ANNUAL REPORT 2019

SuperGrid Institute

Shaping power transmission


SuperGrid
Institute
Shaping power transmission

CONTENTS

THE BIRTH OF
A EUROPEAN CHAMPION

The Covid-19 pandemic that hit the world at the end of last year may have significantly destabilised the world's economies, however this should not prevent us from noting that this crisis has had positive effects on our environment. The containment measures applied in most of the major industrialised countries have resulted in an exceptional drop in CO_2 emissions and the air pollution in our largest cities has never been so significantly reduced. We must therefore take on board the lessons we have learned from this episode and move even faster towards energy transition, which will contribute to the reduction of greenhouse gas emissions.

It is this ambition that is at the heart of the SuperGrid Institute project, which we have been carrying out for the last six years. Thanks to the alliance of industrial and academic research expertise, the technologies we are developing will allow us to better integrate renewables, facilitate power exchanges and contribute to energy transition, not only in the context of our home country, but internationally as well. **SuperGrid Institute aims to become tomorrow's European champion for large electrical networks.**

To meet this challenge, we need to be fast. International competition is fierce; China is already promoting multi-terminal networks, with the ambition of penetrating European territory with its own solutions.

Behind SuperGrid Institute's successful mastery of the networks of the future, there is therefore not only a history of technological excellence but also an issue of European sovereignty. We will rise to this challenge alongside our shareholders, partners, teams and customers.

Michel Augonnet,
SuperGrid Institute President

LAUNCH OF A THRILLING INDUSTRIAL ADVENTURE

Six years ago, creating an independent institute that develops technologies aiming to increase energy efficiency and integrate renewable resources into the grid was a leap of faith. Faith in our ability to adapt and to invent new ways of working in a developing market.

Today, **concrete projects are underway.** Our partners turn to us to expand their offers. Our contributions to collaborative projects are ambitious and widely respected.

We focus on **supporting our clients** through our expertise, our state of the art testing and research facilities, registered patents and promising concepts. This strategy gives rise to new collaborations, new partnerships and new research topics that correspond to the market's needs. Alongside our research, we collaborate with academia to define curricula for the next generation of electrical engineers and we support the industry by providing training programs adapted to this evolving market.

With this report, we would like to thank our customers and our partners for their trust, for the quality of our relationships and the pleasure we receive from supporting their development with our complementary skills and competences.

The main objective of this report **is to reach out to industrialists and academics**, particularly all those not yet working with us. **We are strongly committed to opening ourselves up to new partnerships.** With this first annual report, we want to demonstrate to our clients, our partners and the entire scientific and industrial community all that we have already achieved through examples of our technical contributions and value propositions.

The reduction of greenhouse gases, the rapid increase of renewable energy sources' integration into the grid and grid interconnections are giving birth to new challenges - stability, reduced inertia, sharing reserves, transmission of ever-growing off shore sources. All of these challenges have a vital impact on the security of national and European energy supply. SuperGrid Institute's success will therefore play a major role in supporting the reliability of our power supply.

In this context of international competition, we can count on our skilled and passionate teams to help us achieve our goal. Our staff are united by their energy, enthusiasm, drive, creativity, and their commitment to energy transition. They bring a human element to SuperGrid Institute, which is today one of its greatest strengths.

Hubert de la Grandière,
SuperGrid Institute Chief Executive Officer

01 | KEY FIGURES

1 public shareholder:
Banque des Territoires
(Caisse des Dépôts group)

6 industrial shareholders

7 academic shareholders

€220 M
of **investment**

€20 M
annual budget

€3 M turnover
in 2019, compared to
€1.2 M in 2018

SuperGrid Institute
Shaping power transmission

30 completed theses since 2014,
of which 9 in 2019

1 training programme

164 publications since
2014, including 44 in 2019

65 patent applications
made since 2014, with 13
filed in 2019

Supported by 3 public bodies:
- General Secretariat for Investment,
- Auvergne-Rhône-Alpes Region,
- Greater Lyon

