydroelectric power plants in the Alps so industry along the Rhine and Ruhr rivers could be supplied with power. The main control centre in Brauweiler managed this new electrical supply system and still plays a key role in managing the system today. It fulfils this role using cutting-edge IT and artificial intelligence solutions. Without it, our engineers wouldn't be able to process the volumes of data collected from the more than 2,800 lines and more than 50,000 switchgear at 160 substations.

**»For us, it's a matter of adopting new approaches so we can carry out our responsibilities, which are crucial to the economy.«**



**WHAT INNOVATIONS DO WE NEED FOR THE ENERGY TRANSITION?**

Our challenge is to convert the energy system to electricity generation from renewable sources. We're increasingly turning away from, for example, conventional power plants that have generators to maintain voltage stability in the power grid. In their place, we're integrating new kinds of equipment in the grid such as rotating energy system stabilisers. Another example is the System Vision 2050 project. It brings together political, commercial and societal partners to identify and discuss the various requirements imposed on a climate-neutral, cross-sector energy system in order to form the basis for creating a joint vision for an energy system of the future. As a result, the project provides a blueprint for preparing a future system development plan that examines and optimises the electricity, thermal-energy, methane and hydrogen sectors of the energy industry in conjunction with each other.

**HOW DOES INNOVATION HELP WITH EXPANDING THE GRID?**

An entire chapter in the report you are reading is dedicated to this topic, which shows how important it is to Amprion. Together with research and industry partners, we're working on new drilling methods that disturb the earth less. To speed up approval processes, we have co-developed a computer program that helps plan line locations so fewer conflicts with stakeholders in the region occur. Innovative communication measures also help speed up processes: In future, we'll be able to involve stakeholders through digital dialogue formats, such as an online "info market" for local residents. This lets us increase our reach. The more people feel informed, the more willing they are to tolerate the construction of power lines in their neighbourhood.

**»We only apply new solutions when they have proved themselves practically and take us forward.«**

**HOW DOES AMPRION PROMOTE INNOVATION?**

We adhere to three main points: objectives, processes and culture. We have strategic objectives and, to achieve them, we rely on things such as innovation. Over the next year, we'll host an internal innovation conference. Amprion's corporate culture is directed towards sharing knowledge and experience, adapting to challenges, and expanding our ability to change. For this reason, I'm confident we'll continue to have great ideas for new technologies and new solutions. And we'll tap our networks to find partners for both developing innovations and testing them. As a transmission system operator, this is important. We should not pursue innovation solely for the sake of innovation. We only apply new solutions when they have proved themselves practically and take us forward. We're conservative in this respect and in a good way.





# »WE RELY ON NEW SOLUTIONS.«

**For a successful transition to a climate-neutral energy system, Amprion is intensifying its work on innovations. A lot of innovations arise in partnership with national and international partners.**

The energy industry in Germany and Europe is facing major challenges. Meeting the German government's and the EU's climate targets calls for a transformation of our entire electricity and energy system, our contemporary way of adding value in industry, our approach to mobility, and, in some ways, our way of living – and all at an unprecedented speed. The current energy crisis clearly demonstrates how urgent change is and shows our society once again how critically important having a secure and affordable energy supply is.

We will not be able to overcome these challenges only using the solutions of today. We rely on new, innovative solutions and technologies. With its innovations, Amprion is already making a key contribution to the transition towards a climate-neutral energy system. These efforts, however, need to be intensified. Not just at Amprion, either, but across the entire energy industry.

## BASIS: THE AMPRION STRATEGY

Amprion focuses its innovation activities on areas derived from the company's corporate strategy: as a "next-generation transmission system operator", we want to develop considerable competencies in cross-sector system planning and in system operation. Progress on expanding the transmission grid must be made much more quickly. In the short and medium term, the performance and utilisation of the existing grid infrastructure must increase while maintaining system stability.

## DEVELOPMENT WITH PARTNERS

For developing innovations and broadening expertise, Amprion is able to draw on many years of operational experience in many areas. Simultaneously, Amprion obtains new findings by applying innovative technologies and processes as well as digital solutions. We develop many of our innovations in cooperation with national and international partners in research and industry. In these collaborations, Amprion often takes the role of an initiator or works as a project partner to integrate technical solutions into the transmission grid and test them as part of pilot projects. Amprion does not rely on single examples of innovation, but rather a large number of innovative approaches and technologies within individual areas of the company.

The European energy system is strongly interconnected. We can only achieve the ambitious goal of climate neutrality by working together with our partners. To this end, we closely cooperate with the other national transmission system operators: 50Hertz, TenneT and TransnetBW. In addition, we are involved in international committees such as the International Council on Large Electric Systems (CIGRE) and the European Network of Transmission System Operators for Electricity (ENTSO-E) as well as national associations such as the Network Technology/Network Operation Forum at VDE (VDE FNN). Furthermore, Amprion has maintained an intensive partnership with E.ON, Europe's largest transmission system operator, since 2020.

## AREAS OF FOCUS FOR INNOVATION

The energy transition can only succeed when the various stakeholders and interest groups involved communicate more intensively with each other and when businesses in different sectors, system operators and market participants work together more closely. Amprion therefore focuses its innovation work on the transmission grid's interfaces and sector boundaries [→ CHAPTER 1, SEE PAGE 17].



The transmission grid of tomorrow will have fewer synchronous generators, significantly more distributed converter feed-in, higher volatility, generation at greater distances from consumption centres and, consequently, transmission over longer distances. To integrate renewable energies while maintaining grid and system stability, Amprion is making greater use of new equipment and interconnected grid elements [→ CHAPTER 2, SEE PAGE 29].

Moreover, expanding the grid needs to speed up significantly. This applies in particular to planning and approval processes. Key legislative changes have already been implemented for this in summer 2022, however they are not enough. For this reason, Amprion is employing innovative approaches and new methods to accelerate construction and increase acceptance [→ CHAPTER 3, SEE PAGE 49].

To transmit more power, Amprion has been working for many years on measures to increase utilisation of the existing grid. These measures will, however, become a particular focus of our innovation in the short and medium term, which will also intensify the demands placed on the system's management and grid's efficient operation [→ CHAPTER 4, SEE PAGE 59].

Another important field for Amprion's innovation is leveraging the potential to digitise processes. By optimally analysing data, improving simulations and adopting AI-supported processes, we at Amprion can make quicker and more sustainable decisions [→ CHAPTER 5, SEE PAGE 75].

**Amprion is facing what may be the most exciting yet challenging decade in its company history. Together with our partners, we drive innovation and thereby make an important contribution to a climate-neutral energy system.**

**THE AUTHORS OF THIS ARTICLE:**

**THOMAS DEDERICHS**
Head of Corporate Strategy and Public Affairs

**DR BARTOSZ RUSEK**
Head of Technological Innovation

**JAN PETER GETZLAFF**
Head of Digital Innovation and IT Governance

# A TRANS-FORMING ENERGY SYSTEM

The energy transition is a joint project. Its success depends on political, commercial and societal stakeholders communicating with each other more intensively about the energy system of the future and developing solutions together for issues in systems and markets. Amprion has contributed innovative proposals to these discussions.

# “SYSTEM VISION 2050”

BENEFITS OF INNOVATION

Vision of a climate-neutral, cross-sector energy system developed through partnership

**FIG. 01** systemvision2050.de website

The “System Vision 2050” project brings together political, commercial and societal stakeholders. The aim behind it is to identify and discuss the various requirements and expectations that are imposed on a climate-neutral energy system. It incorporates not only the electricity sector, but also the thermal energy, methane and hydrogen sectors, and in doing so shows clearly how broad the possible solutions for achieving a climate-neutral energy system are. The infrastructural implications are assessed, obstacles addressed and considerations weighing up sustainability, security of supply and cost-effectiveness are made.

In keeping with our motto of “Amprion connects”, we provide a platform through this project. It lets our project partners share with us their individual assumptions for the achievement of a climate-neutral energy system. Based on the energy system model developed at Amprion [→ESMA, SEE PAGE 22], an individual, climate-neutral scenario is calculated for each of the partners. At the same time, the sectors are examined and optimised in conjunction with each other. The modelling approach allows for a quantification of the assumptions as well as the outcomes.

A core, innovative element of the System Vision 2050 is that the participants do not just agree on a small number of consensus-based scenarios, as is the case in typical energy system studies. Instead, all partners work out an individual scenario for themselves. Using the consistent modelling, we make all “system visions” com-

parable with each other in a way that lets the individual scenarios be discussed objectively. These scenarios provide the basis for the project.

Based on the scenarios, the partners formulate their respective system visions in articles that present their figures as well as the partners' individual view of the energy transition. All articles are published on the project website, systemvision2050.de.

The website also provides additional content: the Forschungsstelle für Energiewirtschaft ("research institute for energy", FfE) has conducted a scientific, cross-sectional analysis of all system visions and compared them with the latest energy system studies by the German Energy Agency (dena), the German Federal Ministry for Economic Affairs and Climate Action and other highly regarded think tanks. Our partners are also given the opportunity to present their views in more detail through interviews.

The project's marketing is innovative, with new methods being adopted on social media. The factors in the success included a clear definition of target audiences for social posts, the use of paid social media and search engine optimisation. Additional, brief videos were created for social media using the Lumen5 AI engine.

A crowdsourcing scenario was created as a further online element and involved us asking the community for its opinion on the energy system of the future. It attracted 143 participants and showed a broad spectrum of solutions. The scenarios differ in their efficiency, focus areas for the expansion of renewable energies and level of green-hydrogen usage.

A key outcome of each scenario is the "energy flow diagram", or Sankey diagram [SEE FIG. 02]. It shows at a glance the energy sources that are used for each system vision – for instance, the amount of hydrogen that needs to be imported or how much wind energy is produced, the transformation steps taken in the form of electrolysers or heat pumps and how the energy is used in individual consumption sectors.

The project's website now counts several thousand visitors, which is a testament to the interesting content on it.

We firmly believe that the project makes a key contribution to improving people's overall understanding of the energy transition and increasing the acceptance of it. Because we include various interest groups closely and because the project is modelled across the different sectors, it produces – in our view – a blueprint for the creation of a future system development plan that maps out and optimises the electricity, thermal, methane and hydrogen sectors of the energy industry in conjunction with each other.

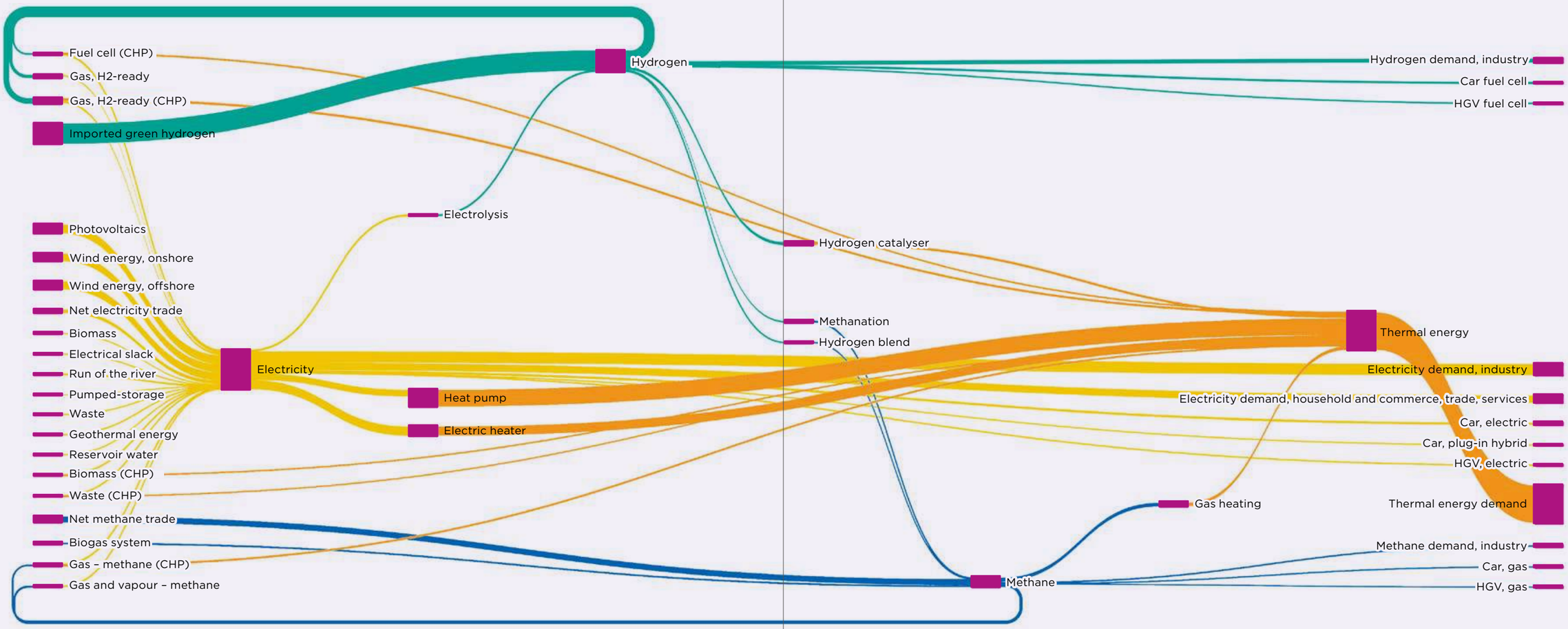



**FIG. 02 Example outcome: cross-sector energy flows**





1.1 A TRANSFORMING ENERGY SYSTEM "SYSTEM VISION 2050"

# ENERGY SYSTEM MODELLING AND ANALYSIS (ESMA)

## BENEFITS OF INNOVATION

Modelling and analysis of the future climate-neutral energy system in order to calculate complex scenarios and determine infrastructure needs

Germany and Europe have committed to full decarbonisation of the energy system by no later than 2045 and 2050 respectively. To accomplish this, not only will the electricity sector have to reach climate neutrality, but also all energy sectors generally. The electricity system will have a key role in decarbonisation as solar and wind energy in particular are available in abundance and provide renewable power. By coupling sectors, this power can be used to decarbonise other sectors. In return, these sectors can provide flexibility for the integration of volatile generation based on renewable energy sources. The developing hydrogen sector can be mentioned in this context, for instance, as well as the transport sector and thermal-energy and natural-gas sectors. An energy system that is coupled in this manner cannot be planned in isolation any longer. It requires an integrated perspective in order to analyse the impacts and interaction of all sectors with the electricity system.

This makes the energy system significantly more complex and is why existing modelling approaches are reaching their limits. What's more, the distant horizon of 2045+ combined with the constant incorporation of new sectors and technologies make it difficult to define future scenarios. However, these scenarios form the foundation for all modelling.

Despite the growth in complexity, the impacts of current developments on the energy system will need to be analysed quantitatively and objectively in the future, too. They demand a standalone and advanced framework for modelling and analysis, and this requires a high level of automation in order to examine the integrated energy system in combination with a large number of scenarios and, above all, to analyse, plan and evaluate the consequences and implications of these scenarios for the electrical grid of tomorrow – in fine detail, down to the specific lines and nodes.

Amprion has developed an Energy System Modelling and Analysis (ESMA) process that meets these requirements. ESMA combines and manages methods and tools for energy system modelling and analysis and their use in case studies for topical, non-area-specific and interdisciplinary issues relating to energy systems. The "System Vision 2050" project [→ "SYSTEM VISION 2050", SEE PAGE 19] makes use of newly developed ESMA methods and tools.



Below, we outline three examples of innovative methods that have been enhanced as part of ESMA.

### "LISA" – ENHANCEMENT OF CROSS-SECTOR PLANNING METHODS FOR A CLIMATE-NEUTRAL ENERGY SYSTEM

Amprion has developed the LISA tool as part of ESMA for cross-sector planning. LISA stands for "Light Integrated System Analysis" and makes it possible to capture and analyse the entire energy system, including hydrogen, natural gas and thermal energy, and quantify the energy flows within Europe and beyond. All energy sources and sinks, possibilities for flexibility and transport capacities are examined together in one optimisation model. Moreover, LISA can be used to determine the infrastructure expansion needed for it, such as the transport capacity for interregional energy transmission or locating and dimensioning electrolysers for generating hydrogen from electricity. Figure 03 shows an example of the expansion needed in the hydrogen network and electrical grid in a future scenario. In addition to a target year examination, it is also possible to calculate a transformation pathway spanning multiple years in order to consider the energy transition "from start to finish".

LISA deliberately conducts these long-term analyses at a high level and concentrates on the essential interrelationships to arrive at answers very quickly. The results can then be analysed further in detailed grid calculations.

### FUTURE SCENARIOS

With the distant horizon of 2045+ and the wider spectrum for examining various sectors and future technologies, there is greater uncertainty about the changes in the underlying conditions of the energy system. The impacts of these developments on the entire energy system must be anticipated in order to identify the requirements for the electricity system of the future.

To do this, the underlying conditions and potential future developments are translated into a variety of key figures, such as the demand expected from the sectors or the installed capacity for renewable and sector-coupling technologies. A set made up of these key figures depicts a specific scenario in the future and considers the relevant aspects of the entire energy system with all sectors. To capture a wide spectrum of future developments, a broad funnel of scenarios should be established. In doing this, the future infrastructure can be identified based on actual needs while revealing optimal pathways to climate neutrality for various scenarios.

To calculate the scenarios, Amprion has utilised methods such as the scenario technique and identified numerous different key factors with different characteristics and projections that could have a decisive influence over the energy system of the future. We translate them into quantifiable parameters that we can combine to calculate a large number of scenarios. We then break them down into a manageable number through consistency checks and cluster methods.

The scenarios serve as the basis for calculations for the aforementioned LISA energy system model. Furthermore, they act as the foundation for the scenarios presented by the partners in the "System Vision 2050" [→ "SYSTEM VISION 2050", SEE PAGE 19].

### AUTOMATED GRID PLANNING

In terms of the more detailed, long-term grid planning, as opposed to an examination of the entire energy system, Amprion pursues a goal of determining cost-effective, needs-based grid structures that can fulfil its power supply duties and ensure the system's security. Due to the extremely large number of potential solutions and the mutual interdependencies between the various expansion options, we use highly automated algorithms that we have developed in-house to efficiently determine grid expansion variants and, during the first step, evaluate them. Using these methods, the calculation times for the evaluation of individual expansion variants can be reduced significantly while considerably increasing the number of planning alternatives that are examined.