33 is the **average age** in the research teams

174 staff
representing
28 nationalities,
133 full-time equivalent

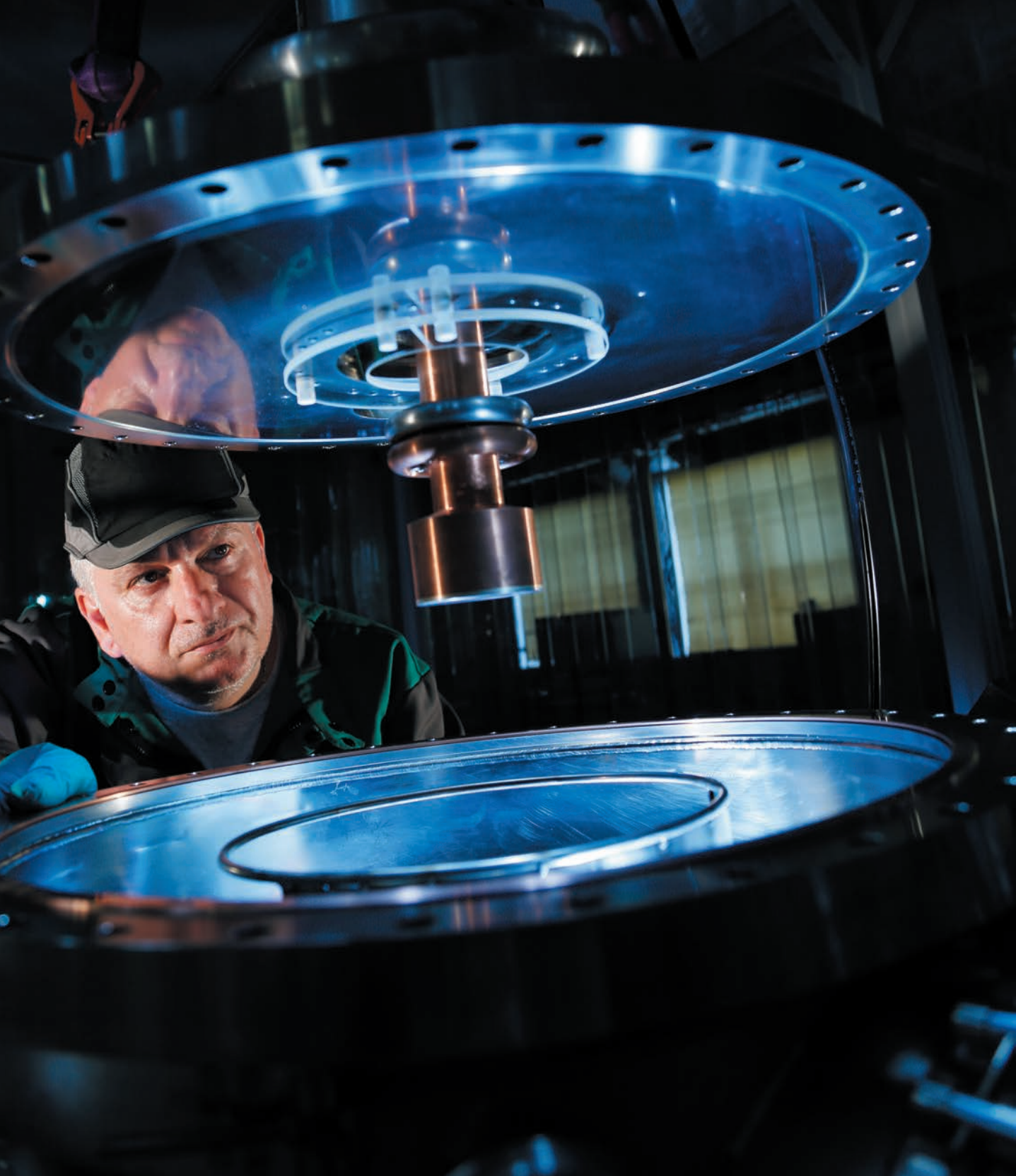
2 research centres:
Villeurbanne and Grenoble

6,000 m²
of **laboratories**
and **test platforms**

18 test platforms

2,400 m²
of **offices**

5 research programmes



02 | OUR SHAREHOLDERS & PARTNERS

LE GRAND PLAN D'INVESTISSEMENT

INDUSTRIAL SHAREHOLDERS

ALSTOM · EDF · GE Grid Solutions / GE Hydro France · Nexans BRINGS ENERGY TO LIFE · VETTINER

ACADEMIC SHAREHOLDERS

CentraleSupélec · ECOLE CENTRALELYON · Grenoble INP · INSA INSTITUT NATIONAL DES SCIENCES APPLIQUÉES LYON · Université Claude Bernard Lyon 1 · UGA Université Grenoble Alpes · université PARIS-SACLAY

WITH THE SUPPORT OF

La Région Auvergne-Rhône-Alpes · GRANDLYON la métropole · ANR

PUBLIC SHAREHOLDER

BANQUE des TERRITOIRES GROUPE CAISSE DES DÉPÔTS

ASSOCIATED LABORATORIES & THEIR ADMINISTRATORS

Laboratories	Administrators
ies l'institut d'électronique	cnrs · Université de Montpellier
L2S	CentraleSupélec · cnrs · université PARIS-SACLAY
G2Elab	cnrs · Grenoble INP · UGA Université Grenoble Alpes
Laplace	cnrs · INP ENSEEIHT · UNIVERSITÉ TOULOUSE III Paul Sabatier
Ampère	cnrs · ECOLE CENTRALELYON · INSA INSTITUT NATIONAL DES SCIENCES APPLIQUÉES LYON · Université Claude Bernard Lyon 1
L2EP	ARTS ET MÉTIERS ParisTech · centralelille · HEI INGÉNIEURS POUR LE MONDE · Université de Lille
Institut Camille Jordan	cnrs · ECOLE CENTRALELYON · INSA INSTITUT NATIONAL DES SCIENCES APPLIQUÉES LYON · Université Claude Bernard Lyon 1 · UNIVERSITÉ JEAN MONNET SAINT-ÉTIENNE

Laboratories	Administrators
CREMHyG	Grenoble INP
IJL INSTITUT JEAN LAMOUR	cnrs · UNIVERSITÉ DE LORRAINE

03 | SHOWCASING FRANCE'S TECHNOLOGICAL EXCELLENCE

The Institute for Energy Transition (ITE) SuperGrid Institute came into being two years after having been selected as part of a call for proposals launched by the French State in 2012. **Dedicated to researching and developing technologies for future electrical energy transmission grids, it is supported by a consortium of industrial and academic shareholders, the State and local authorities.**

By the time the initial investment phase comes to an end in 2024, this highly ambitious project **will have ultimately required a total investment of over €220 M.**

To make this project, which lies at **the very heart of the drive for energy transition,** a success, the French State (via the General Secretariat for Investment), the Auvergne-Rhône-Alpes Region and the Greater Lyon authority decided to support the proposition of **a consortium of private and public shareholders:** Alstom, EDF, General Electric Grid Solutions, GE Hydro France, Nexans and Vettiner on the industrial side, and CentraleSupélec, École Centrale de Lyon, Grenoble INP, INSA Lyon, Université Claude Bernard Lyon 1, Université Grenoble Alpes and Université Paris-Sud on the academic side.

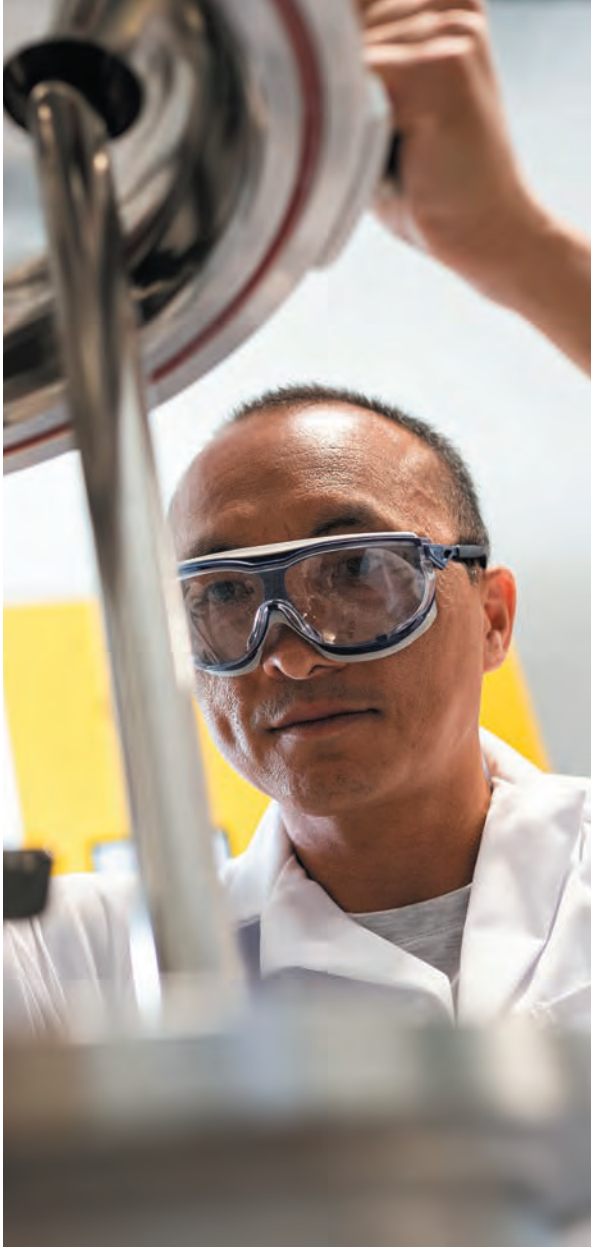
A SHINING EXAMPLE OF R&D

SuperGrid Institute moved into its new headquarters in Villeurbanne in October 2017. By the end of 2019, a total of **174 engineers, researchers and support staff** were employed between this location and the Grenoble site. A first building of nearly 5,700 m² is home to the head office, research facilities and test platforms. This building acts as a showcase for the company's Research and Development activities.

A second building which was completed in 2019, is used for testing equipment under very high voltages. It was designed to withstand intense impacts from explosions and projections. As such, numerous in-depth structural engineering studies were carried out, **in order to assess the building's structural resistance.**

A third building, designed to house a high voltage power source, is due to be completed by 2021. It will comprise of an alternator, which will produce very high voltages, transformers, and an energy converter to generate direct current from alternating current. This equipment will also be used for testing materials under very high voltages.

The Grenoble office and test platform, home to the Institute's Power Storage and Balancing research activities, complete SuperGrid Institute's set of locations.



AN INSTITUTE FOCUSED ON RENEWABLE ENERGY INTEGRATION

Today, SuperGrid Institute is fast becoming a reference for renewable energy integration issues, at a time when it is increasingly important to decrease our dependence on fossil fuels and reduce greenhouse gas emissions. The Institute's research interests are centred on improving conventional networks and developing hybrid ones by increasing the use of rapidly evolving Direct Current technologies, and managing these technologies in a way that will limit the impact of integrating renewable energy into existing AC networks.

By prioritising technologies that deal with the electricity networks of the future and working to improve their flexibility and resilience, **the company aims to deliver solutions that provide its customers and partners with a strong competitive advantage.**

Recognising the importance of these issues, the French State decided to support the Institute. Playing host to a European champion not only increases the notoriety and attractiveness of France's research capabilities but also gives a competitive edge to the industry.

SuperGrid Institute's long term ambition is to establish itself as the leading European authority on supergrid technologies and a key player in collaborative innovation for the development of electrical power systems.

ADAPTING, DEVELOPING AND STRENGTHENING THE NETWORK

Today, electricity is generally transmitted via grids at a national level, which feed the output of fossil fuel, nuclear or hydraulic power stations to the end user via distribution networks. Traditionally, these power stations were built as close as possible to the end users, usually between 50 and 100 km away. However, with the **large-scale integration of renewable energy sources** (wind or solar), **the distance between the production centres and end consumers has significantly increased.** Using direct current can considerably reduce the losses incurred over these long distances.

Furthermore, using underground DC cables to transport energy also alleviates the social pressure building against overhead power lines.

The intermittent nature of renewable energy production, which often depends on climatic variations (e.g. wind and sunshine), **makes it difficult to keep the network stable and balanced.** If renewable energy is to be integrated on a large-scale, **the grid must be adapted, strengthened and developed; interconnecting different countries and thereby insuring this balance is maintained.** To this end, the European Union requires each country to be able to connect 15% of its production capacity to its neighbours by 2030. **The ultimate objective is to build the electrical transmission grid of the future:** a large-scale, cross-border network designed to interconnect with existing alternating current systems.

FIVE COLLABORATIVE RESEARCH PROGRAMMES

As direct current is a suitable solution for both transmitting power over long distances and managing the intermittent nature of renewable energies, SuperGrid Institute has chosen to develop technologies for networks capable of carrying this form of power.