**»ESMA combines and manages methods and tools for energy system modelling and analysis and their use in case studies for topical, non-area-specific and interdisciplinary issues relating to energy systems.«**

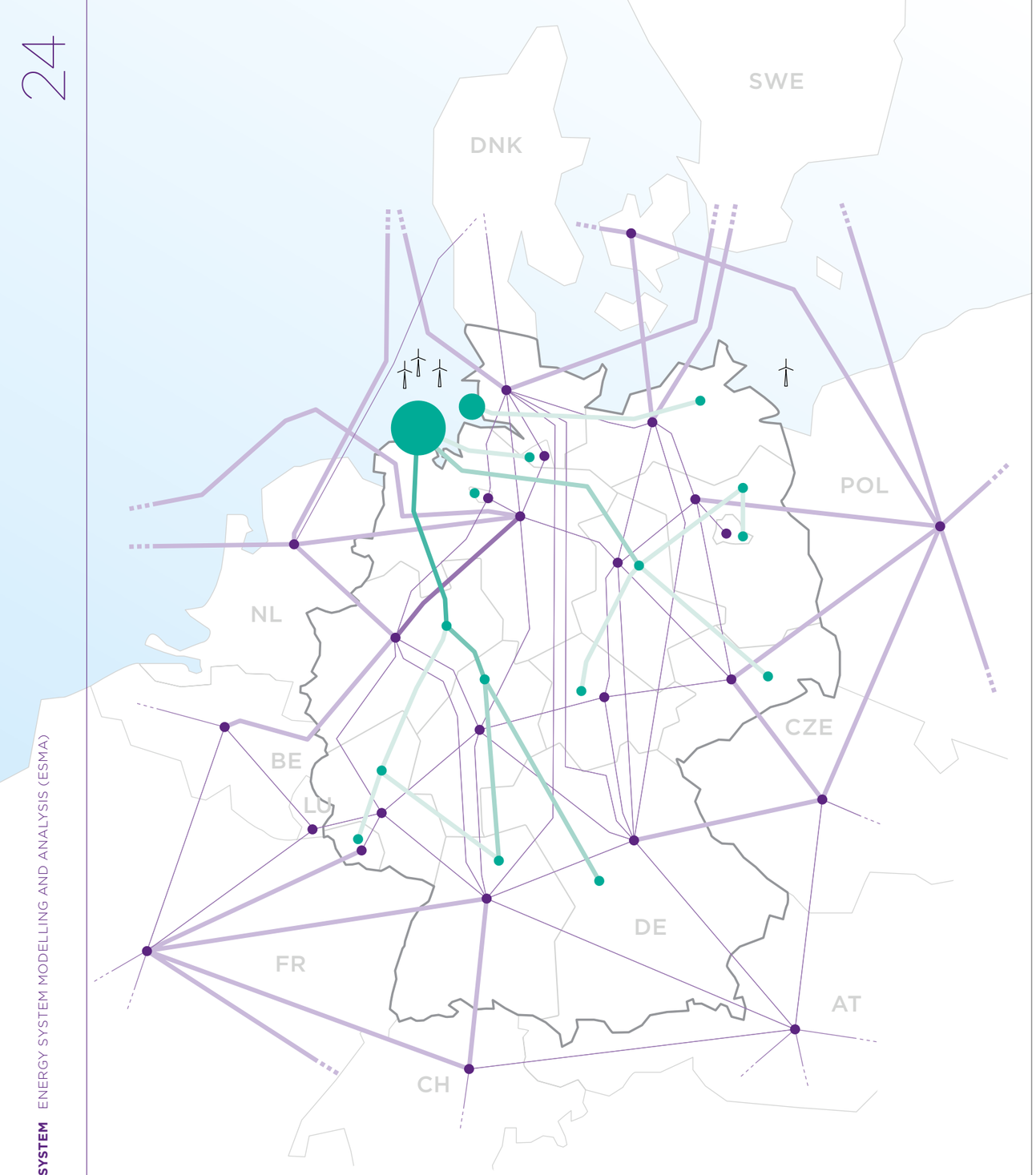



**FIG. 03 Example of expansion needs in the $H_2$ network and electrical grid in a future scenario**

Electrical-grid region  $H_2$ network region





# REACTIVE POWER EXCHANGE BETWEEN DISTRIBUTION NETWORK OPERATORS AND TRANSMISSION SYSTEM OPERATORS

BENEFITS OF INNOVATION

Supply of reactive power from distribution grids to support voltage in the transmission grid

To regulate the voltage in the transmission grid, reactive power is currently fed in either through a system operator's own compensation stations or as a system service through power plants that are connected directly to the transmission grid. However, the prospective closure of directly connected power plants reduces the potential reactive power available in the transmission grid considerably. In the future this loss can be, at least partially, compensated for by supplying more reactive power from the distribution grids.

To this end, Amprion is working together with distribution system operators (DSOs) to take on the task of evaluating and developing the potential of coordinated reactive-power exchange between DSOs and transmission system operators (TSOs). The concept, which was developed jointly with E.ON DSO Westnetz and is now applicable, provides for an adaptation of reactive-power exchange to the conditions of the increasing expansion of distributed-generation systems and therefore enabling of reactive-power exchange even when there is little active-power exchange between DSOs and TSOs. Penalisation for crossing reactive-power limits has been abolished. As an alternative, countermeasures are coordinated with the DSOs and TSOs when limits are breached.

Future plans provide for the reactive-power exchange being able to be changed actively if requested by the TSO, letting the distribution grids assist with the voltage in the transmission grid. Since there are technical limits on the utility of the total installed reactive-power potential from distributed generation, the actual usable potential must be calculated before applying the concept.

The theoretical and actually usable reactive-power potential from decentralised generation with Westnetz was calculated for a sample grid region, using grid calculations at first, and then confirmed in real field tests. The total installed reactive-power potential in the grid region that was studied was 638 MVar.

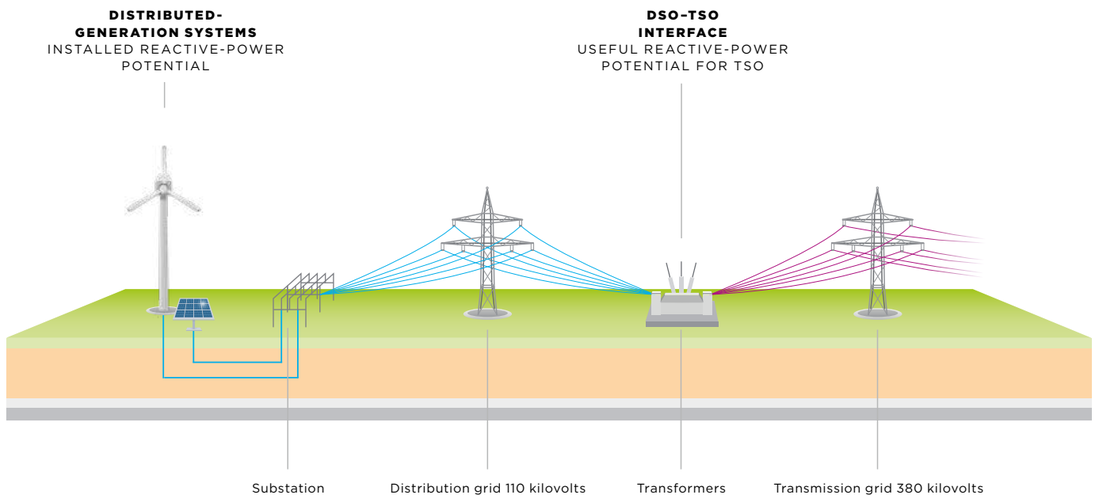



**FIG. 04 Reactive-power potential from distributed-generation systems in the distribution grid and interface between the distribution network operator and transmission system operator (DSO/TSO)**
*Schematic illustration*

The pilot studies carried out afterwards revealed various technical restrictions that reduced the actual usable reactive-power potential:

- Different technical rules for connection
- Most distributed-generation systems in the low-voltage grid are uncontrollable due to the lack of communication integration
- Compliance with local voltage limits in the distribution grid
- Long electrical distance to transmission grid
- Too much effort needed to coordinate controllable small-scale systems

The reactive-power potential actually used in the field test at the DSO/TSO interface was approximately 75 Mvar voltage-increasing and approximately 80 Mvar voltage-decreasing [SEE FIG. 04]. To compare, a reactive-power compensation system is usually dimensioned at about 300 Mvar.

The results of the field tests show for the first time that deliberate reactive-power exchange between DSOs and Amprion is possible and beneficial in practice. Moreover, it can to a limited degree help reduce the need for new reactive-power compensation systems. The findings from the field tests are being contributed to a current partnership between E.ON and Amprion. They can be used to calculate the actually usable and already existing reactive-power potential in further grid groups and improve the reactive-power exchange between DSOs and TSOs.



# SYSTEMMARKT: CONCEPT FOR A SYSTEM-SUPPORTING MARKET DESIGN

BENEFITS OF INNOVATION

Market model with incentives to design electricity generators and consumers in a way that supports the system, combining the security of supply with the security of the system


**FIG. 05 systemmarkt.net website**

Amprion unveiled Systemmarkt, its proposal for enhancing the current electricity market design, in early 2022. Systemmarkt does not function as "the single quick, short-term solution" in the context of the current energy and pricing crisis or the current challenges ensuring supply during the winter. However, it does address existing issues and would reduce the risk of such a crisis in the future. Systemmarkt aims to provide capacity payments that differ in terms of technicality and geography and that act as a financial incentive for market participants to design their assets in a way that supports the system and choose their respective locations accordingly.

The current market design often does not consider, or does not consider appropriately, the downstream grid costs and system costs associated with the investment and operational decisions made by market stakeholders. The system is not viewed as a whole. Systemmarkt addresses these issues and complements the current spot and futures sections of the energy-only market. It functions like a classic, central capacity market, though it adds a local component as well as ancillary services' needs.

Specifically, the concept is based on a central platform that shows the energy system's needs at a glance and coordinates their procurement process. First, the needs that contribute to the security of the system and supply are defined and evaluated, allowing for regional differences. However, Systemmarkt should only create incentives for system needs that are suited to market-based procurement. This should be assessed beforehand from a technical, financial or operational perspective. If market-based procurement is generally relevant for a particular system need, a corresponding procurement process is started. If, contrary to expectations, the local system need cannot be satisfied efficiently either in whole or in part by the market participants, the grid operators satisfy the remaining demand.

### GUIDING THOUGHT: VIEW THE SYSTEM AS A WHOLE

Systemmarkt combines the strengths of long-term, coordinated system planning with the innovation of the electricity market **[SEE FIG. 06]**. In doing so, it supports a cost-effective and secure transformation of the energy system. It ensures that sufficient potential will be available at suitable sites in the future to guarantee the electricity system's stable operation. Moreover, market participants are given incentives to design their equipment in a way that supports the system. The grid reserves that are less efficient economically do not grow further as a result. Instead, the investment goes towards a future-proof reconstruction of the electricity system.

**Further information about Systemmarkt can be found at systemmarkt.net**

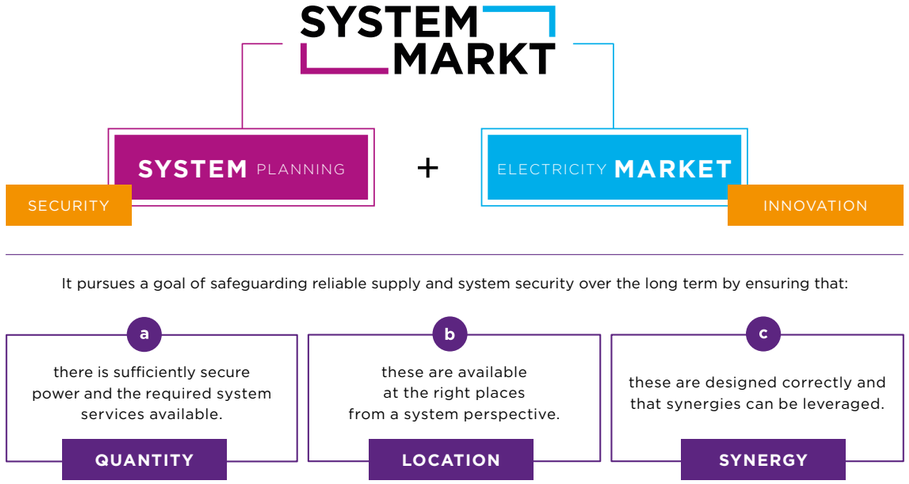



**FIG. 06 Guiding thought: view the system as a whole**





# NEW GRID ELEMENTS

2

In the energy world of tomorrow, power will come from renewable energies. The transmission grid will be marked by higher volatility and transmission over longer distances. To keep it stable and operate it efficiently, Amprion is particularly reliant on new equipment and offshore interconnectivity.





# ONGOING DEVELOPMENT OF HIGH-VOLTAGE DIRECT-CURRENT (HVDC) TRANSMISSION

BENEFITS OF INNOVATION

Underground-cable and overhead-line projects with direct-current technology for affordable, smaller-footprint and efficient grid expansion

Progress is being made on the reconstruction of Germany's energy system to make it climate-neutral. As part of this transformation process, the distance between the generation centres and the load centres is growing. Consequently, there is an increasing necessity to transmit energy over long distances. High-voltage direct-current (HVDC) transmission is the most cost-effective and, sometimes, the only possible technical solution for this. Amprion is therefore using this technology for the future integration of offshore wind farms in the North Sea as well as for long-distance north–south corridors.

HVDC technology can normally be implemented using underground or overhead power lines. Underground projects include the completed ALEGrO project as well as the Corridor B and DC34 HVDC projects that are currently being planned and approved respectively as well as a variety of offshore integration systems (DolWin4, BorWin4, BalWin1, BalWin2 etc.). Furthermore, Amprion is involved in the construction of Corridor A, which is partly being realised as underground cabling (A-North) and partly as an overhead line (Ultranet). This point-to-point HVDC link is made into a multi-terminal system through the addition of a planned intermediate station.

The full interconnectivity of HVDC systems in the Amprion grid is slated to take place with two offshore projects attached to the DC34 project, according to the grid development plan. In this context, the development of a circuit breaker for HVDC grids will be very important. Additionally, Amprion is using the new 525 kV HVDC technology in this project and for the two sub-projects in Corridor B, allowing major advantages from the higher transmission capacity and smaller footprint.

## ALEGRO

Amprion has already gained important practical experience in the construction of an HVDC system through the Aachen Liège Electricity Grid Overlay (ALEGrO), a grid expansion project that was completed successfully with Belgian transmission system operator Elia. ALEGrO was constructed as a symmetrical monopole with a voltage of plus/minus 320 kilovolts (kV) and transmits power of up to 1,000 megawatts (MW). A plastic-insulated, underground cable was used for each pole. The length of the first underground link between Belgium and Germany is approximately 90 kilometres, which represents important technological progress in Amprion's journey towards further underground HVDC cable projects. Since ALEGrO was launched in late 2020, the system has operated reliably and makes a key contribution to the integration of the European energy market as a German–Belgian interconnector.

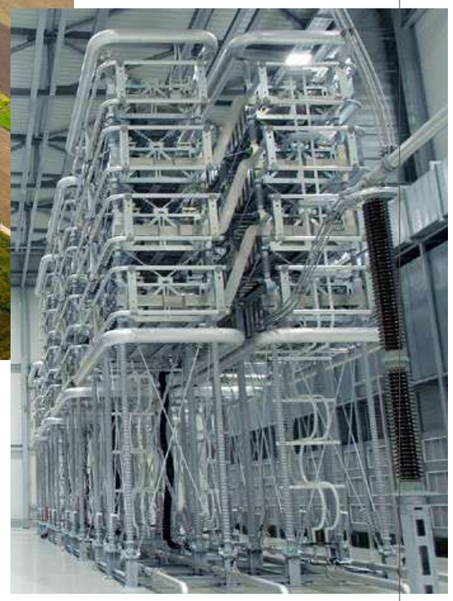


**FIG. 07 TOPALEGrO converter hall, exterior**
**FIG. 08 RIGHT ALEGrO converter hall, interior, with IGBT valve towers**

## CORRIDOR A, A HYBRID MULTI-TERMINAL HVDC LINK

As part of Corridor A, Amprion is constructing the world's first hybrid, multi-terminal HVDC link in the form of the A-North underground cable and Ultranet HVDC overhead line projects and the sub-station in North Rhine-Westphalia on the Corridor A route between Lower Saxony and Baden-Württemberg. To reduce the direct impact on the environment, Amprion is using existing overhead line pylons for the overhead line section. The HVDC circuit will be installed on these pylons, which will require some of them to be reconstructed. To increase the transmission capabilities of the existing overhead-line corridor, Amprion is, for the first time, using 380 kV HVDC technology for Ultranet. Brief disruptions from atmospheric influences and short circuits can be managed and investigated in a controlled way, even without utilising direct-current circuit breakers, through the HVDC converter stations that have been applied for the first time and that feature full-bridge converters. The converters are connected to make a unique multi-terminal system consisting of three converter stations, each with two converters per pole. Together with manufacturers and universities, Amprion is performing extensive analysis on this new technology concept in order to ensure the HVDC link's secure and reliable operation over the long term.

## 525 KV HVDC TECHNOLOGY

HVDC systems with a nominal voltage of 320 kV are excellent for transmitting power of up to 1,000 MW. This technology is used for ALEGrO as well as the offshore grid connections for DolWin4 and BorWin4, for example. If higher transmission capacity is needed, as is the case for the two Corridor B sub-projects, the DC34 project or Amprion's offshore grid connections after 2030, two HVDC systems with a nominal voltage of 320 kV would be required for 2,000 MW. The space needed along the corridor would therefore double. The same applies if using 525 kV HVDC earth cables, which are frequently applied as submarine cables in particular. In comparison, 525 kV technology using plastic-insulated HVDC cables requires only one cable system to transmit 2,000 MW. The space that is needed is consequently significantly less, which reduces the impacts on the environment and nature [SEE FIG. 09].

Plastic cables have so far not been used in real grid operation with a voltage of 525 kV anywhere in the world. However, given the above benefits, this technology is going to have a leading role in the construction of HVDC cable projects at Amprion in the medium term. Amprion is actively involved in the development and application of 525 kV systems through various studies and the pre-qualification tests being supported by the four German transmission system operators on 525 kV HVDC cables. The company's aim is to harness the technology's environmental and economic advantages.

## CIRCUIT BREAKERS FOR HVDC GRIDS

With the increasing integration of individual point-to-point HVDC systems into the transmission grid, there is a growing need to turn isolated systems into interconnected, multi-terminal HVDC systems. These systems provide additional freedom when the task at hand is to transfer the electrical transmission capacity to various different grid interconnection points while maintaining partial transmission capacity if individual lines fail. Amprion addressed this topic very early on: being a founding member of the EUROBAR initiative, Amprion has joined a number of European transmission system operators with similar interests to drive standards and methods for HVDC interconnectivity nationally and internationally. Ultimately, HVDC circuit breakers will also need to be used for full HVDC system interconnectivity and transformation into multi-terminal HVDC systems. In the event of a malfunction, this means that the malfunctioning circuits will be able to be selectively activated in HVDC systems like in the three-phase system, which safeguards the operation of the remaining, intact HVDC grid.

Working with RWTH Aachen University, Ruhr-Universität Bochum and Avasition GmbH, Amprion is conducting detailed simulation studies to analyse the usage and mode of action of circuit breakers for HVDC grids in interconnected HVDC systems. Only a very small number of major international manufacturers master this technology at the moment, and this technology is very relevant for the future. While the rectification of short circuits in the three-phase grid is allowed to take up to 150 milliseconds, malfunctions in the HVDC system must be remedied in fewer than 10 milliseconds due to the very strong increase in short-circuit current. The studies' outcomes will have a decisive influence on the selection of the appropriate technology.

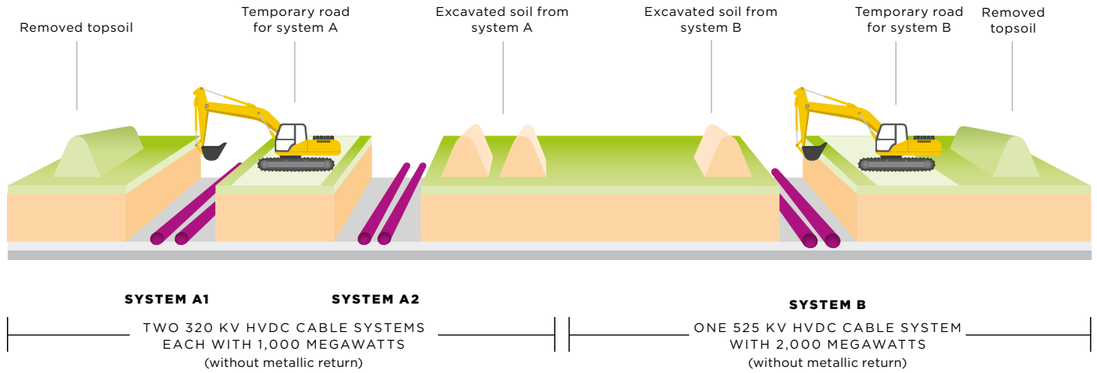



**FIG. 09 320 kV HVDC vs 525 kV HVDC with 2,000 MW**

If the overall system permits it, plastic-insulated 525 kV HVDC cables can reduce the size of the trench for a 2,000 MW power line by up to 50 per cent.
*Schematic illustration*



2.1 NEW GRID ELEMENTS ONGOING DEVELOPMENT OF HIGH-VOLTAGE DIRECT-CURRENT (HVDC) TRANSMISSION

# OFFSHORE INTERCONNECTIVITY

## BENEFITS OF INNOVATION

Additional transmission capacity, greater flexibility and increased efficiency in system planning and operation

To meet its climate targets, the European Union is planning to expand installed offshore capacity to 300 gigawatts (GW) by 2050. The job for Europe's transmission system operators is to integrate this considerable and essential generation capacity into the adjoining transmission grids and ensure its further transmission within these grids. Along with the correspondingly large number of new offshore grid connection systems that are needed and currently realised as point-to-point systems, [SEE FIG. 11, PAGE 36], there is also a need for significant onshore grid expansion.

In this context, there is an increasing focus on grid connection points for HVDC lines that are close to consumption centres. Constructing them avoids onshore grid expansion measures that would otherwise be necessary. Through these measures, wind power would be transmitted downstream from the coastal regions towards the consumption centres, however this would be less efficient economically.

The latest results from system planning studies show that offshore connection systems in particular, with grid connection points that are close to load centres, can be complemented with innovative offshore interconnectivity concepts in the next step. Doing this makes it possible to add substantial value to infrastructure as part of the system integration. Adding such value demands that the synergy effects identified are harnessed with technological, planning and regulatory efficiency and put into practice with little risk.

The overarching concept that Amprion employs in this context is a modular, step-by-step offshore interconnection of point-to-point HVDC systems. The major added value of such offshore interconnectivity can be seen when viewing it from a national level as well as an international one.

With national and international offshore interconnectivity, the designed redundancy produces an economic benefit for the individual wind farm grid connection. With the help of this connection redundancy, the majority of the wind energy can still be transmitted onshore when a high-performance integration system experiences scheduled or unscheduled unavailability, unlike with the current concept that does not feature interconnectivity. However, there are two other modes of action that are much more relevant to the overall benefits of offshore interconnectivity.


FIG. 10 Offshore converter platform in the North Sea

Firstly, what is particularly promising in a national context is connections between offshore grid integration systems that lead to a combination of close-to-consumption and close-to-coast grid connection points on the land. System configurations like these make it possible for grid operators to respond to the congestion situation flexibly when integrating the power from offshore wind farms. If the offshore grid integration systems are not fully utilised, additional transmission capacity can be provided thanks to the offshore interconnectivity. This lets onshore grid congestion be defused or remedied effectively, avoiding the need for redispatching.

Secondly, most of the contribution to the common good is made at the international level by expanding net transfer capacities between market regions and, consequently, by promoting cross-border trade. Furthermore, the system's technological reliability increases internationally because an increase in net transfer capacity improves the ability for asynchronous alternating-current grids to support each other mutually. In the event of critical disruptions, such as system splits, this ability can be significantly important in order to stabilise grid operation quickly and maintain that operation without interruption.

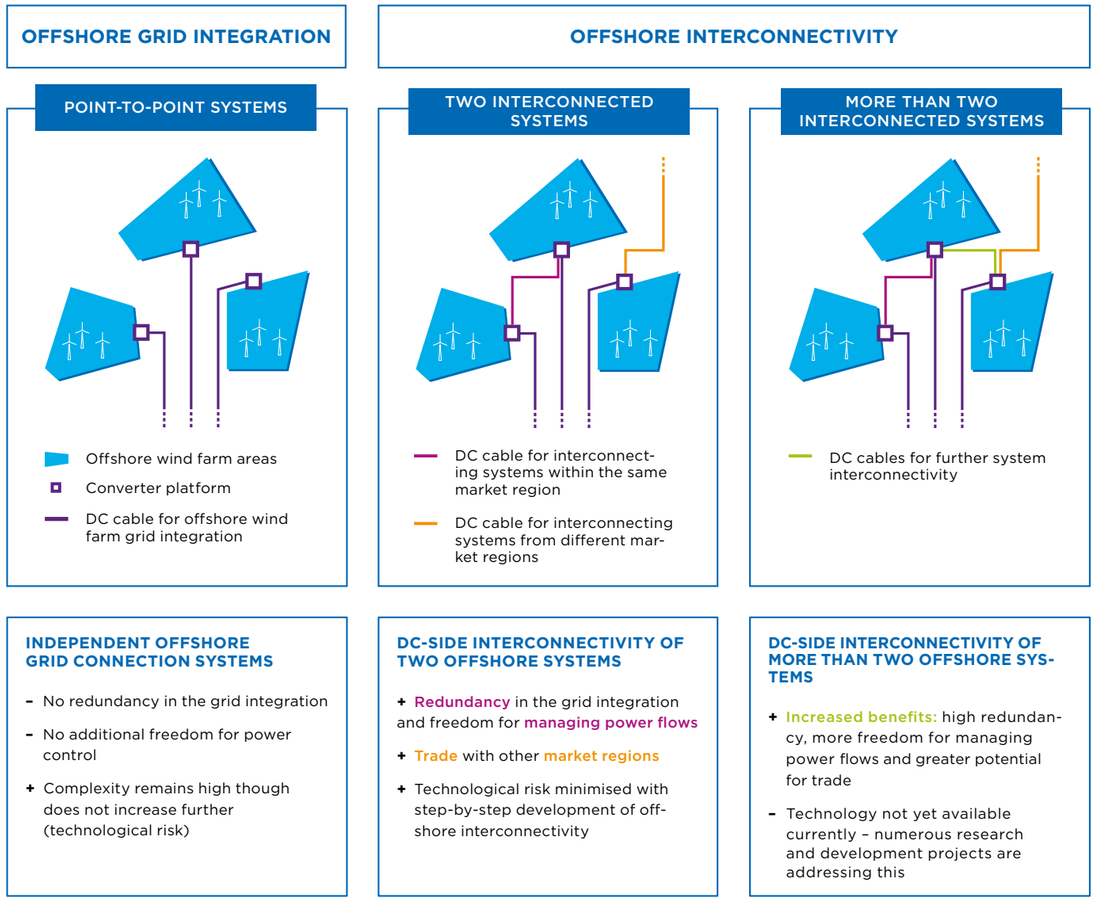
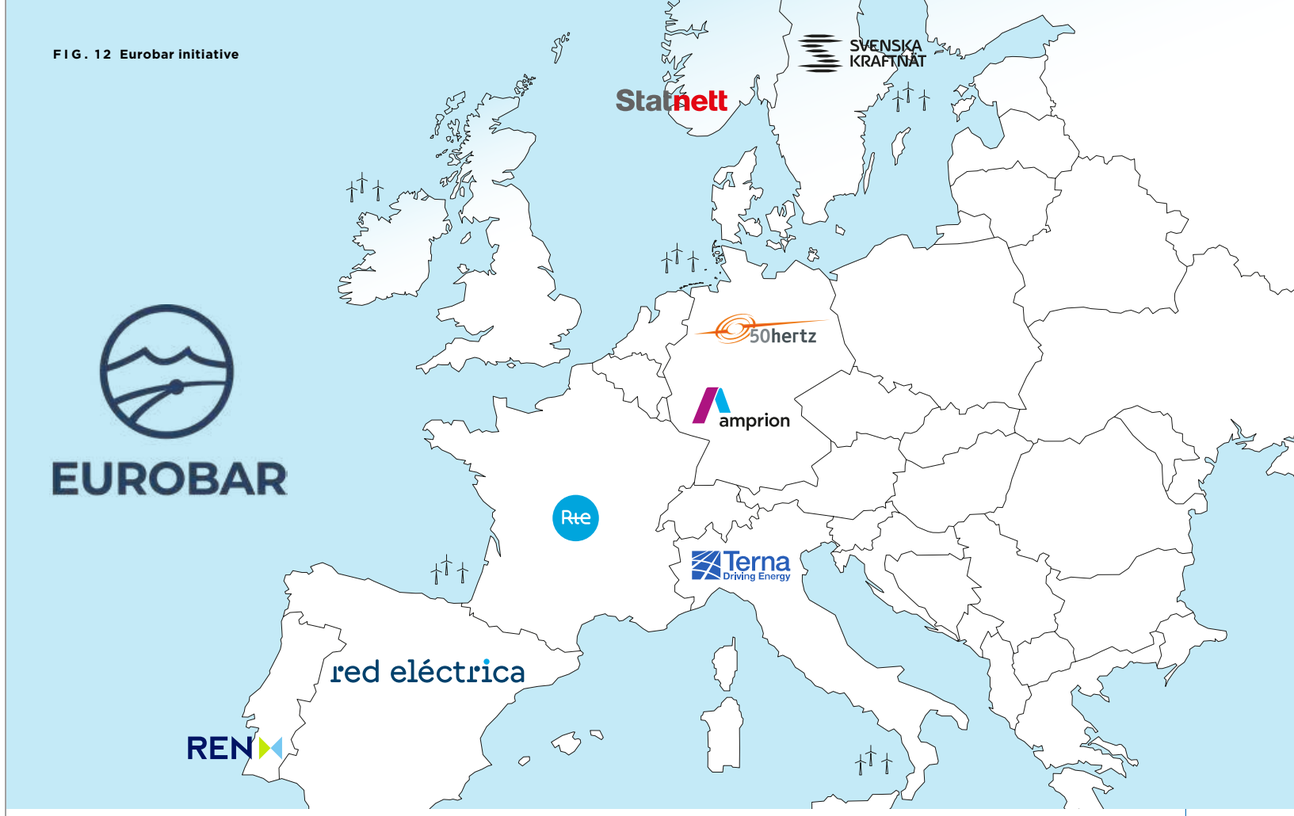



**FIG. 11 Illustration of offshore interconnectivity**

Modular, step-by-step approach for offshore interconnectivity; left: point-to-point systems, centre: interconnectivity of two systems within the same market region, right: interconnectivity of two or more systems possible, including from different market regions

**FIG. 12 Eurobar initiative**




## EUROBAR

Eurobar is an initiative of eight European transmission system operators [SEE FIG. 12] that is intended to enable efficient and secure integration of offshore wind energy by interconnecting offshore systems in Europe. The initiative's tasks include exchanging knowledge about relevant issues in connection with offshore interconnectivity and developing joint TSO positions. The initiative consists of a steering group as well as two working groups focusing on the following fields:

- Policies and Regulation Working Group
  - Cost recovery and the role of anticipative investments
  - Cost-benefit analysis
  - Contractual provisions with manufacturers and liability issues
  - Maritime spatial planning
- Engineering Working Group
  - Offshore HVDC infrastructure
  - High-voltage cables
  - Grid access conditions (network codes)
  - Deep-water infrastructure

Eurobar's overarching goal is to accelerate offshore interconnectivity measures and reduce the risk associated with them. It focuses on providing support for standardisation processes for interfaces and technologies.

## RESEARCH ACTIVITIES

Due to the heavy complexity of interconnected offshore systems, there is a variety of unanswered technological as well as regulatory questions requiring research. They are addressed in various research projects, including:

- ZONES: conceptual analyses for future grid connection concepts
- ZONES EMT: electromagnetic transient (EMT) simulation in the context of future offshore grid connection concepts
- Ready4DC: preparation for multi-vendor and multi-terminal direct-current technology
- InterOPERA: enabling of HVDC grid interoperability with systems from different manufacturers
- HVDC WISE: design of HVDC-based grid architectures for reliable and resilient hybrid AC/DC transmission systems spread across large spaces

A central goal of the research activities is the secure and reliable operation of interconnected offshore systems. Offshore interconnectivity must not produce any risks for the stability of the electrical power grid. Moreover, HVDC systems will need to be interoperable in the future. This means that systems from different manufacturers will have to function in connection with each other. The characteristics required of the systems are frequently referred to as multi-terminal capability, multi-vendor capability and multi-purpose capability in this context.


2.2 NEW GRID ELEMENTS OFFSHORE INTERCONNECTIVITY

# BLACK-STARTABLE OFFSHORE SYSTEMS

## BENEFITS OF INNOVATION

Grid and supply restoration using offshore wind farms

The transmission grid is the backbone of energy supply and is a complex and resilient system. Major disruptions are rare, with the system being designed in such a way that end customers do not experience limitations even if there are malfunctions. Nevertheless, the transmission grid can theoretically also reach its technical limits – and in the worst case, Europe would see its grid collapse. In this unlikely scenario, there would be no power or current at all in the entire electrical grid. Power would need to be restored to the grid step by step before end customers could be supplied again.

Amprion is required to have a grid recovery plan at the ready in the event that the grid collapses. This plan describes strategies for how the electrical-energy supply in the grid region can be restored. The transmission grid currently depends on conventional, large power stations powered by fuels such as gas or coal to implement this plan. These sorts of power plants will need to be shut down progressively as part of the journey towards 100 per cent generation from renewable sources. Consequently, the generators of renewable energies need to become a useful resource for the grid's recovery and restoration of supply.

With Germany's target of expanding to 70 gigawatts (GW) by 2045, offshore wind energy has the potential to play a major role in the restoration, especially because its grid connection systems are connected directly to the transmission grid and can therefore be managed directly by the relevant transmission system operator. The offshore grid connections in Amprion's territory are constructed as high-voltage, direct-current (HVDC) transmission systems due to the distance of the transmission from the wind farms to the grid connection points.

To make the best use possible of this potential, Amprion is already examining how offshore wind farms with HVDC integration can contribute to a restoration of the grid and power supply. This also includes examining "black-startability": the ability to restore a power station or electrical grid on its own, without an external electricity supply. Amprion identifies the requirements for future black-startable offshore grid connection systems and offshore wind farms and develops the necessary interfaces. For these efforts to succeed, it is essential that Amprion's system management, the HVDC systems and the offshore wind farms all interact seamlessly.

For this reason, Amprion works closely with wind farm operators, the manufacturers of HVDC systems and offshore wind turbines; and leading research institutions in R&D projects as well as in accompaniment to DolWin4 and BorWin4, Amprion's first offshore projects.

### HVDC-BLADE

In a research project called HVDC-BLADE ("Black Start Demonstration" of Offshore Wind Parks), Amprion is already working as part of a broad consortium on the concrete design of the individual requirements, functions and interfaces for the black start of offshore wind farms integrated through HVDC. The members of the consortium are RWTH Aachen University, eight offshore wind farm operators (acting together in the Offshore Wind Accelerator programme) and Siemens Energy. The results are validated through simulations as well as through the Hardware-in-the-Loop laboratory at RWTH Aachen University.

### OFFWIPP

In a research project called OffWiPP ("Offshore Wind Farms as Power Plants"), the University of Rostock is working together with HVDC manufacturer Siemens Energy and offshore wind turbine manufacturer Siemens Gamesa to investigate the extent to which offshore wind farms can fulfil the typical duties of conventional power plants in grid operations. One aspect of this includes black-startability. The transmission system operators 50Hertz and Amprion are involved in the research project as associated partners and pass on the grid and system requirements to the research partners.

### DOLWIN4 AND BORWIN4

To support the grid's restoration with offshore wind energy as quickly as possible, the offshore consortium of Siemens Energy and Dragados Offshore is performing a feasibility study on the integration of black-start capabilities into DolWin4 and BorWin4, Amprion's first offshore projects.

**FIG. 13 Offshore wind turbines**





2.3 NEW GRID ELEMENTS BLACK-STARTABLE OFFSHORE SYSTEMS

# INNOVATIVE EQUIPMENT TO STABILISE THE ENERGY SYSTEM

BENEFITS OF INNOVATION

Supply of reactive and active power to ensure stability in a changing energy system

The transmission grids are the backbone of Germany's energy system. Amprion's job as a transmission system operator is to operate the transmission grid in its designated zone stably and securely. At the same time, however, the energy system's reconstruction is progressing further and further and conventional power plants are being progressively shut down. As a result, a large number of synchronous generators that used to have an important role in ensuring system stability are being lost. Meanwhile, the steady expansion of renewable energies is increasing the volume of power electronics in the grid. This technological transformation is leading to changed system behaviours that will also involve new challenges to system stability.

The availability of sufficient reactive and active power provides an important contribution to the system's stability. The reactive-power compensation systems that Amprion uses include rotating phase shifters, static synchronous compensators (STATCOM), converters at HVDC stations, mechanically switched capacitors with damping networks (MSCDN) and compensation chokes, while new technologies such as asynchronous rotating energy system stabilisers (ARESS) are also being investigated.

Changes in active power, such as those caused by power plant failure or "system separation", are fully compensated for from the first moments through the spinning reserve. It is traditionally supplied through the generators and turbines – the "rotating masses" – in power plants. However, due to the power electronics dominating the grid, new solutions will also need to be found for this situation. To counteract the lack of rotating masses, Amprion is working on technological options related to "grid-forming capabilities".





Amprion is applying various innovative technologies and concepts so that sufficient reactive and active power will be available in the future electrical grid.

## CONVERSION OF POWER PLANTS INTO ROTATING PHASE SHIFTERS

Although the construction of new compensation systems is proceeding continuously, the heavy load in the transmission grid and accelerated phase-out of coal means that short-term action is needed in order to supply additional, governable reactive power, both capacitive as well as inductive. Through various feasibility studies and dynamic simulations, Amprion has worked together with power plant operators and manufacturers to analyse the extent to which there is potential to convert generators (synchronous motors) in large, shut-down power plant units into rotating phase shifters. The necessary specifications have also been identified based on this. Accordingly, these systems can be used for a transitional period of about five to eight years until modern reactive-power compensation systems have been installed in the grid, with the rotating phase shifters remaining the property of the power plant operators. In parallel to the technical realisation of the rotating phase shifters, the necessary contracts must be signed with the power plant operators and the Bundesnetzagentur, Germany's energy regulator.

Amprion has carried out Germany's first conversion of this type – at the Biblis A power plant. It was confirmed in the grid operations that the systems have an additional, stabilising character through the supply of short-circuit power and a portion of rotating mass. The underlying concepts that have been developed need to be adjusted for the relevant power plant being converted, with the conversion taking approximately six to twelve months to complete. The concepts are being refined further based on the increasing amount of experience within the company. The most recent conversion was the previously shut-down Westfalen E coal unit, which has been online as a rotating phase shifter since May 2022 to support the 380 kV voltage in the Westphalia region.

While the use of closed power plant systems as rotating phase shifters can generally be seen as sustainable, it should be noted that some of the systems have been in service at power stations for decades and thus have an increased need for repair. Furthermore, the ongoing operating costs are higher than those for new, more efficient compensation systems. Converting power plant generators into synchronous converters can be a good transitional solution to ensure that the need for reactive power is satisfied in critical grid areas.

**FIG. 14 AND 15** Rotating phase shifters with a start-up converter at the Westfalen E power plant


**FIG. 16 TOP** View of Kriftel STATCOM
**FIG. 17 RIGHT** The MSCDN system in Kriftel

## HYBRID SYSTEM FOR REACTIVE-POWER COMPENSATION

A hybrid reactive-power compensation system at the Kriftel substation near Frankfurt am Main went into service in 2019 and is the most powerful system of its kind in Europe as well as Amprion's first such system. The hybrid system consists of two units: a mechanically switched capacitor with a damping network (MSCDN) and a static synchronous compensator (STATCOM).

The MSCDN system is based on capacitors that can be used to raise the voltage in the grid. It reduces the required transmission of reactive power to adjoining lines, which in turn increases the maximum transmission capacity. The STATCOM system is a compensation system for regulating electrical energy. Using it, the voltage in the grid can be raised as well as lowered. It too is used to maintain a given voltage level. The reactive power can be regulated very quickly and with continuous adjustability, which means that Amprion can respond to changing grid conditions directly and stabilise the voltage.

Extensive preliminary studies have shown that the Kriftel station is particularly suitable for the use of such a reactive-power compensation system given its location on the north–south axis in the transmission grid and the heavy electrical load in the Frankfurt region. The hybrid system was integrated into the transmission grid, constructed with the system partner Siemens and successfully put into operation based on the requirements defined by Amprion. The benefits predicted of the system according to the analyses and modelling were confirmed in operation. Furthermore, Amprion has since then gained valuable operational experience in handling a high-performance hybrid MSCDN-STATCOM system and future projects will be able to build on this experience.

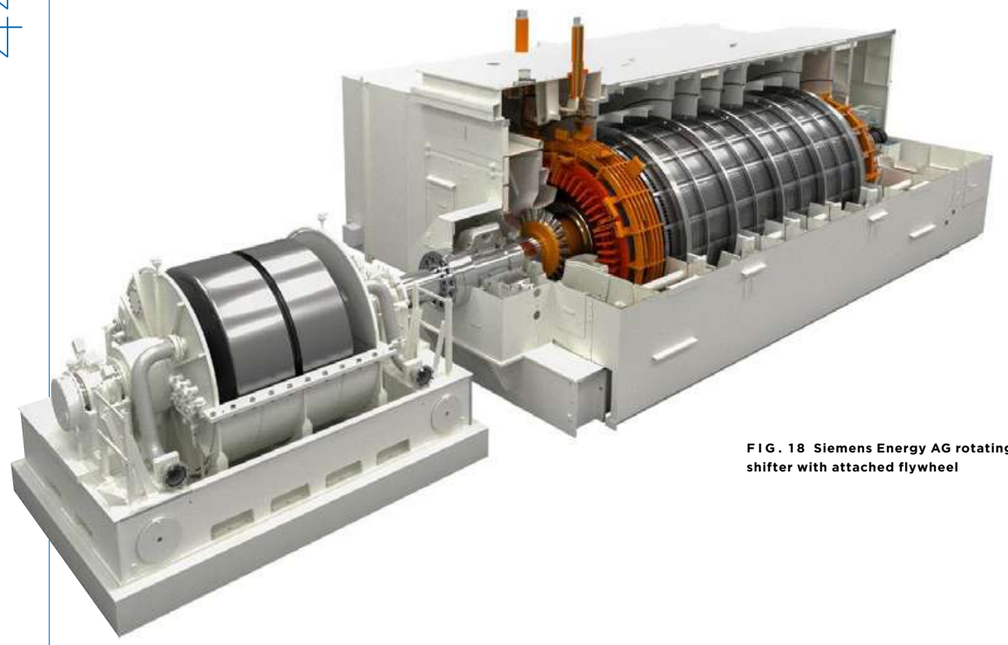


**FIG. 18 Siemens Energy AG rotating phase shifter with attached flywheel**

## ASYNCHRONOUS ROTATING ENERGY SYSTEM STABILISER (ARESS)

The asynchronous rotating energy system stabiliser (ARESS) supplies reactive power and contributes significantly to the fulfilment of the need for short-circuit power and spinning reserve. Unlike conventional rotating phase shifters, far more rotational energy can be taken from the spinning shaft, especially when supplying spinning reserve. Since the asynchronous rotating energy system stabiliser is a fully integrated technology, the requirements for reactive power, short-circuit power and spinning reserve can be met cost-effectively and with an efficient use of space. With these advantages, Amprion and Siemens Energy along with their research and development partners are planning to construct the world's first asynchronous rotating energy system stabiliser capable of high power at approximately 300 megavolt amperes (MVA) in a grid with a frequency of 50 hertz (Hz).