SuperGrid Institute's teams are currently working on five research and development programmes, focused on high voltage alternating and direct currents at the Villeurbanne (Lyon) and Grenoble sites. The teams at these locations have state of the art research facilities, test platforms and laboratories at their disposal to help them succeed in their work.

SuperGrid Institute brings together R&D skills and expertise from industry and academia, giving it the means to overcome any technical challenge. This complex relationship is an ambitious way to work, particularly in France where traditionally academia has maintained its independence from industry, but it works perfectly in this instance and allows the Institute to benefit from the complementary strengths of each of its partners. **SuperGrid Institute is able to develop its research programmes in total independence** thanks to the close collaborative relationships between the industry players involved this project and as a result of the public/private joint investment that finances its work.

SUPERGRID INSTITUTE: A UNIQUE PARTNER FOR YOUR TRAINING NEEDS

By bringing together knowledge and expertise from the industrial and academic worlds, SuperGrid Institute has created a unique environment - an innovation incubator at the cutting edge of supergrid technologies. As the only private sector research centre of its kind in France focusing on HVDC and MVDC technologies, the Institute can devote the entirety of its resources to working for its clients and partners, and supplying relevant training solutions.

SuperGrid Institute also intends to create a gateway between the industrial and academic worlds by developing curricula that will contribute to future electrical engineers' training. The company has the necessary expertise to help higher education and professional training institutions adapt their study programmes and provide them with educational content.

AN UNRIVALLED POSITION

While some universities and research centres are currently working on subjects that partially overlap with those covered by SuperGrid Institute, none of them offer the same comprehensive scope. Similarly, while some industrial players also work transversally, **SuperGrid Institute's unique positioning sets it apart.**

The company's mission is to design solutions which will be useful for manufacturers' customers and for transmission system operators. Positioned halfway between manufacturers and operators, SuperGrid Institute is a truly unique company in its market.

04 | SUPERGRID INSTITUTE'S BUSINESS IS ON THE RISE

In 2019, after four years of concentrating mainly on research, **SuperGrid Institute increased the scope and direction of its activities.**

In addition to its research, the company is now placing a heavy focus on marketing its research results and creating value from its expertise, testing facilities and intellectual property. The business's strategic approach will be fed by these two dimensions, research & development and creating value for our clients, all the while ensuring that neither is prioritised to the detriment of the other.

A COMPREHENSIVE VALUE PROPOSITION

SuperGrid Institute offers its clients a range of services:

- **Innovation & technology transfer:** providing access to cutting-edge research results and offering innovative solutions, including techno-economic optimisation software.
- **Test platforms:** Hardware-in-the-Loop and Power Hardware-in-the-Loop platform; High voltage dielectric platform; DC conductivity testing platform; 200kV and 400kV DC test platform; Power converters; Medium Frequency Transformers (MFT); Power switch characterisation; Hyperbaric test platform; Cable systems & insulation material; Hydraulic test platform, etc.
- **Expertise & consulting services:** Grid consulting services / grid studies, modelling and design for power systems, converters and power electronics; HV/MV product design and troubleshooting; hydraulic turbines and auxiliary services; cable and accessories design; professional training.

SOME SIGNIFICANT ORDERS RECEIVED IN 2019

2019 has been a successful year for SuperGrid Institute, proving that its products and services are meeting clients' needs and paving the way towards a very promising future. Below are detailed a selection of significant orders among those placed in 2019.

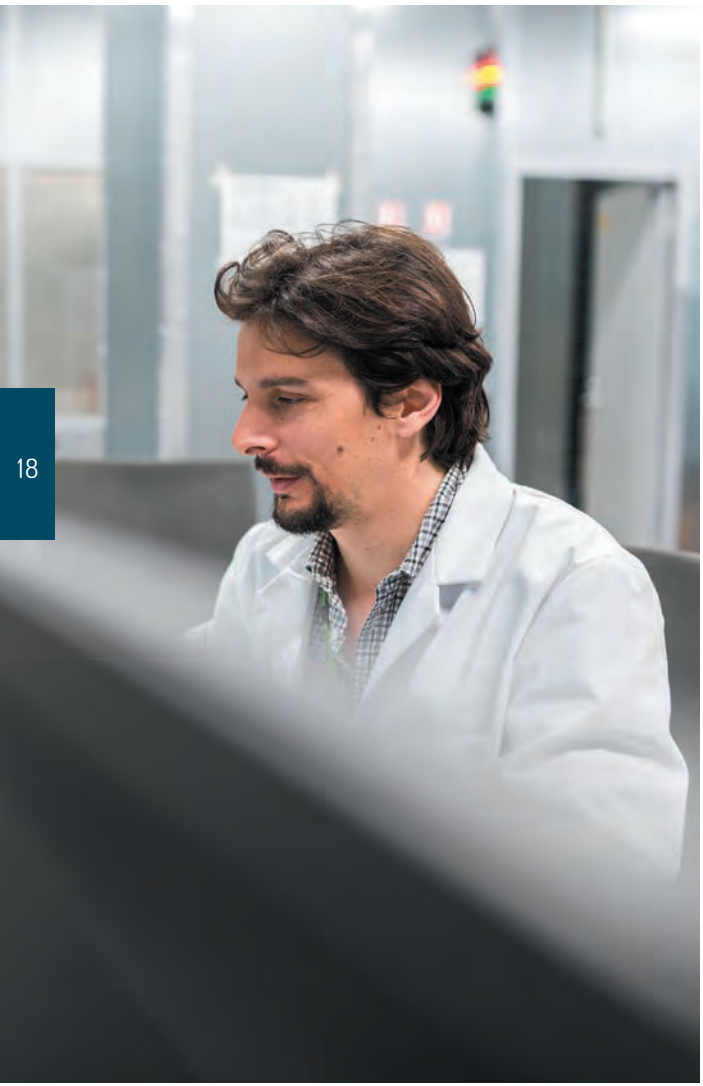
GE Grid Solutions places its trust in SuperGrid Institute

In April 2019, SuperGrid Institute received an official order from GE Grid Solutions for the results of its research into g3 gas. This order demonstrated the high level of confidence this shareholder has in the Institute: a major success for the team.