The ARESS applies the principle of a double-fed asynchronous motor with an attached flywheel as an energy storage system [SEE FIG. 18]. The electric motor's exterior is similar to a rotating phase shifter, though it contains a three-phase alternating-current rotor winding which is fed by a frequency converter (M3C: modular multilevel matrix converter). As a result, the mechanical torque of the asynchronous motor is disconnected from the mains frequency, while a regulated change of torque makes it possible to load and unload energy in the rotating flywheel.

## SERVING REACTIVE POWER AND PROVIDING INERTIA RESPONSE

To ensure the grid's stable operation even with a high 60 to 100 per cent level of converter-based generation, future systems with self-controlled grid converters (such as HVDC links or STATCOM systems) are planned to be complemented with grid-forming capabilities. Grid-forming capabilities include, among other things, the contribution to system intertia. If the frequency deviates because of a disruption, for example, the inertia comes into effect immediately and limits the frequency gradients arising from it until other frequency-supporting or frequency-relieving measures are applied.

STATCOM systems are increasingly being used for dynamic reactive-power supply. Owing to their technological architecture, however, they only have a very limited capability or even no capability of supplying intertia. For this reason, Amprion is currently defining requirements for the provision of spinning reserve by STATCOM systems. The realisation of "intertia" functionality has been examined in extensive simulations. However, there are still other key questions that must be considered, such as the requirements for complying with regulatory parameters, requirements for the environment (installation location and space needed, environmental hazards, etc.) and requirements for the operation of such systems (repair and maintenance, remote access, operational safety, etc.).

Another possibility for increasing the inertia in the transmission grid is to use rotating phase shifters with a flywheel. Rotating phase shifters have been used at Amprion for many years. Since their primary purpose currently is not to supply inertia, rotating phase shifters have a relatively small rotating mass, however this can be increased by attaching a flywheel. One example of this is the flywheel already in operation with the rotating phase shifter at the Uchtelfangen station. Moreover, Amprion is planning to equip rotating phase shifters with a flywheel at further stations, too.





# DISTRIBUTED GRID BOOSTER

BENEFITS OF INNOVATION

Higher utilisation of the transmission grid in "curative" operation


**FIG. 19 Large battery storage for a grid booster with modular architecture**

Maintaining the stability of the transmission grid while increasing its utilisation simultaneously is a constant challenge for transmission system operators like Amprion. Grid boosters are an instrument to help with this challenge.

The term "grid booster" refers to large battery energy storage systems (BESS) that are integrated into the control systems employed by the transmission system operators as part of their "curative" system operation [→ CURATIVE SYSTEM OPERATION, SEE PAGE 63]. They provide a backup reserve that enables higher utilisation of the grid in its normal state prior to a disruption (preventive). This reduces the need for expensive, preventive congestion management. If a disruption occurs in the transmission grid, a grid booster can be used as a fast (curative) response to avert overload caused by the disruption before the aforementioned potential overload can cause follow-on damage. Grid boosters counteract disruptions within minutes and for up to one hour before needing to be replaced by other assets. Grid boosters are available solely for grid operations as a form of "insurance" against disruptions in the transmission grid, and cannot be used for market applications.

In keeping with the principle of systemic thinking and acting, Amprion has refined the grid booster concept. Multiple smaller, distributed and modular units are deployed instead of using one central BESS [SEE FIG. 20, PAGE 46]. This modification allows the modules to be integrated into the distribution grid in locations that are useful for the grid, creating a benefit for the transmission grid as well as the distribution grid. The distributed concept allows for greater resilience against disruptions and has less of an environmental impact thanks to the significantly smaller dimensions. This in turn leads to higher acceptance among the population. In conjunction with E.ON, Amprion is currently pursuing a project called "Dezentraler Netzbooster" (Distributed Grid Booster) in the Bavarian Swabia region. The plans provide for total power of 250 to 300 megawatts (MW), spread across various battery modules.

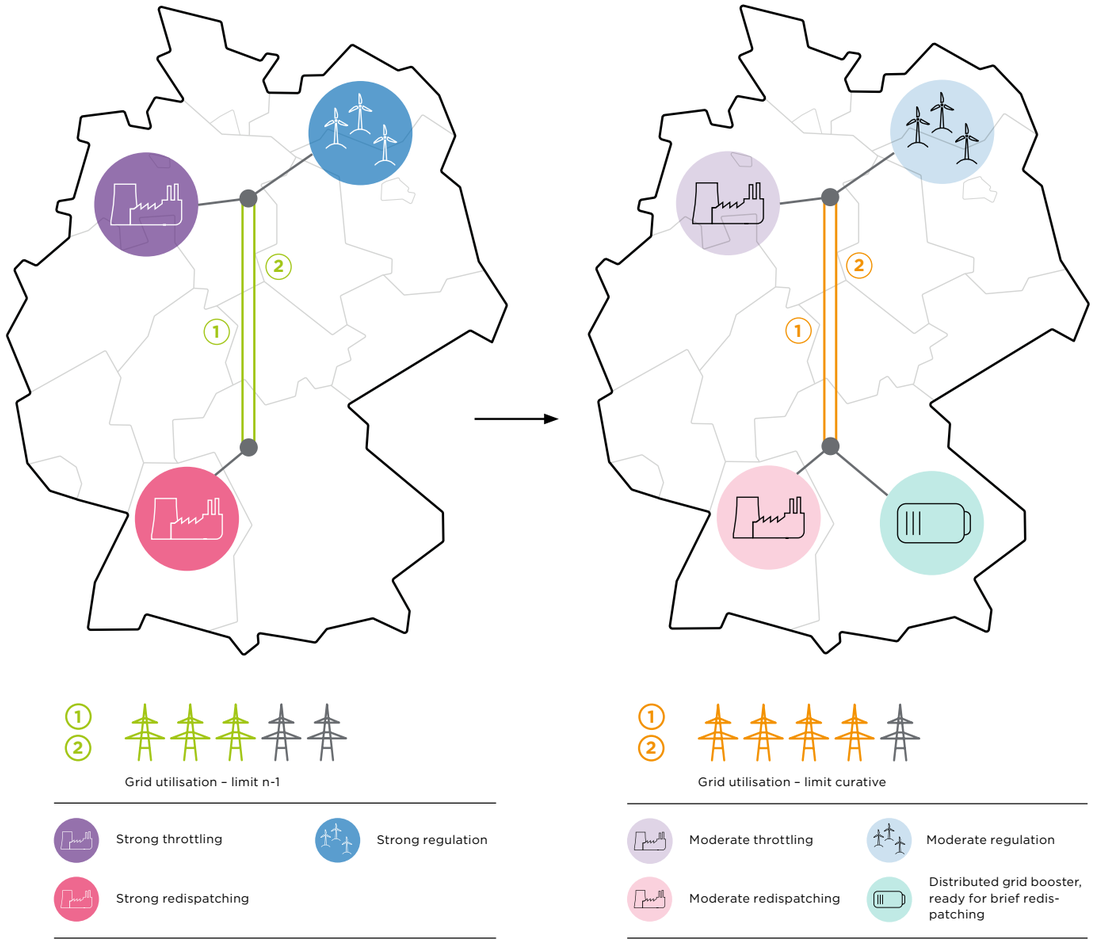



**FIG. 20 Simplified illustration of the higher transmission grid utilisation enabled by the distributed grid booster**

Left: status quo without grid booster, right: target "curative" operation with grid booster.
*Schematic illustration*





# NEW EQUIPMENT IN THE EXRA-HIGH-VOLTAGE GRID

BENEFITS OF INNOVATION

Increased transmission grid performance

To cope with the challenge of the increasing transmission needs in the grid over the long term, Amprion is already examining new operating equipment and concepts with its partners in industry and academia. Developers and grid operators benefit equally when a transmission system operator supports promising ideas from an early stage, as special requirements are placed on grid equipment due to the transmission's grid societal relevance. By engaging in partnerships, these requirements can be incorporated in research and development early on. At the same time, technologies and concepts that are already mature can be considered in system and grid planning processes so that the benefits of innovation are leveraged as quickly as possible.

## FLEXIBLE COMPONENT FOR MANAGING LOAD FLOW IN THE 380 KV GRID

The load flows within the grid are changing significantly due to the expansion of renewable energies and rising power consumption. This produces an uneven distribution of load flows in certain parts, which can lead to grid congestion and redispatching measures. Five substations are going to be equipped with load-flow-managing equipment over the next five years as an ad hoc measure to increase the flexibility and optimisation of the grid's utilisation. This equipment mainly consists of quadrature boosters. Other equipment for managing load flow within Amprion's grid has been examined in a project done with Smart Wires Inc., a company from the United States. This feasibility study assessed extensive conditions for using modular units to manage the load flow within Amprion's 380 kV extra-high-voltage grid.

The SmartValves™, which are components that are categorised as modular static synchronous series compensators (mSSSC) and based on power electronics, can be used in addition to or in place of a quadrature booster if the latter cannot be integrated due to the physical dimensions, weight or impact on the system's stability [SEE FIG. 21 AND 22]. In addition, SmartValves™ are scalable and can be shifted to other locations in a variable manner. Along with the calculation of needs analyses, the technical parameters for integrating SmartValves™ into Amprion's stations have also been examined. Furthermore, additional studies have been initiated to evaluate the power electronics components' flow-on effects on random grid connection points. Through this project, Amprion has taken advantage of a further, innovative grid element to make the grid's utilisation more flexible. A potential pilot project for validating the findings is currently being assessed.

**FIG. 21 AND 22** Example customer system, SmartValves™ from Smart Wires Inc.

## SUPERCONDUCTING DIRECT-CURRENT CABLES IN THE TRANSMISSION GRID

Materials are referred to as superconductors when they lose electrical resistance upon falling beneath a certain temperature, for example high-temperature superconductors (HTS), which must be cooled at less than –180°C using a coolant such as liquid nitrogen. In conjunction with Vision Electric Super Conductors GmbH (VESC), the Karlsruhe Institute of Technology and Messer SE & Co. KGaA, Amprion has performed a study examining the use of HTS cables as an alternative to conventional direct-current cables. One benefit of superconducting cables compared to conventional cables, for example, is that the transmission capacity for each cable system can be increased significantly. Furthermore, the absence of ohmic losses in the cable means that there is no thermal discharge into the earth and electromagnetic fields outside of the cable can be avoided.

Nevertheless, space is still required along the cable corridors for intermediate cooling stations, and these may be spread from 10 to more than 100 kilometres apart depending on the concept. Cooling the superconductors requires energy, similarly to a household refrigerator. For this reason, there must be safeguards ensuring that the loss reduction on the cable corridor is more than the cooling required. The cost-effectiveness of superconducting cables depends strongly on the price of the superconductors compared to the price of copper. At the moment, there is no experience anywhere in the world with the use or reliability of superconducting cables for bridging longer transmission distances. There are pilot systems spanning ranges of several hundred metres to a few kilometres.

Superconducting cables are a promising technology for long transmission distances in the medium and long term. Compared to conventional cables, however, they still need to prove their ability to be installed and their reliability. Amprion is currently evaluating the applications in which the benefits of superconducting cables can be utilised, and these applications will form the basis for potential follow-up studies. The study outcomes were presented to expert audiences by VESC in 2022 as part of the 8th conference on the “Future and Innovation of Energy Technology with High-Temperature Superconductors”.



# GRID EXPANSION 2.0

3



To advance the energy transition, the grid's expansion must be accelerated. Every action counts. That is why Amprion is working together with partners in research and industry on things such as new drilling methods for underground-cable projects and pursuing new approaches for corridor planning.



# POWERGRID PATHFINDER

BENEFITS OF INNOVATION

Conflict prevention in corridor planning and resulting acceleration of grid expansion projects

With the energy transition, the demand for transmission grid capacity is rising – and so too is the demand for grid infrastructure. It is now supposed to be planned, approved and built even faster in order to make the electrical grid ready for a climate-neutral future. However, the construction of new power lines also affects the interests of many people, interferes with their living environment and impacts the local nature. This can lead to conflicts which draw out the approval processes. For this reason, Amprion endeavours to minimise any form of impact and conflicts arising from them right from the planning stage for the grid infrastructure and to document these efforts transparently. On top of that, the planning for power line construction projects must be done according to uniform principles, even if the individual projects may vary considerably. The standards on which impacts and conflict intensity are measured must therefore be consistent regardless of the project.

Amprion has for this reason developed the Powergrid Pathfinder (or "$P^2$" for short) in cooperation with TU Dortmund. It helps the project teams to identify low-conflict line corridors between two pre-defined connection points. $P^2$ is tailored to the professional planning conditions for power line infrastructure projects and integrated into GIS-based planning software.

The lengths of line required in various spatial categories (such as the resistance associated with a given space, space usages, spaces already under stress) are viewed as decisive criteria for the conflict potential. The aim is to minimise the length of line required in these spaces. Unlike previously used methods for marginal-cost analysis, the methodology developed at Amprion is based on a multi-criterion optimisation approach. The benefit to it is that the previous weighting of criteria against each other is no longer needed, which means that the balancing of criteria that is necessary in the planning can be modelled more precisely.

What results from this multi-criterion optimisation approach is not a single solution for all problems. Rather, it ultimately produces many solutions. These solutions are referred to as the non-dominated or Pareto-efficient solutions to the optimisation problem.

It means that a possible line corridor is dominated by another when the latter is at least just as good in all the criteria examined and better in at least one criterion (less length required). The alternative corridors represent precisely the conflicts between the individual optimisation criteria. Improving a solution against a criterion is only possible when multi-criteria optimization against at least one other criterion is accepted. The planning tool maps out the project team's criteria consideration process and helps it to evaluate a given space.

Using the "spider charts", it is possible to navigate through the mass of solutions interactively [SEE FIG. 23]. Various alternatives can be evaluated and the interactions between the criteria juxtaposed intuitively.

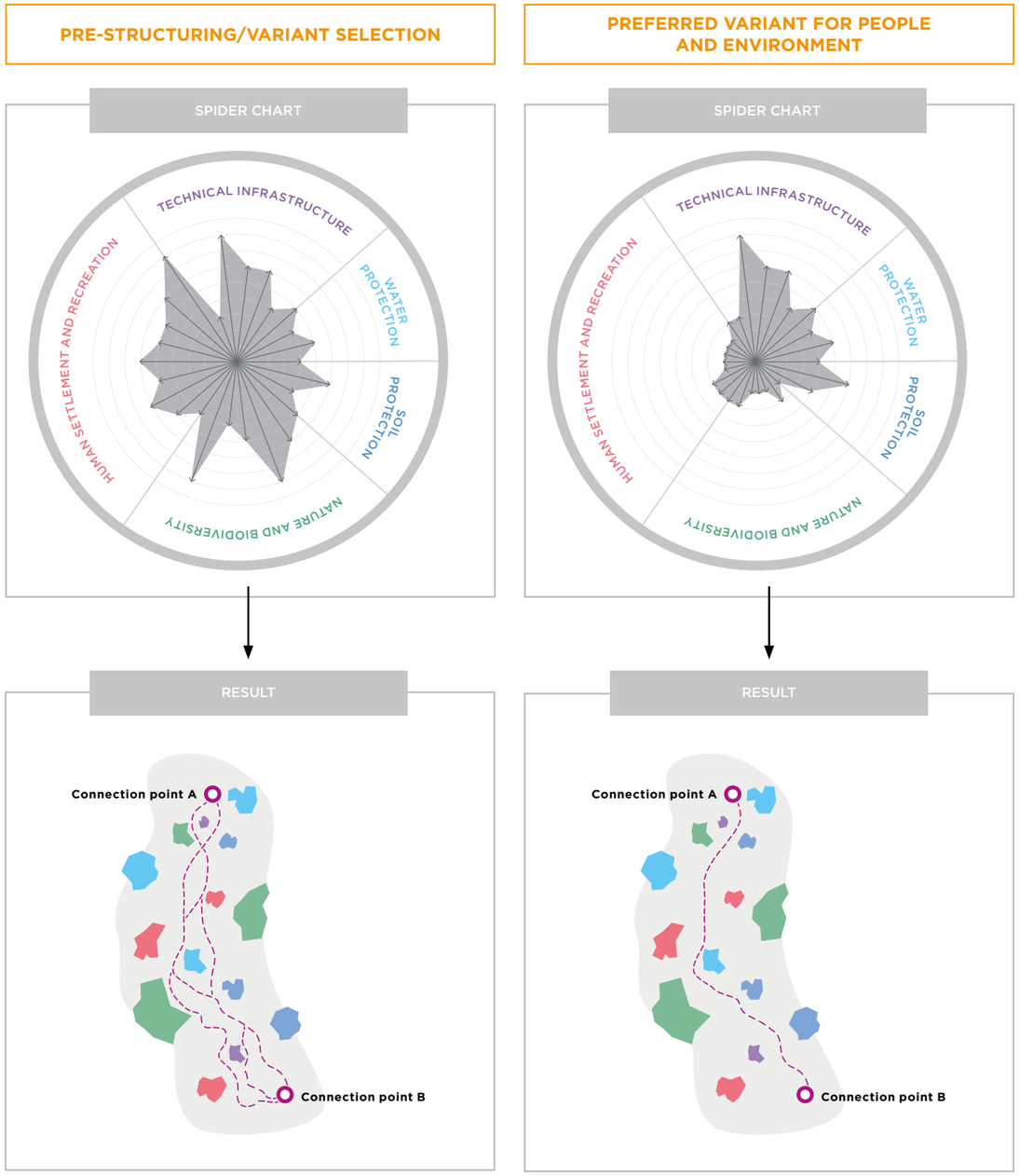



**FIG. 23 Potential corridors, including illustration of different spatial categories (bottom) and multi-criterion consideration using a spider chart (top)**
*Schematic illustration*





# E-POWER-PIPE

## BENEFITS OF INNOVATION

Installation of underground cabling over long distances with little impact on the environment


**FIG. 24 Amprion GmbH E-Power-Pipe construction site in Bacharach**

When pipes are installed underground, the methods used include the standard open-cut line trench or, depending on the location, tunnelled, i.e. trenchless techniques. When planning its first cable corridors, Amprion found that the available tunnelled construction methods lacked an option for installing smaller pipes close to the surface over long distances.

With funding from Germany's Federal Ministry for Economic Affairs and Energy, Herrenknecht AG has developed the E-Power-Pipe method in conjunction with Amprion and RWTH Aachen University. It combines the proven boring technologies of horizontal directional drilling (HDD) and microtunnelling (pipe ramming). The method is being continuously technically refined by Herrenknecht AG and can also be used for pipeline construction.

The newly developed microtunnel boring machine (MTBM) used for it has a bore diameter of 505 millimetres. It can currently be rammed across a distance of up to 2,000 metres to its destination. The use of a control and navigation system makes it possible to bore horizontal as well as vertical curves. Existing infrastructure such as pipes, bodies of water, roads or railways can be tunnelled under, too.

A first practical test took place in 2017 in connection with one of Amprion's underground-cable construction sites in Borken. It saw the performance of the newly developed method being proved on a 300-metre corridor. Since this time, further applications with higher levels of difficulty have been realised successfully.

The major advantage of the E-Power-Pipe method is that cable conduits can be installed close to the surface across long distances and that only a small number of scattered intrusions into the surface above are needed, which was previously impossible in this form. These intrusions into the surface are concentrated mainly on the construction site equipment spaces in the start and destination areas, where temporary trenches, work zones and material storage areas must be built. The environmental impacts that must be taken into account as part of the approval procedures can, depending on the individual situation, be considered as relatively low-cost. Disadvantages include the higher construction costs and longer construction times compared to installation in an open-cut cable trench.

The method is currently not explicitly mentioned in the technical standards yet. Owing to the applications that have already been realised, the method can be seen as the current state of the art.

# MULTI-BLADE PLOUGHS FOR UNDERGROUND-CABLE CORRIDORS

BENEFITS OF INNOVATION

Faster completion of direct-current projects in sections

**FIG. 25** Two-blade cable-laying plough during the Amprion test

The use of ploughs is considered a half-open-cut installation method. The soil is displaced using a plough blade. A cable or conduit is led through a suitable guide so it can be laid on the bed of the opening created through the ploughing or fed into a cavity that has been widened with a reaming tool. Digging is not necessary for it.

Cable ploughs have already been used reliably in grid expansion projects for a long time to lay cables and pipes in low-, medium- and high-voltage grids for up to 110 kilovolts (kV). The cables here are cables with smaller dimensions. Among the construction methods that the public is familiar with, the method is considered an affordable and fast method. For this reason, property owners ask us continually to use this method on their land, even for extra-high-voltage cables. They believe, among other things, that this method allows a gentler use of the soil than is possible when digging cable trenches for example.

However, the opinions of power line construction experts differ. While some standalone cables can be laid nicely using this method, depending on the circumstances of the individual situation, the extra-high-voltage grid – which has voltages of 220 to 525 kV – requires the installation of two to three side-by-side pipes with precisely defined dimensions in the soil.

Manufacturers of cable ploughs have now developed multi-blade ploughing devices. Nonetheless, the tests conducted so far have not been able to convince Amprion's experts. We have therefore decided to research the potential of this half-open-cut installation method with a two-blade plough conceived especially for its needs and with a series of dedicated tests. We are testing:

- project-specific applicability: the straightness of the corridor, spatial requirements and tolerable obstacle numbers
- cost-effectiveness: amount laid and purchase costs
- usage limits: installation precision, soil type, weather, environmental impacts





# MODIFIED DIRECTIONAL DRILLING

BENEFITS OF INNOVATION

Trenchless, close-to-surface underground-cable installation over long distances with small diameters

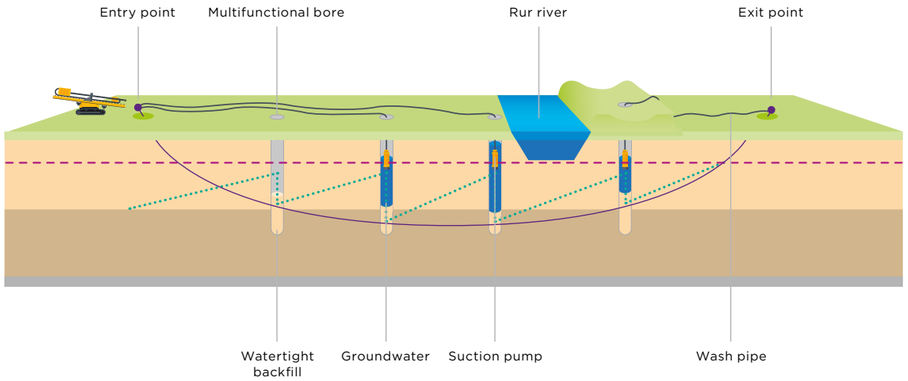



**FIG. 26** Planned bore profiles and position of the suction pumps (multifunctional bore)
*Schematic illustration*

Using modified directional drilling, drilling companies have successfully developed a trenchless construction method that can be classified as in between traditional directional drilling and installing pipes in trenches. The pipes can consequently be installed under a flat surface or a body of water, close to that surface and with little risk of uncontrolled leaks of drilling fluid, or "frac-outs" as they are called. The risk of the drilling fluid leaking is reduced because a certain degree of the drilling fluid volume can be pumped out of the fluid recycling process at predefined places, which helps to keep the annular pressure in the bore beneath the permissible pressure level that has been calculated for the construction site.

The method was tested in a field trial for the first time in March 2018 with Amprion's participation. It proved that it was suitable for drilling close to the surface.

Amprion applied the new technique for two trenchless cable corridor sections as part of the ALEGrO grid expansion project [→ ONGOING DEVELOPMENT OF HIGH-VOLTAGE DIRECT-CURRENT (HVDC) TRANSMISSION, SEE PAGE 31] in 2019. Specifically, we applied the modified directional-drilling method to tunnel under the Rur river near the town of Düren [SEE FIG. 26]. This required an 850-metre-long horizontal bore at a shallow depth beneath the Rur, the Lendersdorfer Mühlenteich mill race and a main road. Leaks of drilling fluid into the bodies of water would have been practically inevitable when using a conventional drilling technique. In contrast, modified directional drilling proved to be a success despite the extremely difficult conditions. Thanks to the findings that have been gained, the method can keep being optimised so that corridor planners will have access to an additional tool for trenchless pipe laying.

# $SF_6$-FREE TECHNOLOGIES

BENEFITS OF INNOVATION

Reduction of equipment's greenhouse gas emissions

**FIG. 27 Voltage transformers with climate-neutral insulating gas synthetic air at Amprion**

Due to its outstanding properties for insulation and arc quenching purposes, the gas sulphur hexafluoride ($SF_6$) is used in high and extra-high voltage equipment for more than 40 years. Since $SF_6$ has a very high global warming potential – about 25,000 times that of $CO_2$ – Amprion has been implementing instructions and measures to reduce $SF_6$ emissions for a long time now. The gas treatment is carried out in a circulatory system and the gas compartments are monitored continuously. Therefore, potential leakages can be detected and eliminated promptly. Nevertheless, Amprion contributes to the emission of $SF_6$ even if this only accounts for a very small proportion of the total $SF_6$ emissions in Germany.

Only the use of new, innovative, $SF_6$-free technologies can reduce emissions over the long term and, prospectively, put a full stop to usage of the gas. In addition to the use of $SF_6$-free technologies at a medium-voltage level, Amprion is already testing the first innovative technologies containing climate-neutral alternative gas at high-voltage and extra-high-voltage levels. This includes:

- Since 2018: 245 kV voltage transformers with climate-neutral insulating gas synthetic air [SEE FIG. 27]
- Since 2021: 420 kV voltage transformers with climate-neutral insulating gas synthetic air
- Starting in 2023 (planned): 123 kV circuit breaker with vacuum switching technology
- Starting in 2026 (planned): GIS bus ducts with climate-neutral insulating gas synthetic air

An additional pilot project with $SF_6$-free technologies involving combined instrument transformers has been started. In addition, Amprion monitors developments in the use of alternative gas in other components of gas-insulated switchgear.

For the use of $SF_6$-free technologies, further research and development by the manufacturers is required, particularly in the field of critical switching tasks of up to 420 kilovolts (kV).

Amprion is willing to test further innovative products and thus to increase the technological readiness level. Using the measures described here, Amprion is contributing to reducing the greenhouse gas emissions from the power grid. At the same time, it is ensuring the security of supply during the currently planned grid expansion and the associated integration of renewable energies.





# COMPACT DIRECT-CURRENT PYLONS

BENEFITS OF INNOVATION

Ongoing development of compact overhead power lines for DC applications so that sparsely populated, topographically challenging corridors can be utilised

For most of the high-voltage direct current (HVDC) transmission lines included in the Federal Requirements Plan, preference is given by law to underground cables (exception: Ultranet). The regional authorities affected can demand that options for overhead lines be examined, if needed. In practice, however, this examination has not produced success or led to processes becoming faster.

**»Amprion has an extensive toolbox with a wide variety of pylon construction methods.«**

Given this background, more flexibility will be needed for further grid expansion in order to overcome exceptional challenges in underground cabling. In particular, topographic conditions such as those in low mountain ranges can be very challenging in terms of technology and time when planning and constructing underground cabling. Amprion therefore proposes to legislative authorities to create an overhead line option for extraordinary technical challenges in underground-cable projects.

Amprion is currently developing compact pylons for direct-current overhead lines for this scenario. They have a smaller influence on the surrounding landscape and consume less space. Amprion has a variety of possibilities for making pylons for direct-current overhead lines more compact. For example, it uses braced-post insulators instead of classic steel lattice construction [SEE FIG. 28].

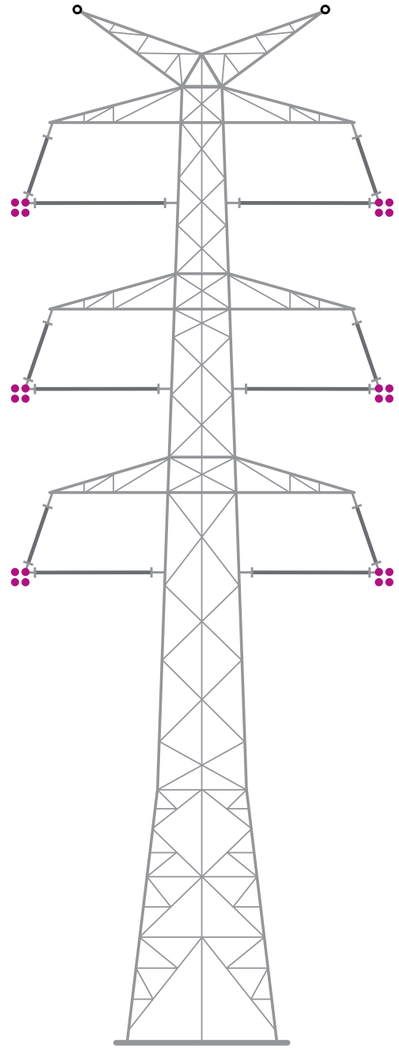


**FIG. 28 Compact direct-current pylon with steel lattice construction and insulated cross-arms**
*Schematic illustration*

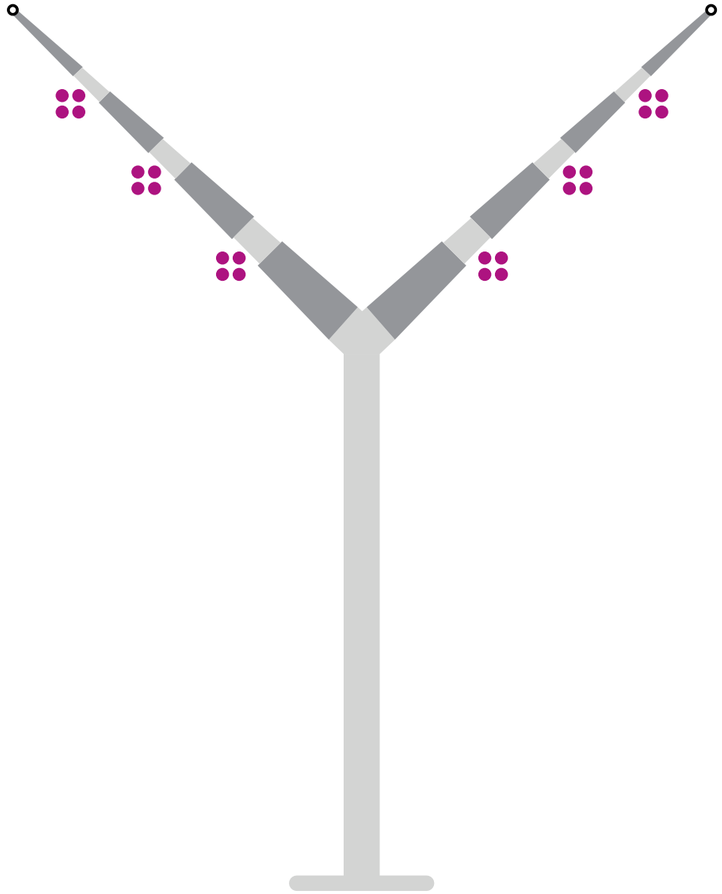
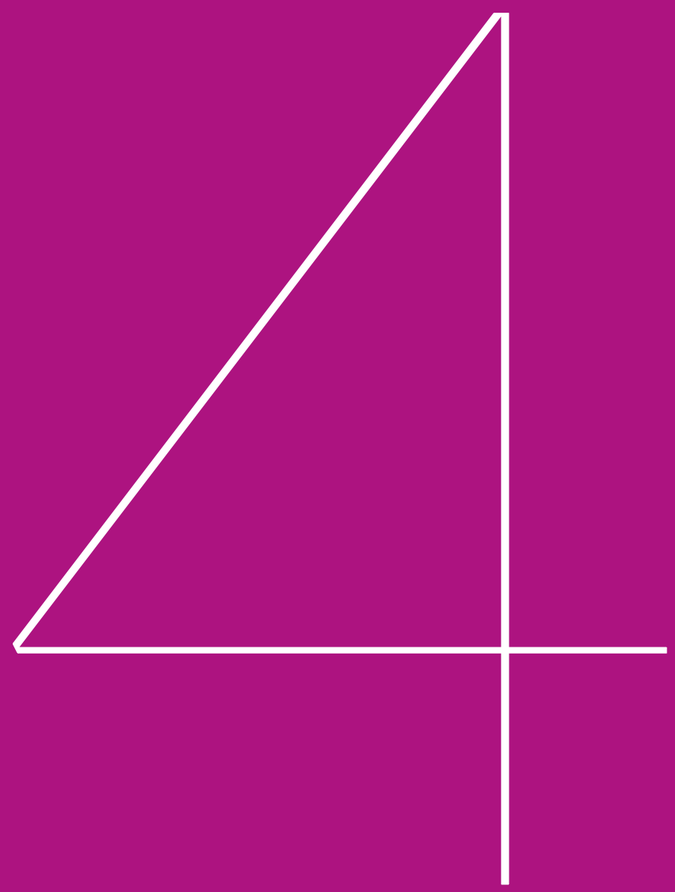


**FIG. 29 Monopole tower constructed as a European Composite Pylon**
*Schematic illustration*

According to the individual requirements of each project, Amprion can draw on a comprehensive toolbox of different tower designs that use lattice construction. To this end, the heights and widths can be reduced for direct-current pylons, although the static possibilities and mandated distances must be taken into account. In addition, specific insulator string shapes and phase arrangements as well as the choice of wire tension and pylon distance can be optimised in such a way that the construction has little impact on the surroundings. Amprion is currently examining complementary direct-current construction types, such as an enhancement of monopole direct-current towers with smaller foundation dimensions [SEE FIG. 29].



# FUTURISTIC SYSTEM MANAGEMENT AND OPERATING CONCEPTS



With the reconstruction of the energy system, the requirements for the system management and operation of the transmission grid are increasing. The new main control centre in Brauweiler shows how Amprion is paving the way for next-generation system management. It uses things such as innovative methods to increase the utilisation of the existing grid.





# BRAUWEILER MAIN CONTROL CENTRE

## BENEFITS OF INNOVATION

Real-time system management with the support of ultra-modern data centres and artificial intelligence to ensure a secure grid in Germany and Europe.

**FIG. 30** Video wall in the Brauweiler main control centre

At Amprion's new main control centre, engineers monitor the transmission grid's current load flows, voltages and the grid frequency in real time. At the centre of the main control centre is a wall of monitors **[SEE FIG. 30]** covering an area of 108 square metres. This makes the wall one of the world's largest in the energy sector. Using it, the employees can identify the load flows in their observation area even more quickly and keep track of things even in challenging situations. Because the scope and volatility of interregional load flows are increasing, the observation area extends far beyond the Amprion grid region. It comprises the extra-high-voltage grid in all of Germany, in the Netherlands, in Belgium, in large parts of France, in Switzerland, in Austria, in northern Italy, in Slovenia, in the Czech Republic and in Poland.

## SYSTEM MANAGEMENT WITH ARTIFICIAL INTELLIGENCE

The engineers at the main control centre can display illustrations and overviews on the monitors of the video wall individually. It lets them identify and evaluate all important system values and figures – and ensure reliable electricity transmission even in extreme situations. They are supported in this by two ultra-modern data centres which process millions of data records from the grid every day. For example, they record the condition of more than 50,000 switchgear at 800 substations and the measurements of approximately 2,800 grid elements.

Amprion makes use of different types of artificial intelligence at the new main control centre, primarily so that it can predict the feed-in from renewable energies [→ ARTIFICIAL INTELLIGENCE, SEE PAGE 81]. Algorithms analyse weather predictions from various sources for this. A self-learning algorithm, when calculating the current prediction, makes stronger reference to forecasts that in the past gave the best predictions in comparable general weather situations. This improves the prediction further and further.

## EUROPE AT A GLANCE

Amprion has taken on wide-ranging coordination duties for the European Continental Synchronous Area. Accordingly, Amprion makes an important contribution to the functioning of the EU's internal electricity market. Amprion's main control centre plays a key role by performing a "synchronous area monitor". The grid frequency must remain stable within the Continental Synchronous Area. For this reason, a special section of the video wall at the main control centre comprises a map of Europe and displays for system condition, alert messages and cross-border power flows. It also provides information about the inter-area oscillations that are increasingly becoming more of a focus and are calculated using a Europe-wide network of high-detail measurement devices. In addition, the contributions made by each individual transmission system operator in the Continental Synchronous Area to maintaining the grid frequency and synchronous time are displayed graphically. Through it, the causes of a disruption can be identified, communicated and rectified promptly. The SCADA system and the constantly refined visualisation of grid data therefore contribute to secure and reliable energy supply in Europe.

In the main control centre, a large number of systems must be monitored and operated at each of its workstations. In the past, the engineers each used separate input devices for different systems and computers, which was inefficient, especially in tense grid situations. Today, all main control centre systems are controlled efficiently using just one single keyboard and computer mouse thanks to the multifunctional keyboards designed especially for the Amprion main control centre.

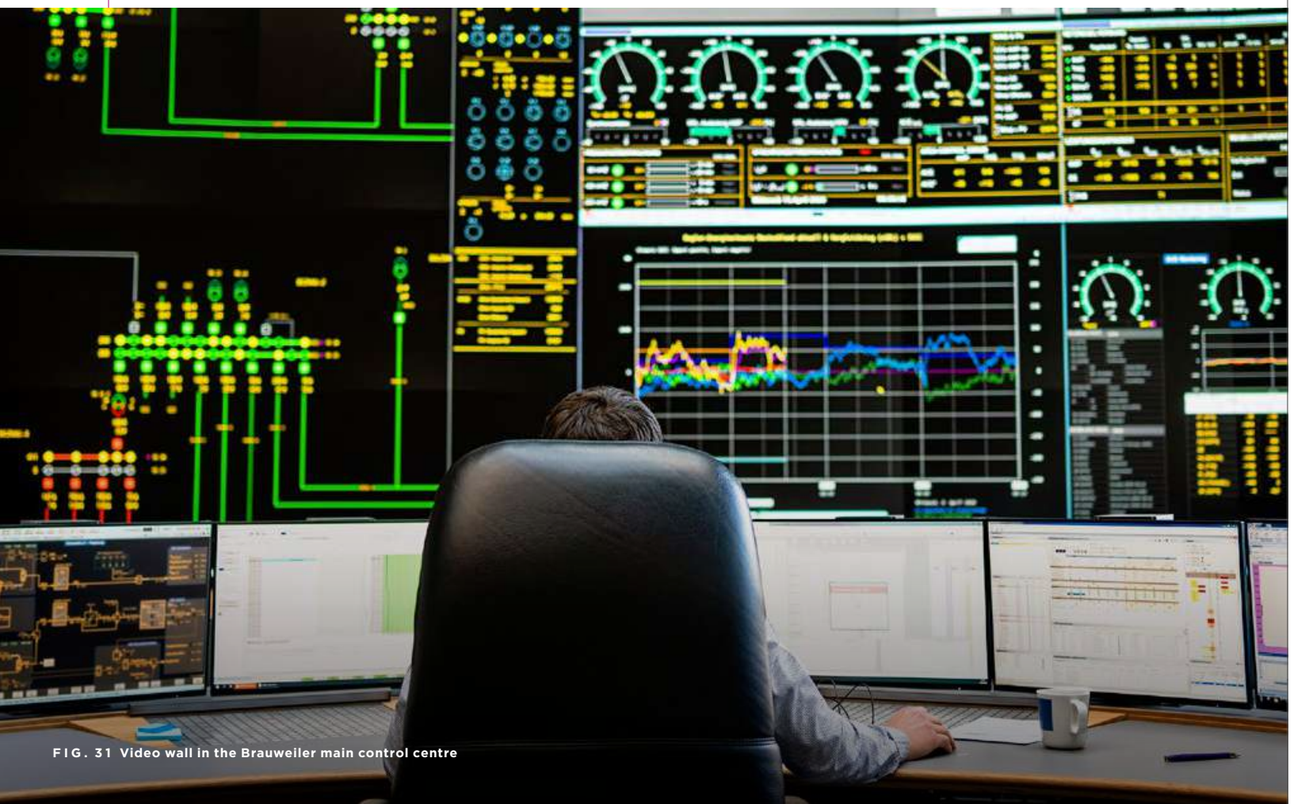


**FIG. 31** Video wall in the Brauweiler main control centre



# CURATIVE SYSTEM MANAGEMENT

## BENEFITS OF INNOVATION

Optimising congestion management and reducing preventive redispatching – the duties of transmission in the future

The costs of fixing congestion in the German transmission grid have risen significantly in recent years. Relief is not expected for the grids in the medium term either due to the accelerated expansion of renewable energies and integration of European markets. Amprion is therefore pursuing innovative approaches in grid operation with a goal of increasing the utilisation of the existing grid and, in doing so, reducing expenses for congestion management. An approach that is discussed often in the context of increased utilisation and innovative technologies is "curative system operation".