This important order confirms GE Grid Solutions's commitment to reducing the environmental impact of SF_6 gas. **For several years, SuperGrid Institute's teams have been carrying out fundamental research into the intrinsic properties of different gas mixtures** (small quantities of NovecTM with CO_2 as the primary gas). This work was the subject of a thesis carried out at the Institute's premises, in collaboration with the Ampère laboratory. The design criteria for equipment that will use this gas mixture were also defined by the Institute's teams, with particular interest taken into the effect that the surface texture and size would have on the equipment sections being subjected to High Voltage.

Kohler-Soreel turns to SuperGrid Institute for its high level of expertise and state of the art facilities

In October 2019, SuperGrid Institute received an order from Kohler-Soreel, who placed their trust in the company's power electronics expertise. **This electrical equipment manufacturer, working in the field of AC/DC rail solutions, turned to the Institute to support their customers' projects.** Kohler-Soreel identified SuperGrid Institute's high level of expertise and state of the art facilities, including a simulation platform, which would allow them to validate their product design for high voltage switching technologies for railway applications.

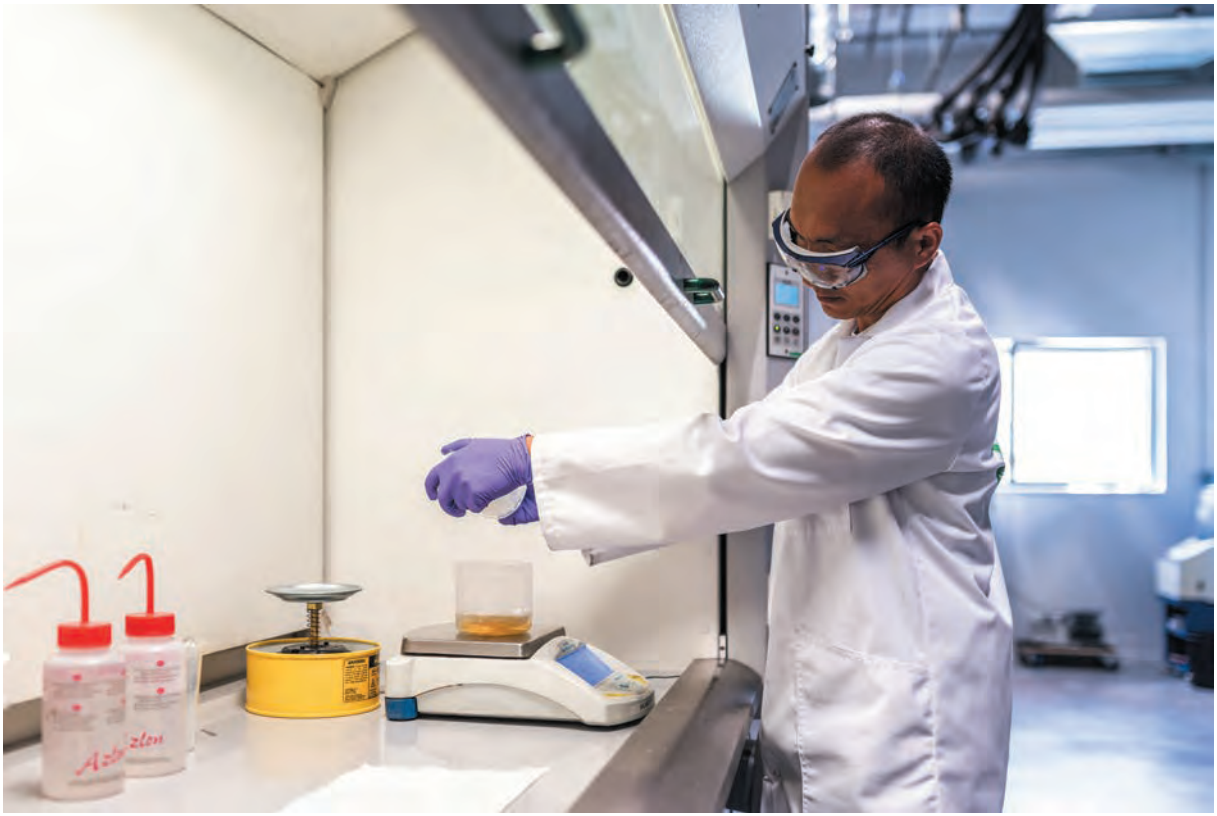


SuperGrid Institute is chosen to collaborate in the innovative Grid2030 programme

The "Reduced Inertia Transient Stability Enhancement" (RITSE) proposal from the "Supergrid Architecture & System" research programme, was selected for the Grid2030 programme by Red Eléctrica de España (REE) and InnoEnergy. This programme aims to accelerate the development of innovative technological solutions within the energy transmission sector. **SuperGrid Institute, REE and IMDEA's combined proposal was chosen from among almost 70 projects.**

In February 2019, SuperGrid Institute hosted the first RITSE project members' meeting. The meeting featured technical presentations on the project's various concepts (e.g. the Dynamic Virtual Admittance Concept, a SuperGrid Institute innovation, and IMDEA's Virtual Synchronous Machine). These presentations led to further discussions with Red Eléctrica de España (REE), the Spanish Transmission System Operator (TSO), about the types of models and tools to be used throughout the project. In addition, SuperGrid Institute presented an overview of its power conversion activities with the aim of prompting synergies between IMDEA and the Institute's "Power Electronics & Converters" research programme.