In particular, curative system operation differs from the previous form of preventive system operation in the time at which the congestion is fixed [SEE FIG. 32]. A preventive measure, such as redispatching with power plants, is already activated before a potential disruption and reduces the transmission load accordingly so that the grid can continue to be operated without congestion if there is an outage. A consequence of this is that valuable transmission capacity is reserved for rare events.

In contrast, a curative measure is only activated when there has actually been a disruption. The equipment's "thermal reserves", which allow higher currents for a short period, are used until the curative measure has its full effect. The equipment in the grid, such as power lines or transformers, is utilised more for a short time directly after the disruption. The equipment's utilisation is not reduced before the disruption, with the result that the overall utilisation of the equipment can be higher.

Both concepts continue to be subject to the (n-1) criterion, which specifies that congestion must not occur if there is a disruption such as a power line or transformer failing.

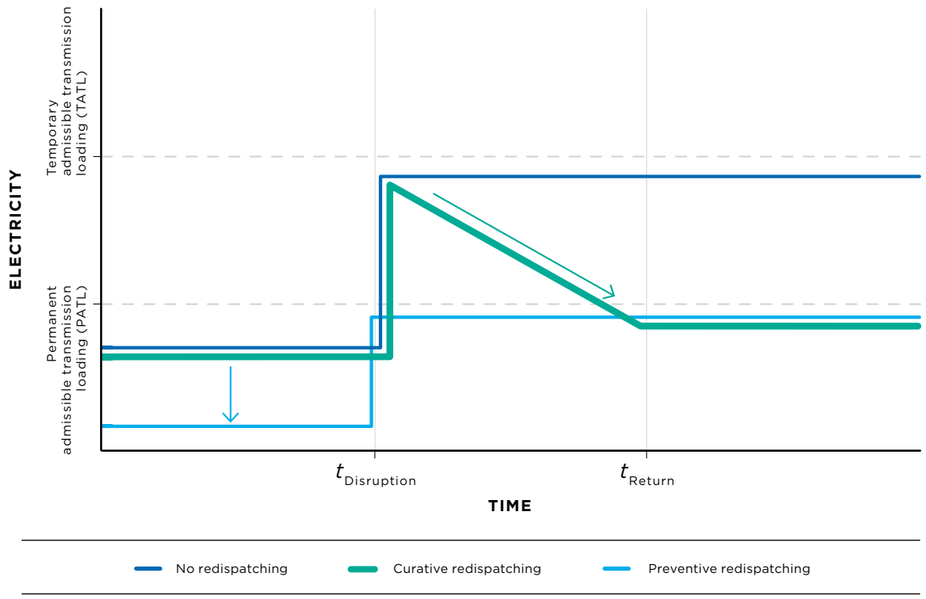



**FIG. 32** Modes of action in preventive and curative congestion management

Amprion has examined the innovative approach of curative system operation extensively and evaluated the potential together with a total of 17 partners in a research project called “Innovation in System Operation by 2030 (InnoSys 2030)”. A key finding was that the combined use of preventive and curative measures is what enables a secure increase in the electrical grid’s utilisation. This means that curative system operation must be integrated into the current form of congestion management. Amprion has already laid the first foundation for it through InnoSys. A field trial in the company’s control system tested the practical incorporation of curative measures into the company’s security calculation and successfully provided valuable findings about operational challenges for the research project.

Based on it, Amprion is now working on the concrete conceptualisation and implementation of selected curative measures. Priority is being given to applications of curative redispatching with conventional and renewable generators, curative topological measures and the use of distributed grid boosters [→ DISTRIBUTED GRID BOOSTER, SEE PAGE 45]. A step-by-step approach is beneficial for this:

First, the measures are tested in pilot projects. Amprion has set a goal of implementing pilot operations of curative measures by 2024. These pilot operations will involve a practical test of the complex interactions in the system landscape, in small dimensions at first. There will be a focus on the curative measure being triggered reliably directly after a disruptive event. While the activation of preventive measures can currently be coordinated with sufficient preparation time, the direct activation of a curative measure must take place fully automatically. To this end, the infrastructure at the system operator and in the control technology must be adapted extensively.

Following a positive test phase, a targeted increase in utilisation is planned to take place in appropriate circuits using curative measures. The challenge will be to gain operational control over the significantly higher complexity of curative system operation. Firstly, an individual curative measure can now be planned for every failure situation and these measures will need to be coordinated reliably with other grid operators. Secondly, the increased utilisation comes with greater requirements regarding power stability and reactive-power needs. It is therefore important that the assistant systems used for system operation are enhanced gradually so that preventive and curative measures can be planned, monitored and coordinated properly, intuitively and robustly.

Having this level of control is essential for making it operationally possible to reduce preventive redispatching by a limited degree while maintaining consistent system security. Regulators and legislatures can create the corresponding legal environment for increased utilisation in order to leverage these potential savings as soon as possible.

**»Curative system operation offers possibilities for reducing the costs of congestion management as well as for supporting system operators with an additional degree of freedom while maintaining reliable grid operations.«**

Curative system operation using this approach offers possibilities for reducing the costs of congestion management as well as for supporting system operators with an additional degree of freedom while maintaining reliable grid operations. Aspects such as system security remain the top priority. They serve as the parameters for integrating curative measures into congestion management. By considering these parameters, Amprion is addressing the sometimes major challenges that it will have to overcome over the next few years together with other grid operators, system operators and governments.





# MARI BALANCING PLATFORM

## BENEFITS OF INNOVATION

European platform for exchanging alancing energy with high efficiency gains

There must be an even balance of feed-in and withdrawal of electrical energy in the power system at all times. Transmission system operators (TSOs) activate balancing energy to cover imbalance at short notice. The manually activated frequency restoration reserve (mFRR) is one of the balancing services used for this purpose. Previously, the mFRR has been activated at a national level and each TSO only had access to generation units in their own country to balance out the power system.

Amprion has been operating the Manually Activated Reserves Initiative (MARI), a Europe-wide platform for mFRRs, on behalf of the European transmission system operators since autumn 2022. The guiding principle is to enable the European TSOs to share offers and demand for mFRRs across national borders.

TSOs forward bids submitted by balancing service providers (BSPs) on the national markets as well as their mFRR demand and the available cross-border capacity to the platform. The platform’s activation optimisation function calculates the lowest-cost way to activate balancing energy bids to cover all demand in Europe, taking into account the information of all participating countries.

Together with the associated projects TERRE (Trans European Replacement Reserves Exchange), PICASSO (Platform for the International Coordination of the Automatic Frequency Restoration Process and Stable System Operation) and IGCC (International Grid Control Cooperation), MARI is one of the cornerstones for the implementation of the European domestic market for balancing energy in accordance with the EU’s Guideline Electricity Balancing. From a technical view, the platforms form the world’s largest system for the real-time optimisation of balancing. The platforms are the basis for the secure and affordable operation of the European power system, especially in times of volatile prices in the wholesale market and increasing uncertainty. In 2022, the savings across all platforms summed up to 1.9 billion euros.

Amprion has been systematically driving the platforms’ implementation since 2017 and therefore provides components that are crucial for TSOs participating in the platforms. In addition to hosting the MARI platform, Amprion is responsible for hosting a communication network for MARI and PICASSO based on the ENTSO-E Connectivity and Communication Service Platform. In the long term, this network will also include the balancing platforms’ capacity management module.

Overall, Amprion’s activities in the field of balancing demonstrate that we are a pioneer in the development of European processes for coordinating international system operations.

**Further information about the MARI balancing platform can be found at**
entsoe.eu/network_codes/eb/mari/

# DYNAMIC LINE RATING

## BENEFITS OF INNOVATION

Weather-based increase in grid utilisation

There are various technical options available to optimise the transmission capacity in the electrical grid operationally. For example, elements that control power flows can be used or switching measures performed in the grid. The most efficient option for increasing transmission capacity is weather-based overhead-line operation or dynamic line rating (DLR), since it does not require any grid expansion or corridor planning. The aim behind it is to increase the load on line corridors based on the weather. For the technical implementation, new approaches from weather model reanalysis ensembles are used at Amprion, along with fluid mechanics processes, static processes and machine learning processes. Unlike the measures of temperature, air pressure or humidity, which are relatively homogeneous regionally, simulating wind conditions and global radiation in terms of space and time is significantly more complex. The reasons for this are primarily the land's micro-scale effects, the land usage and the local cloud cover, which means that weather stations are required on the pylons in the grid region in order to use dynamic line rating. There are currently 120 weather stations in operation in Amprion's grid to supply the data required. Consequently, using the analysed data through the system management, the optimal utilisation for real operations as well as for congestion management can be identified based on individual weather forecasts. The main reason why this is important is that an overhead line's load-bearing capacity is limited by the thermal expansion of the overhead line conductor and therefore the conductor's slack. Dynamic line rating is continuously being developed further with additional new ideas and approaches being pursued in research projects. A project known under the acronym WAFB 4.0 (which in German stands for "dynamic line rating 4.0") is being funded by Germany's Federal Ministry for Economic Affairs and involves working jointly with the Fraunhofer Institute for Energy Economics and Energy System Technology (IEE) and Luna Innovations Germany GmbH to develop a method for using a fibre-optic measurement system to calculate ambient temperatures with fine-grained spatial and time detail across an overhead line's corridor and evaluated for dynamic line rating. For temporary cabling used during construction, the use of a fibre-optic measurement system to determine the cable temperature is being tested as part of the project. Temporary construction cables of this type are usually installed above ground during the relevant construction project. However, buried sections can frequently still be found at crossings, for example. Consequently, weather data such as solar radiation and air temperature have a large role similar to how they do for overhead lines, while the conditions in each section of the soil influence the cable temperature. Since circuits with this type of temporary cable have so far only been eligible for dynamic line rating in exceptional situations with fully above-ground installation, knowledge of the cable temperature for above-ground and underground sections of temporary cables would enable needs-based inclusion of the relevant circuits in dynamic line rating. The results of the three-year research project are expected in 2024.

**FIG. 33 AND 34** Amprion weather station on an electricity pylon

# ONLINE MONITORING

BENEFITS OF INNOVATION

Increased electrical-grid performance and availability

Using online-monitoring systems, information about the condition of the grid can be processed in real time and used in system management, grid operation and grid planning. Alongside a large number of existing systems, such as those for monitoring the weather-dependent capacity of overhead lines or for transformer condition monitoring, Amprion is continuously testing and rolling out further monitoring systems. They include, for example, systems for monitoring cable and cable corridor temperatures and the quality of the grid's voltage as well as systems for identifying functional irregularities in disconnectors.

## MONITORING THE TEMPERATURE OF CABLES AND CABLE CORRIDORS

Amprion uses various sensors on and around extra-high-voltage cable equipment for environmental and operational purposes. To allow more precise predictions about how the operation of extra-high-voltage underground cables impacts the earth, the temperature has been monitored on the German–Belgian ALEGrO interconnector since spring 2022. Measurement sites were set up at four locations for it, measuring the temperature and moisture of the soil in close proximity to the cables. The ALEGrO cable offers the only opportunity in Germany to obtain live measurements of how underground-cable construction and operation impact soil characteristics during regular operation of high-voltage, direct-current cabling. We hope to gain valuable findings from this. These measurements focus on how the seasonal temperature develops and how the warming of the soil caused by the cable operation impacts the soil's water supply. The project is being conducted in conjunction with scientists and soil experts and involves measurement probes monitoring the soil's moisture and temperature at different depths within a defined area. A total of 32 temperature probes and 12 moisture probes have been sunk into the soil above the cable installation at each measurement site and 16 temperature probes and 12 moisture probes in a neighbouring control area not subject to the cables' influence [SEE FIG. 35–37]. The measurements are complemented with further temperature monitoring using fibre-optic cables which are installed in the cable sheath as well as laid above the cable bed structure during construction. The aim is to be able to identify and evaluate changes in temperature across the cable. The project takes into account utilisation, installation types and soil and weather influences. Amprion also plans to use the time-resolved and spatially resolved cable temperature distribution to optimise the operation and maintenance of various cable corridors in the future.

**FIG. 35 LEFT** Measurement probes for monitoring soil moisture and temperature
**FIG. 36 TOP** Installation of measurement probes in the control area

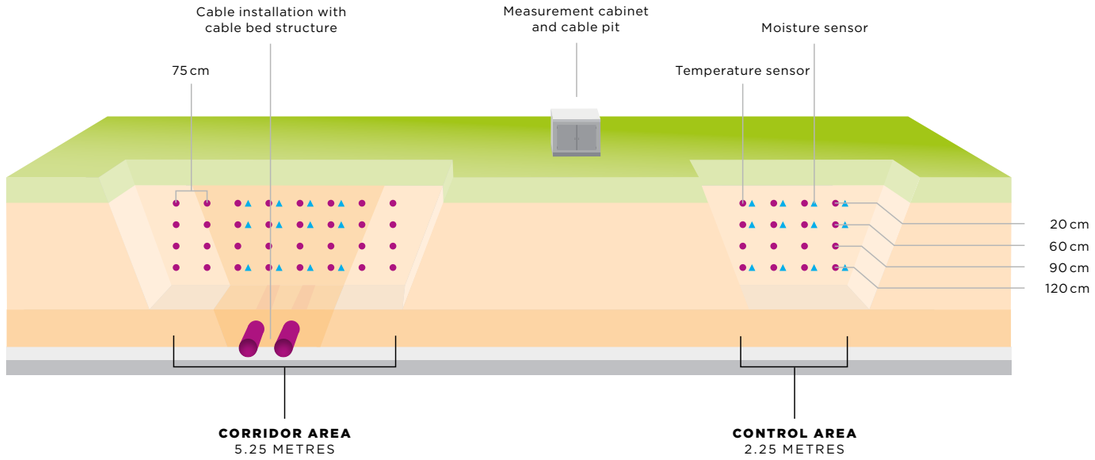



**FIG. 37** Cross-sectional illustration of soil sensors on the ALEGrO corridor
*Schematic illustration*


4.5 FUTURISTIC SYSTEM MANAGEMENT AND OPERATING CONCEPTS ONLINE MONITORING

## MONITORING FUNCTIONAL IRREGULARITIES IN DISCONNECTORS

TrEMoniA ("Trenn- und Erdungsschalter-Monitoring-system Amprion" or, translated, "Amprion Disconnector and Earthing Switch Monitoring System") as a project aims to establish an automated condition monitoring system for disconnectors and earthing switches in Amprion's transmission grid. A disconnector's main function within electrical-energy transmission systems is to create a visible disconnection point if needed. Earthing switches can establish a connection between system parts and potential earthing so that they, for example, can be secured for maintenance work if necessary. This is where TrEMoniA takes action by recording and analysing the motor currents of the devices during switching operations. By monitoring these operating parameters closely, TrEMoniA enables the identification of any irregularities arising during the switching process, as well as the initiation of appropriate maintenance activities. The disconnectors' functionality is kept under continuous surveillance, resulting in an extended maintenance cycle for the equipment and in turn increasing the availability of grid components and lowering operating expenditure.

**»By monitoring these operating parameters closely, TrEMoniA enables the identification of irregularities arising during the switching process, as well as the initiation of appropriate maintenance activities.«**

The monitoring system consists of multiple components: centralised tracking of the motor currents in each system, centralised data storage, connection of the data with the SCADA system, a diagnostics process and the display of results at the point of operation. The system's core component is a diagnostics algorithm which analyses the motor current to detect irregularities. Amprion determines the condition by comparing against a reference graph, taking into account the ambient temperature as well as system- and device-specific properties. Deviations identified by the algorithm are then categorised and provide an indicator about the action required. Poor conditions are communicated by sending a notification to the relevant operational unit for control and follow-up measures. TrEMoniA is currently being rolled out for regular operations.

## MONITORING THE GRID'S VOLTAGE QUALITY

With the increased usage of power electronics such as in converters, the increasing cabling of transmission lines and the removal of high-capacity synchronous generators at large power plants, the voltage quality in transmission grids is growing more and more important. Impermissible violations of quality parameters and grid resonance in lower-frequency ranges can pose a risk to the grid's stable operation. For this reason, Amprion is currently expanding its measurement of voltage quality. Amprion is using a specially developed measurement system that builds on the existing infrastructure. If the pilot phase is successful, the realisation will be able to take place quickly and at low cost.

An accurate measurement of the voltage quality requires additional characteristics regarding the frequency behaviour of the instrument transformer being used and are not met by conventional, inductive voltage transformers. Inductive voltage transformers are standard components in the extra-high-voltage grid that are designed to measure the grid's voltage at 50 hertz. Measurements of higher-frequency components are subject to errors that are not insignificant, which means they cannot be used to monitor voltage quality in the scope that is required.

The transformer condition monitoring that has featured in Amprion's operations for many years provides an ideal starting point for extensive monitoring of voltage quality. For voltage conversion, the capacitive-graded transformer bushings are used. They build up a voltage divider through the connection of an additional measurement capacitor at the bushing tap. Intensive studies confirm that the characteristics of the voltage divider meet the requirements, with the result that a quantitative evaluation of the voltage quality is feasible up to high frequency ranges. A power quality meter processes the measured voltage and derives the quality parameters in conformity with international standards in order to assess the voltage quality. After having already confirmed the functionality of the measurement system in test measurements, a pilot system with selected measurement locations will be built up in the next step of the project. The pilot phase also includes the development of tools to analyse and visualise the large volumes of measurement data efficiently.





# DRONES

## BENEFITS OF INNOVATION

High-quality aerial shots that make power line inspection easier

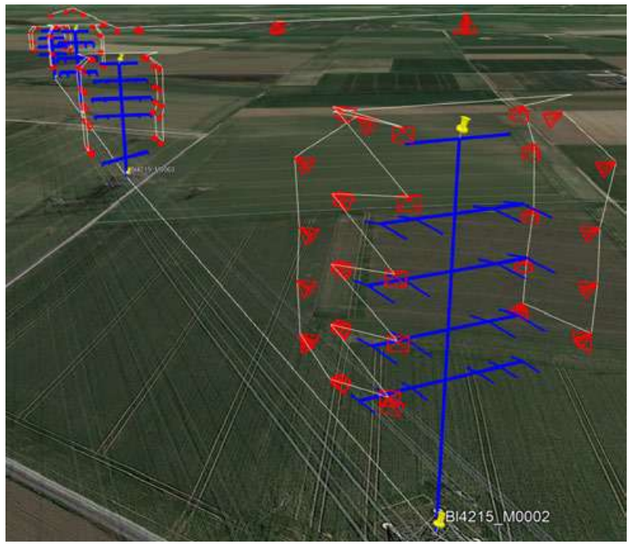



**FIG. 38 Prescribed flight pattern for pylon inspection**

Amprion uses drones for a variety of applications and is increasingly integrating them into existing work processes. The overall systems of drones, remote control, sensor technology and camera equipment are referred to as unmanned aircraft systems (UAS). Presently, there are about 25 UAS with qualified pilots in use across our company. UAS are used for things such as:

- Inspecting pylons or lines
- Reviewing corridor geography
- Monitoring/inspecting construction
- Photographic/film documentation
- Thermography
- Surveying

For example, inspections of the extra-high-voltage grid using UAS allow individual maintenance components to be examined in greater detail than with existing inspection methods, without needing to take circuits offline. Thanks to the higher degree of detail, the grid availability rises and worker safety increases simultaneously. UAS are a highly appropriate tool for snapshots of specific points, particularly in line sections on impassable terrain.