Through the RITSE project, SuperGrid Institute aims to improve the transient stability of AC grids by combining the use of batteries with HVDC links.



Nexans entrusts SuperGrid Institute with a research project on HVDC cables

Since 2019, Nexans has relied on SuperGrid Institute's expertise as subcontractors to characterise marketable insulation materials for HVDC cables. Insulators in cable systems that are subjected to direct currents are put under considerable stress and this effect can be amplified over time by the phenomenon of space charges.

SuperGrid Institute was commissioned to find solutions for this problem. In a second phase of collaboration, SuperGrid Institute will continue developing innovative solutions to overcome technological barriers and enable the deployment of underground and underwater HVDC cable systems, while ensuring their reliability.

05 | RAISING OUR PROFILE IN EUROPE AND WORLDWIDE

In 2019, SuperGrid Institute's teams, who are widely recognised for their high quality research, **were invited to present their work at a number of major electrical industry events,** in France, Europe, the United States and Asia.

PCIM Europe

In May, SuperGrid Institute's representatives travelled to Nuremberg (Germany), for PCIM Europe where the Institute had a booth for the first time. The European power electronics sector's flagship event is an important gathering where SuperGrid Institute's teams **present their research and development work** every year.

ENTSO-E / T&D Europe International Conference

SuperGrid Institute's experts travelled to Brussels to attend the "ENTSO-E and T&D Europe cooperation in 2019 for a smart, digital and future-proof electricity network" meeting. The company presented its vision and proposals for interoperability during this key conference for transmission system operators.

Jicable International Conference

SuperGrid Institute presented its simulation methods and DC dielectric design at Jicable, the landmark event for professionals in the power cables and accessories sector, **from the 23rd to the 27th of June, in Versailles (France).**

PEDS 2019 Toulouse

In July, SuperGrid Institute was invited to Toulouse to deliver a keynote address on power electronics for MV & HV grids.

EPRI 2019 HVDC & FACTS International Conference

September saw SuperGrid Institute's teams travelling to Palo Alto (California, USA), to take part in the EPRI 2019 HVDC & FACTS conference following an invitation from EPRI (Electric Power Research Institute), the organisation that unites electric utilities, businesses, government agencies, regulators and public or private entities involved in electricity generation and delivery in the United States.

CIGRÉ-IEC

At the CIGRÉ-IEC conference in Tokyo in April, SuperGrid Institute unveiled an exciting, innovative concept in its paper entitled "A New Energy Management Control of Modular Multilevel Converters for Coping with Voltage Stress on Sub-Modules".

20th International Symposium on Power Electronics

During the 20th International Symposium on Power Electronics, which took place from the 23rd to the 26th of October in Serbia, SuperGrid Institute presented a **keynote address on integrating renewable energies via HVDC grids.**

Kick-off meeting for the LISORE project coordinated by France Energies Marines

This project aims to explore the viability of innovative offshore sub-stations (floating and subsea) as a means of integrating renewable marine energies. During this 15 month long project that brings together 9 partners, SuperGrid Institute is contributing expertise from its "Architecture", "Equipment" and "Cables" programmes.

PROMOTioN

In April, a new work package was set up to explore new avenues for DC terminal testing as part of Europe's PROMOTioN project. In total SuperGrid Institute is now involved in 5 of the project's work packages.

PROMOTioN
PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS

Cnam Entreprises signs a framework agreement with SuperGrid Institute for lifelong learning

In January, SuperGrid Institute and Cnam Entreprises signed a framework agreement for lifelong learning. The Conservatoire National des Arts et Métiers (Cnam), a national institute of higher and further education operated by the French government that is focused on science and industry, will thus be offering courses on DC grids and related technologies that SuperGrid Institute is helping develop.

French Institutes of Technology Forum

On the 7th & 8th of October, France's Energy Transition Institutes (ITE) took part in the French Institutes of Technology Forum for the first time. The ITEs were invited to attend the event in view of them joining the French Institutes of Technology (FIT) association in 2020. During his official address at the Forum, **the French Prime Minister's General Secretary for Investment, Guillaume Boudy, congratulated SuperGrid Institute on achieving first place in the French National Institute of Intellectual Property's (INPI) rankings for patent applications in 2018 (in the SME category).**

INSA INSTITUT NATIONAL DES SCIENCES APPLIQUÉES LYON

INSA Lyon signs a framework agreement with SuperGrid Institute

A framework agreement was signed in April between SuperGrid Institute and INSA Lyon (Lyon National Institute of Applied Science) for the provision of further and higher education. The first task is to develop the HVDC curricula for Masters' students in the REEL (Electricity Networks) pathway in the Electrical Engineering department.

Collaboration with the CPES laboratory

A SuperGrid Institute Ph.D. student crossed the Atlantic to spend a year working with the Center for Power Electronics Systems (CPES) in the United States. In 2019, this Virginia Tech laboratory was ranked as one of the 300 best universities in the world by The Times. Whilst there, this student will continue his work on designing MMC sub-modules for HVDC applications, as part of a Ph.D. that began in 2018 at SuperGrid Institute, in collaboration with the Ampère laboratory.

Science Festival

As part of the French Science Festival that took place from the 5th to the 13th of October, **four high school classes came to the Villeurbanne headquarters** for half a day each to take part in the various events SuperGrid Institute had organised. On the Saturday, the site opened to the public, **welcoming over 300 visitors who came** to find out more about the electrical grids of the future and the institute itself.