There is a variety of drone models in the market, each with different camera equipment and quality. The models are enhanced and improved continuously. Amprion is watching the market and analysing the extent to which progress in drone technology is unlocking new fields of application. Amprion tests new drone models before procuring them.

UAS are subject to numerous legal requirements which are intended to ensure the safety of the products and their application. Furthermore, various software solutions are needed to collect, integrate, store, analyse and visualise the data that is captured. These software solutions need to be continuously developed, although artificial intelligence will also be able to be used in the future. In order for UAS and the captured data to be used functionally at Amprion, the technologies need to be secure and ISMS-compliant (ISMS standing for "information security management system") as well as economical and easy to use. Amprion will likely use UAS significantly more in the future.

A validation process for automated flying checks is being carried out at Amprion at the moment. It sees the drones flying out to check the pylons based on a prescribed flight pattern and capturing a snapshot of individual pylon components [SEE FIG. 38].

**FIG. 39 TOP UAS are used for a wide variety of types of work at Amprion**
**FIG. 40 LEFT There are currently about 50 qualified UAS pilots at Amprion**

**FIG. 41 Inspection of a 15-metre-deep cable pit with an indoor cage drone**



# SATELLITE-BASED CORRIDOR MANAGEMENT

BENEFITS OF INNOVATION

Optimisation of corridor management through the use of satellite imagery

Overhead-line corridors run through public spaces. For this reason, Amprion needs to check regularly that they are in fault-free condition and, above all else, safe for traffic. These checks also prove if the live overhead line conductors have a sufficient distance from the vegetation under the power line.

In addition to purely visual inspections, Amprion also calculates distances between objects through laser scanning, which enables centimetre-precise measurements of distance. However, significant effort and expense is required for this. Accordingly, we are looking for more efficient ways of calculating distances between objects. One option is to analyse available satellite imagery.

Amprion is working on examining the efficiency and precision of this new option through two feasibility studies on satellite-based corridor management. The studies are intended to analyse previous experience and, in the medium term, compare various providers at a European level as part of cooperation with other European transmission system operators and the European Space Agency (ESA).

As part of these feasibility studies, current satellite imagery is analysed for selected corridor sections and compared with geographical line data. This enables a detection of changes in the protected zone around the lines as well as the distances between the overhead line conductors and vegetation.

Both projects apply innovative methods for automatic image analysis. They evaluate the precision of the measurements in relation to the different image analysis methods and the different resolutions of the satellite images. The results of the laser scans are used for reference.

The studies' initial outcomes show, among other things, that changes in the protected zone, such as construction sites, can be detected more frequently while images of hard-to-reach locations can be created more frequently, too. However, while the measurements of the distances between vegetation and overhead line conductors are less precise and reliable, they still offer a possibility for assessing changes in the protected zone. In keeping with the German saying of "appetite comes with eating", the studies have also led to ideas for using the satellite imagery in different ways to identify changes along cable corridors or to roughly categorise the spaces in protected zones.

# DIGITISATION OF BUSINESS PROCESSES

5

FIG. 42 Overhead-line corridor with protected zone



Amprion is using the potential from digitising its work and communication processes, for example by implementing innovative data management. By providing data optimally, improving simulations and using processes based on artificial intelligence, Amprion can make decisions more quickly and more sustainably.

FIG. 4

# CLOUD INFRASTRUCTURE FOR INNOVATION

## BENEFITS OF INNOVATION

Provision of a secure and flexible IT environment to innovate in the energy system

To clear the way for innovation technologically, IT infrastructure is needed that is flexible, fast, easily available and high-performing. Amprion has decided to lay the foundation for digital innovation with a single-cloud strategy. The following explains the advantages of this cloud approach based on focus areas.

Storing the vast amount of data generated in digital processes and making them useful is a major challenge, particularly in a fast-paced technological environment and when the questions to answer are constantly changing. For this reason, Amprion is implementing a dynamic data platform in the cloud with a centrally organised pool of data, the "Amprion Data Lake" [→BIG-DATA PLATFORM, SEE PAGE 79]. Amprion makes use of a sophisticated combination of data analytics options and data management as well as automated integration of various data sources. Workloads are planned to build upon this data platform in the future. This includes, for example, a sandbox environment available in just a few hours. This environment will allow departments to top up credit in order to supply infrastructure themselves, allowing IT solutions and products to be evaluated efficiently and with effective use of resources – making the infrastructure for innovation as easy as a prepaid phone plan.

The increasing digitisation of processes means that the number of data transfers and interfaces between Amprion and its service providers is rising rapidly. To keep the data flow under control, Amprion is evaluating API management. By doing so, interfaces for accessing systems in the data centre and cloud can be provided securely and flexibly from the internet as well. For example, it lets apps on the devices of maintenance contractors provide automated feedback without the added expense of developing an internal environment or modifying in-house software. It enables fresh innovation at defined digital interfaces and leaner operating processes.

The requirements for grid development planning are becoming increasingly demanding and dynamic. This requires that the existing computing power can be scaled seamlessly at short notice and for a limited period of time, which is accomplished with cloud computing. Consequently, high-performance virtual machines (VMs) can be used as needed, providing far more than 100 powerful processor cores and multiple terabytes of memory and incurring costs only at the time when they are used. They let simulations and calculations be performed quickly for use in subsequent processes.

However, just having flexible and high-performing infrastructure for innovation in the aforementioned focus areas will not meet our requirements. As a transmission system operator, Amprion has responsibility for the power system's stability. For this reason, the operational stability of our IT and the security of our information are top priorities. Before using the cloud, we developed a comprehensive security policies approach spanning from A for "access control" to Z for "zero trust". For example, innovation teams sometimes meet from all across Europe and use vastly different IT systems, yet quick and secure access must still be possible. To this end, access is provided via guest identities that are managed separately from local on-premise environments. Access to them is secured by using risk-based access rules and multi-factor authentication. These security measures are complemented with AI-based anomaly detection and a strict separation of individual workloads. We therefore lower the risk that attackers penetrating our flexible innovation environments may move into IT systems with real relevance for production.

As a result, we are creating a secure and flexible IT environment for innovation for the energy system of the future.

# DIGITAL TWIN

BENEFITS OF INNOVATION

Using data efficiently in order to keep managing the enormous challenges of grid expansion and system operation securely

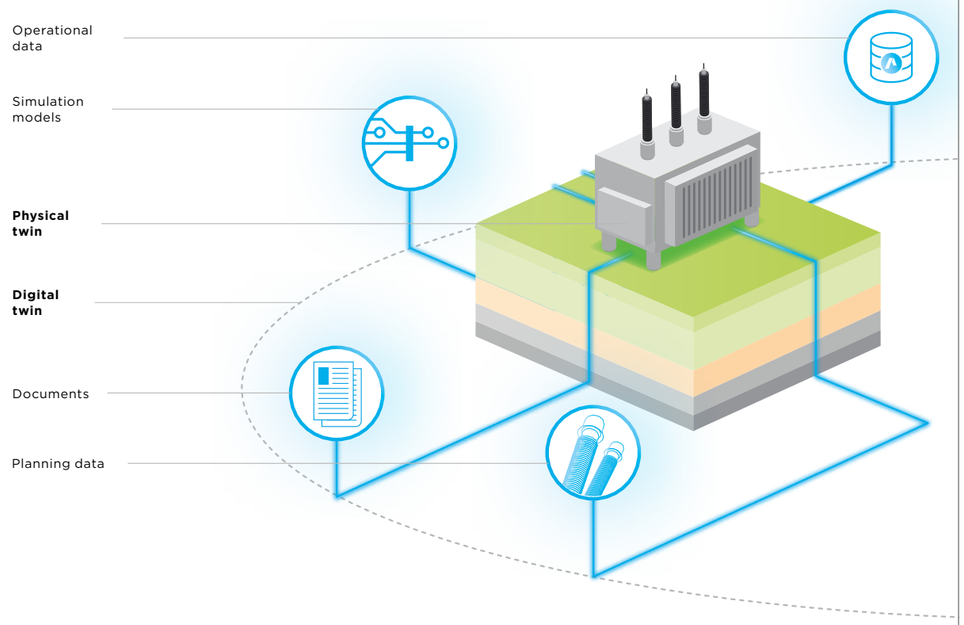



**FIG. 43 Digital twin for joint and efficient usage of a wide variety of data**

As a transmission system operator with Europe-wide coordination duties and major responsibility for data processing in relation to grid operation, Amprion aims to operate efficiently and securely. With the growing volumes of data and increasing complexity of business processes, digital information on transmission grid assets, i.e. the stations and power lines, needs to be used more efficiently.

The term "digital twin" commonly refers to a general, cross-industry concept for combining various worlds of data to generate new information.

For Amprion, this means a combination of electrical, structural and business data, with an aim of connecting all available data. The intention is to bring closer together aspects of grid planning, projects and operations, and that enables the data sources in different systems to be used together efficiently. The basis upon which this is done is unique asset identification (ID) within the company and, in the future, even beyond the company. Unique identification allows links to be made to the same object from any connected system at any time [SEE FIG. 43].

Amprion is already creating a digital twin in various projects today. One pilot project, for example, is testing links between digital images of real assets at the interface between planning/construction and operation. Linking all captured and existing information about grid assets throughout their complete life cycle – from planning and construction to operation and decommissioning – adds significant value, especially in relation to recycling data, identifying a clear origin of the data and safeguarding current data stores continuously.

In the future, this will let consistently up-to-date grid data be generated, enabling the coordination of grid operation with other grid operators without manual, cost-intensive data entry. Analyses can proceed significantly faster when the necessary input data is always up to date and available without major effort to procure it. The digital twin provides benefits for the visualisation of data, allowing easy navigation to the data that is being sought.





# BIG-DATA PLATFORM

BENEFITS OF INNOVATION

Support for the continuing digitisation of work methods

The transmission grid is heavily required to adapt and system operation is becoming increasingly complex. What's more, stakeholders are making increasing demands of Amprion. This growing dynamism requires faster analyses and decisions at various internal and external levels, and there are very high quality requirements that must be met simultaneously. Moreover, processes for operating and planning need to be supported and optimised with new findings, while accounting for the limited availability of resources. Efficient availability of data and data analysis options is needed across the company for this.

The data from grid operation and management has provided the basis for analyses and forecasts for a long time. For historical reasons, the data is often copied into the analysis and forecasting systems, requiring heavy manual labour. This means that the relevant data required may well be available for an individual application at the given time, however there is difficulty when other processes or parts of processes require the data or when the data needs to be updated. In addition to these system-based barriers, there is simultaneously also a very wide variety of security requirements for the data. They delay the provision of the data significantly and create conditions that lead to redundancies in data storage.

In order for data to be exchanged successfully between different business processes with clear roles and responsibilities, Amprion has decided to set up a company-wide data platform that meets the requirements of a transmission system operator.

Amprion is pursuing a hybrid approach with this: the "Advance Data Landscape Amprion" (ADLA), which is being created on the Microsoft Azure cloud platform. It is a tool for central storage of all the data that is created and needed outside of the critical system management processes. The cloud-based analytics tools and data self-services can be used and supplied with data through it. Since data for several grid planning and maintenance processes is needed from the system's operation, the data lake is being expanded with a component from the analytics platform for critical process data in system management ("amAIse" project). This component also makes it possible to supply the data lake with data from system management. The primary objective is to make the data available more quickly and more easily. Allowances are also made for the increasing need for data analyses and the use of AI-based approaches in system management by training AI models outside of

critical system management areas [→ ARTIFICIAL INTELLIGENCE, SEE PAGE 81]. Trained models then require significantly fewer resources in system management.

The data platform makes it possible to integrate an extremely wide variety of data silos, remove redundancies in data storage and therefore improve data quality in the future. Furthermore, it enables a robust view of all of Amprion's data. Moreover, the platform can support various projects, for example, the creation of a digital twin of our grid [→ DIGITAL TWIN, SEE PAGE 78].

### AMPRION DATA LAKE

The ADLA project centres around the establishment of a "data lake" as well as the secure provision of the cloud platform. An extremely wide variety of raw data in different formats can be fed into a data lake. Based on the raw data, the data for various applications is edited and provided later on in automated processing steps. The data sources are therefore integrated in a sustainable and automated manner. At the same time, the raw data is not erased after it is processed, which means it can be edited again quickly for future requirements at any time. Future data analytics projects at Amprion will be implemented mainly in ADLA and, as such, the time taken to pre-process the data should be reduced significantly. It will let experts and data analysts focus on the actual analyses while the data is edited centrally.

ADLA
AMPRION DATA LAKE

### "AMAISE" PROJECT

This project sees Amprion pursuing an integrative approach to providing data. In addition, we are striving for shared usage of analytics tools for data analysts inside and outside of system operations, e.g. for the purposes of reporting, advanced analytics or machine learning. To support system operation processes with the AI that is used, data-driven use cases in the company's departments were first identified and the required data and data flows determined. A suitable architecture concept and the necessary technology will be chosen based on this in the future. The high security requirements for system management processes represent a major challenge.





# ARTIFICIAL INTELLIGENCE

## BENEFITS OF INNOVATION

Optimisation of the operation, planning and management of the transmission grid

A large number of forecasts and analyses are performed at Amprion to enable the secure operation, the planning and the management of the transmission grid. Due to the high investment and long implementation times, we systematically analyse system modifications, such as the ones made through the grid's expansion, in advance. In operations, Amprion meets the high requirements for system security through short-term and medium-term forecasts of the system's behaviour. Simultaneously, data about the system and its behaviour is created by collecting measurements and reports in the system's operation and management.

With the rising complexity in the operation, planning and management of the transmission grid, there is a growing need for analyses and forecasts that are more extensive and more detailed than they used to be. For instance, possibilities and time frames for disconnection must be identified, even with the existing grid being heavily utilised, so that maintenance or reconstruction or expansion projects can be completed during ongoing operation.

Modern data science approaches utilise algorithms and self-learning processes that are frequently referred to collectively using the term "artificial intelligence" (AI). They all handle available data systematically in order to predict the system's behaviour based on scenarios and, in doing so, support decision-making. For this reason, the use of AI at Amprion is an increasingly important complement to expert knowledge and established analysis and forecast approaches. The AI-based analysis of extremely large volumes of data makes it possible to identify patterns in the system's behaviour. Alongside approaches implemented at the company's data centres, the conscious decision to use cloud technologies makes it possible to test AI-based approaches quickly and scalably.

Whereas large internet technology companies use AI to predict user behaviour and come up with suggested purchases, Amprion uses AI mainly to optimise the system's operation and reduce the costs of redispatching and system services as well as to apply custom-made models to manage grid equipment. The ultimate purpose of all of this is for operations to be sustainable and conserve resources whilst simultaneously fulfilling the high expectations for the availability and system security of the transmission grid.

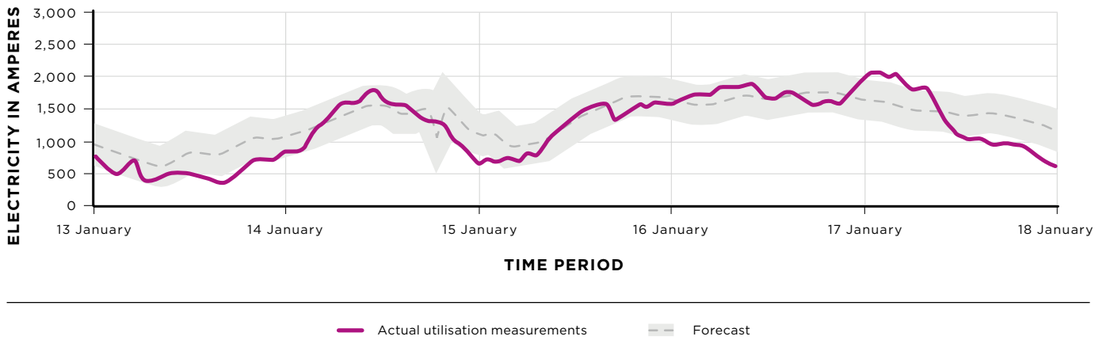



**FIG. 44 Comparison of forecast and actual utilisation measurements of a selected transmission grid power circuit**

## FORECASTING OF CIRCUIT UTILISATION

To enable efficient system utilisation, Amprion defines the corresponding threshold values dynamically. Forecasts of the circuits' expected utilisation make it possible to calculate thresholds and plan repair and maintenance activities. For the creation of the forecasts, an AI-based approach was chosen in the "Blackbird" project that analyses a large volume of relevant input data and then provides a medium-term forecast. In addition to weather data, the applied algorithms also consider market data as well as past measurements, reports and switching conditions in the transmission grid. The approximately 2.5 billion data records that are currently drawn on for the forecast are processed in a cloud-based application. It enables a more precise forecast of the time period being studied because it can take into account utilisation profiles that differ dramatically according to the season. Figure 44 shows a comparison of the forecast created through Blackbird and the actual utilisation measurements in Amprion's circuits in the northern grid area.

## ALGORITHMIC TRADING

As a transmission system operator, Amprion also plays the role of an electricity trader – with a legal mandate. Since the German Renewable Energies Act (*Erneuerbare-Energien-Gesetz*, EEG) came into effect, the German TSOs' tasks include marketing the power from renewable energies on the electricity exchange when it is not marketed directly. In addition, Amprion also performs intra-day management of its own portfolios which, for example, serve to cover any grid losses incurred or preserve the system's stability. In addition to continuously improving the power forecasts that are used for this purpose, Amprion uses automated traders to carry out electricity trade using automated and optimised methods.

In order to manage the challenges associated with volatile wind and solar feed-in forecasts – combined with rapidly changing power market conditions – Amprion is currently developing innovative algorithmic trading as an enhancement of the automated traders. Unlike the automated traders, it is meant to perform ongoing analysis of the forecast and market changes based on a broad foundation of data and, from that, identify a dynamic trading strategy that is adapted to the market developments in real time. Consequently, real-time orientation to current energy market developments should be automatically ensured in the future.





## VOLTAGE DROP FORECASTS

Since the winter of 2017/2018, short-time, significant voltage drops in the range of minutes have been observed in the German transmission grid [SEE FIG. 45].

The voltage drops usually occur across stations and mainly in two geographical regions (north and south).

Because these sorts of voltage drops can endanger compliance with the operating voltage band, a forecast process has been developed that can be used to forecast the occurrence of these voltage drops with appropriate forewarning (day ahead). The process has been part of the operational-planning processes of the four transmission system providers in Germany since October 2019.

The existing operational-planning processes have focused on predicting active-power load flows and potential electricity congestion at an hourly level. New process steps and improved data models are required to forecast occurrences in the minute range.

For this reason, the so-called random-forest classification method from the field of machine learning has been used for the development of the calculation kernel of the forecasting tool. With this classification method, an indication for the occurrence of a voltage drop can be determined on the basis of various input data.

Amprion is in charge of the support for as well as regular further development of the forecast tool.