Two Master's Degree programmes from Grenoble INP and INSA Lyon start the year at SuperGrid Institute

As students returned to their classes in September, **SuperGrid Institute welcomed students studying for an International Master's Degree in Electrical Engineering for Smart Grids and Buildings, from Grenoble INP.** After learning about the Institute's various research programmes, the students visited some of its test platforms. The following month, **SuperGrid Institute welcomed students from INSA Lyon's Electrical Engineering department (Electricity Grids pathway)** for a similar visit.

06 | A LOOK BACK AT 2019: MEMORABLE MOMENTS

2019 saw SuperGrid Institute strengthen its reputation amongst major industry players, in Europe and worldwide. Here is a look back at a landmark year.

JANUARY

SuperGrid Institute **launches a new test platform in a dedicated new building at their Villeurbanne site, the High Power Hall,** which will be used for testing equipment subjected to very high voltages.

MARCH

The European XFLEX HYDRO project, involving 19 partners, is selected following the European Union's Horizon 2020 call for proposals

The project's aim is to roll out a series of demonstrators based on hydraulic technologies that are designed to bring flexibility to the electricity grid. **SuperGrid Institute's task over the next 4 years will be to test new turbine technologies and lead the work on the impact, economic viability and European deployment** of these ground-breaking innovations.

SuperGrid Institute's official inauguration

SuperGrid Institute's headquarters in Villeurbanne are inaugurated in the presence of representatives of the French state, the Auvergne-Rhône-Alpes Region, Greater Lyon and Villeurbanne as well as its industrial & academic partners.

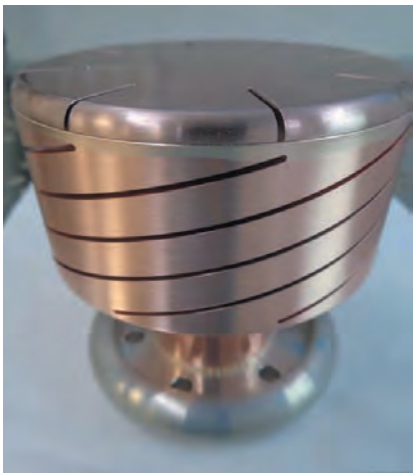
APRIL

INPI INSTITUT NATIONAL

The spotlight shines on SuperGrid Institute as it is rewarded for its ambitious intellectual property strategy.

The French National Institute of Intellectual Property (INPI) ranks SuperGrid Institute at number 1 of the top 10 patent applicants in the SME category for 2018, with 16 patent applications in 2018 alone.

After months of preparation, **the vacuum brazing platform is up and running,** with the first prototypes due for production in the weeks that follow.



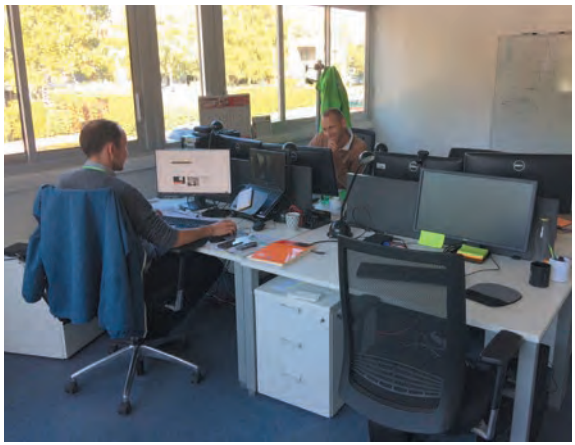
SuperGrid Institute launches its ISO 9001 quality management initiative, to achieve certification for the first of its test platforms and offer its clients the best possible service.

Committed to Quality

MAY

InnoGrid2020+ in Brussels, gives SuperGrid Institute a boost.

SuperGrid Institute is able to network with many key players at this major event for TSOs and DSOs, thanks in large part to its booth at the event.



In Grenoble, the "Power Storage and Balancing" research programme moves to a new site near the CREMHyG laboratory, on the edge of Grenoble INP's Saint-Martin-d'Hères campus, to make room for its growing workforce.

SEPTEMBER

Success at the "Défi inter-entreprises" inter-business sports challenge !

One of SuperGrid Institute's women's teams wins first place in their category at Villeurbanne's inter-business sports challenge for local businesses.

SuperGrid Institute takes delivery of its new cryostat tank. The tank undergoes additional checks and calibration before being fitted with cryogenic feedthroughs and pancake coils of superconducting tape for current limiter tests.

OCTOBER

Phase 1 of "PV Grand Linéaire"

The first phase of this project is launched after SuperGrid Institute signs a contract with the Compagnie Nationale du Rhône (CNR). The project brings together teams from SuperGrid Institute, the CNR and the French Alternative Energies and Atomic Energy Commission (CEA). It focuses on developing a techno-economic study of an MVDC network for a solar power plant on the banks of the river Rhône (France).

NOVEMBER

SuperGrid Institute holds its first Technical Days event

This two-day workshop is organised for the Institute's industrial shareholders, in order to better align the Institute's work with shareholder expectations and gain a better understanding of real market needs.

Françoise Lamnabhi-Lagarrigue, a member of the "Supergrid Architecture & Systems" programme committee, is awarded the 2019 Irène Joliot-Curie Prize in the Female Scientist of the Year category. This prize was created in 2001 and aims to promote women's place in research and technology in France.


ATTENTION
RISQUE DE
CHUTE

07 | FIVE MAIN RESEARCH DOMAINS

SuperGrid Institute's teams are currently working on five main areas of research in the fields of high and medium voltage, and alternating and direct current.