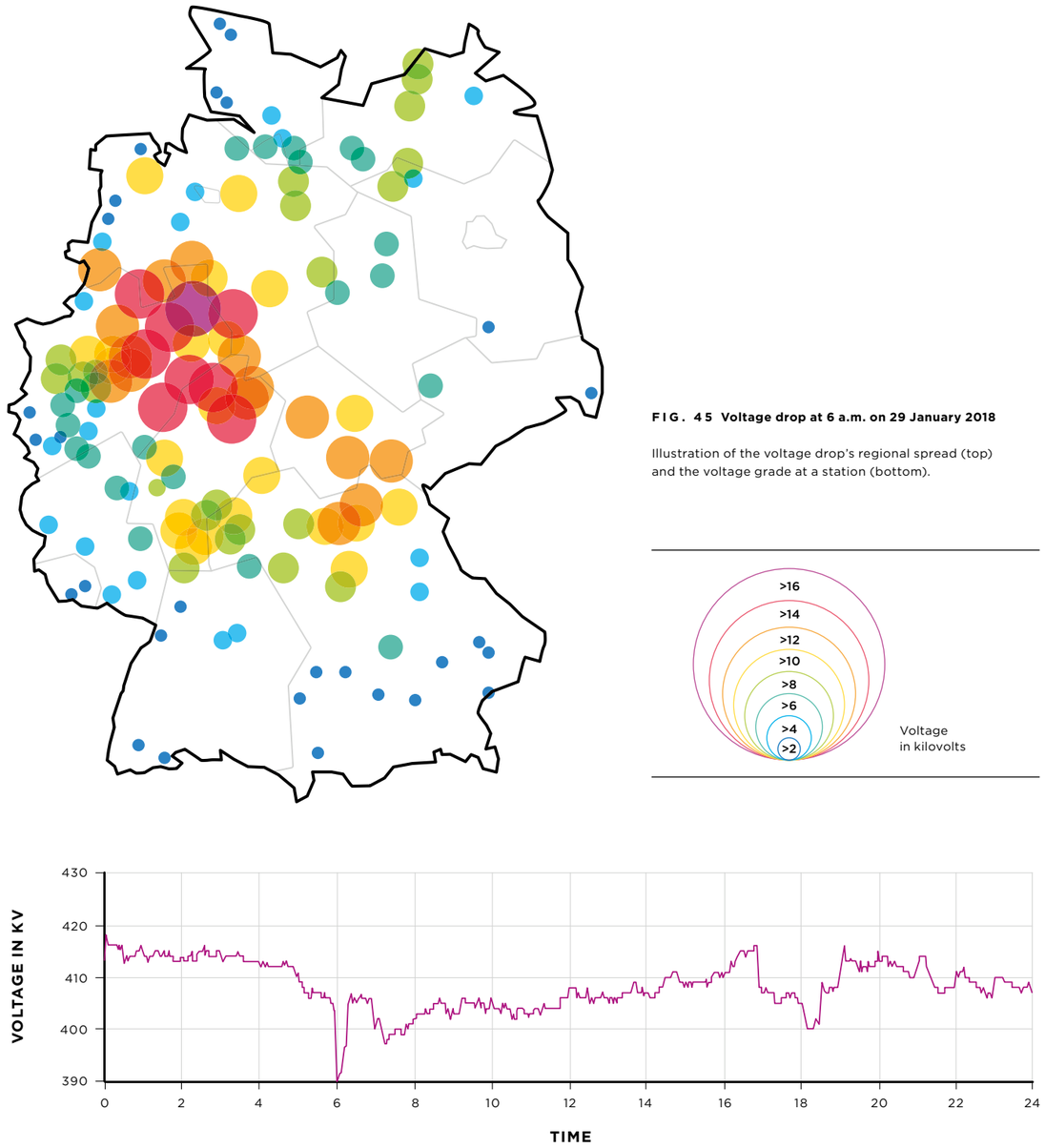



**FIG. 45 Voltage drop at 6 a.m. on 29 January 2018**

Illustration of the voltage drop's regional spread (top) and the voltage grade at a station (bottom).

**FIG. 46 TOP** Front-office marketing of renewable energies
**FIG. 47 RIGHT** Wind turbines

## FORECASTS OF RENEWABLE-ENERGY FEED-IN

Forecasts are one of the most important foundations for the successful integration of renewable energies into the electrical grid. They are used for a broad variety of purposes. As a transmission system operator, Amprion relies on forecasts having high quality and very high availability to keep its grid operations secure. For this reason, Amprion generally uses forecasts from different sources of data and different basis models for all purposes. The forecasts are used for things such as the marketing of renewable energies by the transmission system operators, operational-planning processes and feed-in management in the Redispatch 2.0 process.

As part of the roll-out of Redispatch 2.0, the forecast modules already used at Amprion so far have become more detailed and local. Making these modules more local has involved the use of new types of AI in order to raise the quality of forecasts as the previous processes aimed for optimisation of Amprion's transmission grid as a whole.

The newly developed forecasting processes use various AI-based methods to achieve as high a forecast quality as possible for every individual object forecasted while accounting for differing input data scenarios. As a consequence, Amprion has gained independence and, irrespective of external forecast suppliers, can produce forecasts for the majority of all redispatching-relevant wind turbines and photovoltaic systems in its designated zone with various weather models. The forecast modules create forecasts with prediction time frames of 15 minutes to four days into the future for approximately 1,400 wind turbines and approximately 15,000 solar parks. The forecasts are then merged together using statistical processes and combined with further AI-based processes, providing an optimised forecast for each level of aggregation.

# NEW (DIGITAL) WORKING METHODS

## BENEFITS OF INNOVATION

Improvement of collaboration and increase in efficiency

The digitisation of day-to-day collaboration and improvement of working methods provide a high level of potential efficiency for the company. Minor improvements can have positive impacts for most employees, which adds a significant amount of value. This is why it is important for us at Amprion to continuously question, optimise and digitise the status quo with innovative initiatives. In doing so, we create more freedom for our core duties, strengthen connections within the company and can react flexibly to the requirements of the future. In the course of the Covid-19 pandemic, this approach helped with the switch to a more flexible way of working whilst letting us safeguard efficient communication simultaneously.

For systematic innovation in the field of (digital) working methods to develop systematically, we have developed a user-centric framework [SEE FIG. 48]. It focuses on a variety of applications and characteristics that pertain to almost all employees and therefore promise the greatest added value for development.

Changes are implemented carefully, gradually and with the best support possible for all employees so that broad acceptance can be achieved.

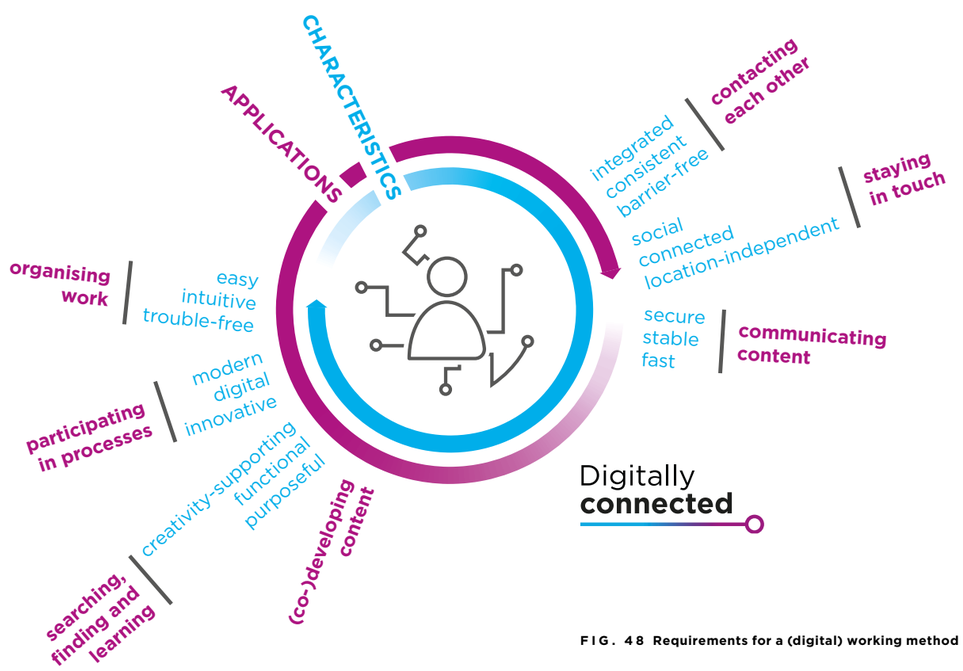



**FIG. 48 Requirements for a (digital) working method**





The following outlines three selected initiatives that have already improved collaboration and will keep improving it in the future, too.

Alongside two digitisation initiatives – the introduction of Microsoft 365 and active process digitisation in all business areas – adapting processes based on, for example, the scrum methodology for agile collaboration has led to optimisation being achieved.

### MICROSOFT 365: INTEGRATED AND EASY COLLABORATION

Amprion decided two years ago to roll out Microsoft 365 as a strategic platform for collaboration. In particular, the use of Microsoft Teams and SharePoint Online as key building blocks in the platform have reshaped Amprion's working methods in some places. It is not the technology that represents the innovation here, but rather the changed working methods of all employees. This applies to smaller modifications such as the use of the chat function and switching from email attachments to document URLs as well as to more extensive changes such as the use of Teams spaces for targeted communication.

Microsoft 365 and the impacts on working methods:

- **Increasing information transparency and knowledge transfer with Teams spaces:** with clear communication structures, even when employees change, across department boundaries
- **Being open to change and fostering a positive culture of learning and mistakes:** using the transparency for a shared learning process and easier collaboration
- **Further boosting trust and independence:** many tools in the Microsoft 365 solution kit are based on mutual trust
- **Consciously taking advantage of freedom – individually, within organisational units and as a company:** Teams offers a great amount of creative freedom which, when used correctly, can add a lot of value
- **Preventing redundancy and creating clarity:** preferring Teams spaces over emails, clearly defining file storage spaces, reducing meetings and sharing information via Teams spaces

### AGILE WORKING WITH SCRUM

Agile working is an innovative working method that has been used in selected, time-limited projects at Amprion based on the scrum framework in order to achieve goals more efficiently. Agile working in itself is particularly suitable for small teams with set targets and a limited time frame. Partial results are produced in short sprints that come together to form an overall result at the end of the project. Fixed events are held in each sprint so as to continuously improve the collaboration within the team and the outcomes of the work. This made it possible for the corresponding projects to achieve the set requirements at all times and, in some cases, exceed them.

### A TWO-STEP APPROACH TO PROCESS DIGITISATION

Company processes should be performed as efficiently as possible, and digitising and automating them helps with that. For process digitisation, we use a two-step approach to increase the speed. Firstly, process digitisation is driven from within IT in the classic way, for example for HR processes digitised with SAP. Secondly, supervised self-service based on the Microsoft Power platform is being developed for the company's departments up until the end of 2022. This will give trained employees the option to make processes digital by themselves and automate simple routines using a modular system. The aim of this is to leverage potential for digitisation in the places where the requirements come from and make automation useful more quickly.

# DIGITAL STAKEHOLDER COMMUNICATION

## BENEFITS OF INNOVATION

Digital stakeholder inclusion as a complement to early public participation

Intensive contact with interest groups in the relevant regions and cross-regional stakeholders will be particularly important to make the energy transition and the associated grid expansion successful. Amprion already informs the entities performing public duties and the general public in a project's region at an early stage of the project, usually long before the formal processes involving government offices for regional planning, specialised federal planning and planning approval.

The communication addresses planning alternatives, project-specific procedures and informal and formal options for participation. We strive for solutions that can be understood by as many stakeholders as possible. For this reason, we wish to provide transparent and continuous information about why we plan and implement projects the way we do. In addition, we illustrate the technical details and process-related information in a manner that is as targeted to the audience as possible.

The Covid-19 pandemic initially made these efforts more difficult due to the government restrictions on events. Nevertheless, to fulfil legal disclosure obligations and meet our own expectations for project communication, we created new formats for participation. As digitisation progresses, these new formats will also add value in the future with clear and self-explanatory information material. The following presents the digital "Bürgerinfomarkt" as a pendant to the traditional information exhibition for local residents as well as the EnLAG14 Rhine Crossing virtual model as an innovative tool for explaining the general conditions surrounding a project.

### DIGITAL "BÜRGERINFOMARKT"

The digital Bürgerinfomarkt ("info market for local residents") is a virtual, three-dimensional space which is used as an information platform for project-related communication. Stakeholders have the opportunity to find information on various topics like at a traditional information exhibition and contact Amprion personally through a chat function or video-conference. The interface is set up like a trade fair hall with a variety of booths which act as theme-specific boxes. Furthermore, there is a possibility of integrating a live stream with a presentation in a separate space, the "forum". For sensitive, personal conversations about things such as matters under private law, a lounge with log-in details for external stakeholders can also be integrated as a separate space. The digital Bürgerinfomarkt can be accessed via a link during the specified opening hours after registering beforehand. Users can navigate through the virtual platform independently and consult the information that they find relevant about a given project individually. During development, a focus was put on intuitive operation so that all age groups could access relevant information without major barriers. The application is browser-based and does not require the installation of software. The digital Bürgerinfomarkt also aims to be fully functional in regions where internet connections are not well developed.

Each theme-specific box provides clear information material on three walls. Videos, overview maps and photo galleries can be incorporated just as much as text fields and roll-up banners. In addition, materials can be provided for downloading.

The tool enabled exchange and information transfer during the Covid-19 pandemic. Using it, we were also able to reach stakeholders who would have been unable to travel out to a face-to-face event. In spite of this, however, the digital Bürgerinfomarkt is not a replacement for in-person dialogue on-site.

### VIRTUAL MODEL OF ENLAG14 RHINE CROSSING

The virtual model presents the current planning status and technical details of a partial underground-cabling project in a very clear and informative way, in this case for the EnLAG14 Rhine Crossing project. Users can obtain information about the planning status, various conditions underlying the project and technical details at any time and at their own speed. The information about the various components of the cable corridor and planned construction methods are illustrated in short videos. The aim when developing the virtual model was to present the dimensions of the power line construction project and the various construction methods for the individual sections realistically, understandably and clearly and, in doing so, create transparency for stakeholders.

Operating it was meant to be as intuitive as possible and seem familiar to other applications such as Google Maps. Individual sections of the power line construction project are set in different colours and can be selected interactively. Explanatory videos are launched when individual points on the map are zoomed in on.

The target audiences for the virtual model are primarily the stakeholders along the line corridor who are directly affected as well as interested members of the public. Stakeholders can gain an impression of how much they will be affected by the grid expansion by navigating to the individual points on the map. People can also see how much they are personally affected by zooming in on the individual points on the map and sensitive issues such as flood protection and nature conservation can be dealt with like this, too.

**The virtual model of the EnLAG14 Rhine Crossing project can be found on our website at** rheinquerung.info

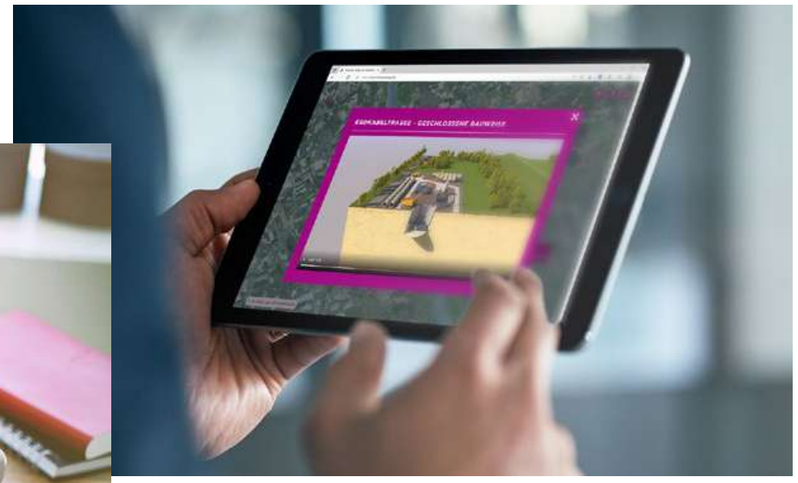


**FIG. 49 LEFT Bürgerinfomarkt website**
**FIG. 50 TOP Website with virtual model**

# ACKNOWLEDGEMENTS

The management team at Amprion wishes to thank all employees who contribute to the development, testing and practical implementation of new technologies and solutions. They are what makes Amprion an innovative company.

The following people contributed to the creation of this report:

Stephan Baack
Daniel Bachmann
Dr Michael Baranski
Manuel Blumenthal
Tom Bösterling
Dr Thomas Butschen
Dr Tim Felling
Dr Kai Flinkerbusch
Jan Peter Getzlaff
Melina Groß
Dr Tobias Hennig
Daniel Henschel
Dr Patrick Hermanns
Dr Maren Herzog
Daniel Hördemann
Tobit Jensen
Dimitrij Kamenschikow
Dr Ulf Kasper
Patrick Kausch
Dr Jan Kays
Dr Matthias Livrozet
Martin Lösing
Kevin Lunge
Peter Milchert
Rainer Millinghaus
Andre Peters
Dr Philipp Ruffing
Dr Jan Teuwsen
Daniel Scherbarth
Kathleen Schirmacher
Niklas Schmack
Thomas Schneider
Dr Alexander Schütz
Stefan Steevens
Martin Swaczyna
Leon van Altena
Zi Wang
Niklas Winkelmann
Stephan Wittner

# IMPRINT

**PUBLISHER**

Amprion GmbH
Robert-Schuman-Straße 7,
44263 Dortmund, Germany
Telephone +49 (0)231 5849 14109
Email info@amprion.net

**CONTACT PERSON**

Thomas Dederichs (U-S)

**CONCEPT AND DESIGN**

Berit Urbaniak, Dominik Buschmann and Elina Hetzel

**EDITORIAL TEAM**

Andre Peters, Christian Schwarz, Liliia Makovii, Maria Bechert and Volker Göttsche

**PRINTING**

Woeste Druck, Essen

**ILLUSTRATION AND PHOTOGRAPHY**

| | |
|---|---|
| Amprion GmbH | pp 32 right, 69 top, 71, 72 |
| Berit Urbaniak | pp 24, 26, 28, 33, 37, 52, 55, 63, 69 bottom, 82, 83 |
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| Dominik Buschmann | pp 78, 80, 86 |
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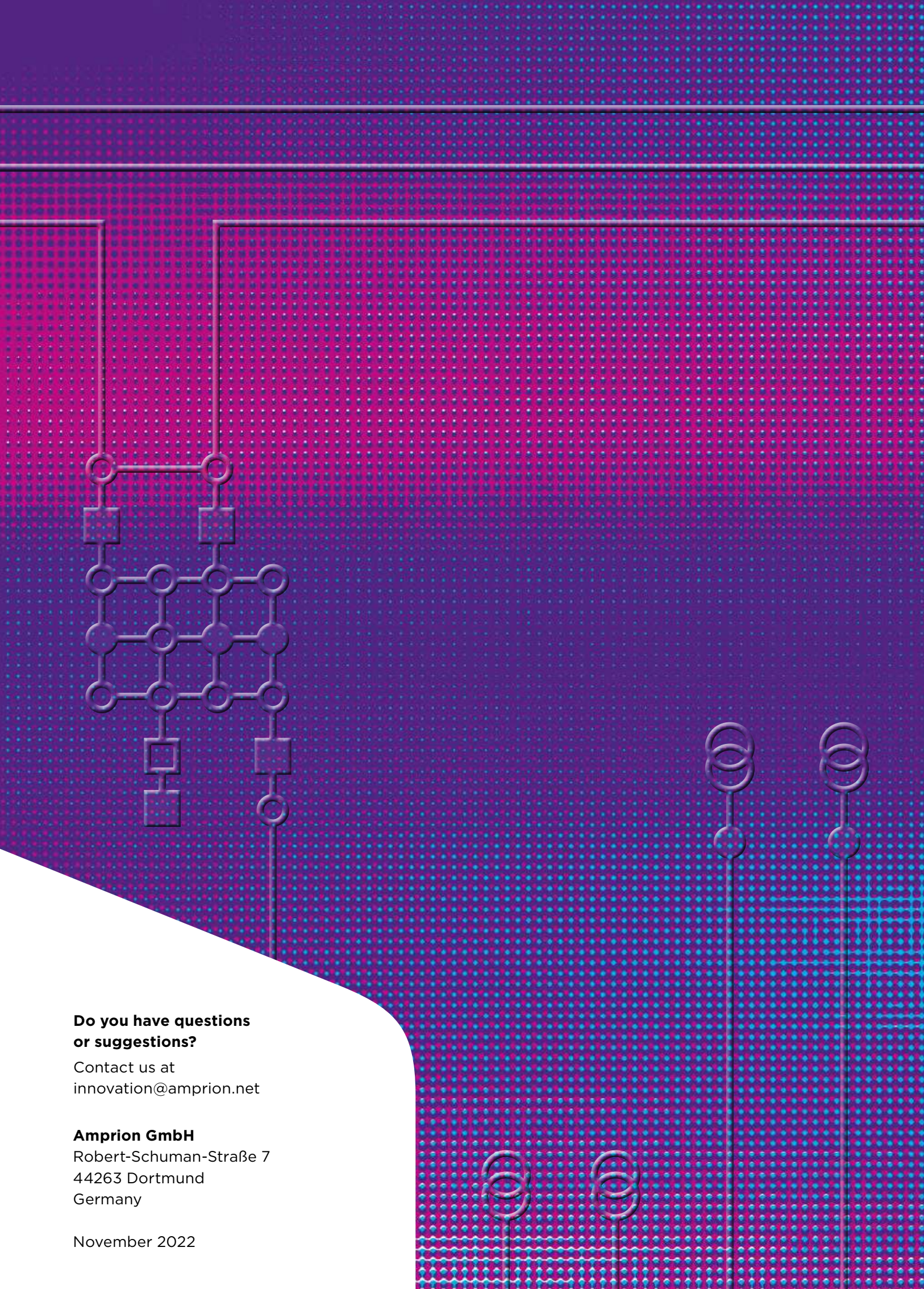

**Do you have questions or suggestions?**

Contact us at
innovation@amprion.net

**Amprion GmbH**
Robert-Schuman-Straße 7
44263 Dortmund
Germany

November 2022