"How should a supergrid system be technically designed and operated? The Supergrid architecture & systems research programme at SuperGrid Institute aims to answer this question. We develop control and protection concepts for HVDC and MVDC systems and define the requirements for key components of the system."

Bruno Luscan, Programme Director
SUPERGRID ARCHITECTURE & SYSTEMS

"The wide-scale integration of renewable energies requires a network that is capable of transmitting electricity over long distances, for which HVDC cable systems are an essential element. We develop innovative solutions to help develop offshore grids and to ensure the reliability of underground and subsea HVDC cable systems."

Martin Henriksen, Programme Director
HVDC CABLE SYSTEMS & JUNCTIONS

"Developing substation technologies adapted to the constraints of future DC networks and that are environmentally friendly is at the heart of the High Voltage Substation Equipment research programme's concerns."

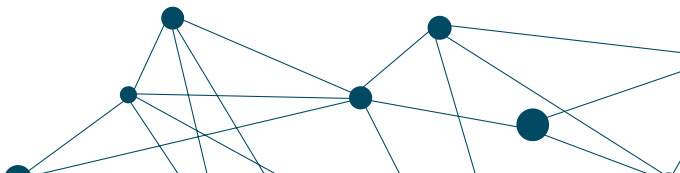
Alain Girodet, Programme Director
HIGH VOLTAGE SUBSTATION EQUIPMENT

"Managing the integration of intermittent renewable energy sources into electricity transmission networks on a wide-scale is essential for ensuring the stability and flexibility of the grid, especially in the context of HVDC current. This will be achieved through innovative storage technologies that use hybrid solutions."

Renaud Guillaume, Programme Director
POWER STORAGE & BALANCING

"Power Electronics pave the way to building the future global electrical grid. At SuperGrid Institute, we develop innovative technologies that are reliable, efficient and cost-effective to bring this web of electricity to life."

Loïc Leclere, Programme Director
POWER ELECTRONICS & CONVERTERS



Each of these five research departments is made up of several sub-programmes that work to overcome the technological barriers impeding the development of the electrical grids of the future.

In total, there are around thirty sub-programmes currently active at our Villeurbanne and Grenoble sites. The following pages are dedicated to some of the key projects they worked on in 2019.

PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS (PROMOTioN): DC GRID PROTECTION SYSTEM DEVELOPMENT

Protection for meshed HVDC offshore networks.

PROMOTioN
PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS

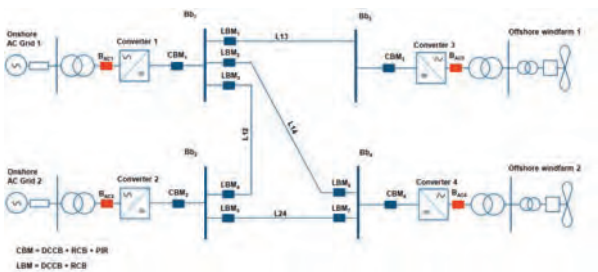
Duration: 4 years
Launched: 2016

Objectives:

- Identify possible protection strategies for use in DC networks.
- Develop the most promising protection strategies in more detail.
- Identify KPIs to assess and compare protection strategies.
- Develop a protection relay (IED) to allow protection algorithms to be tested in real-time simulation.
- Develop a methodology for performing a comprehensive cost-benefit analysis of a given protection strategy.

Scientific and technical scope:

- Performing simulation work based on virtual models, and developing methodologies for techno-economic analysis.



Accomplishments in 2019:

- PhD Guilherme DANTAS DE FREITAS "Development of a methodology for DC grid protection strategies comparison".
- Using the developed methodology on a small benchmark network.
- Implementing the methodology on a large benchmark network in the seas of northern Europe, as suggested by the transmission system operator TenneT.
- Validating several protection strategies implemented in the network suggested by TenneT using EMT software.

Major milestones:

- Report on performance, interoperability and failure modes of selected protection methods, PROMOTioN Workpackage 4, deliverable D4.3 (2019, 1).
- See the related publications on page 60.

Value for energy transition:

This project is important as it will enable Europe to develop a network in the Baltic Sea and North Sea where the wind energy development objectives are huge.

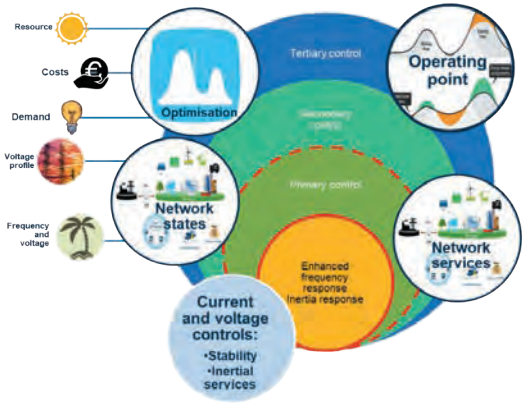
Project partners

DNV·GL, KTH, KU LEUVEN, MITSUBISHI ELECTRIC Changes for the Better, Rte, RWTH AACHEN UNIVERSITY, SIEMENS, SVENSKA KRAFTNÄT, TRACTEBEL ENGIE

REDUCED INERTIA TRANSIENT STABILITY ENHANCEMENT (RITSE)

Control of HVDC links to enhance power network stability.

Duration: 2 years
Launched: 2019



Objectives:

Present the Dynamic Virtual Admittance Control (DVAC) concept with the Spanish operator Red Electrica de España (REE) and two other partners (IMDEA and InnoEnergy), to demonstrate its relevance and utility for the grid.

Scientific and technical scope:

Highlighting the improvements operators will be able to make to their systems and demonstrating how this concept can reach the market.

Accomplishments in 2019:

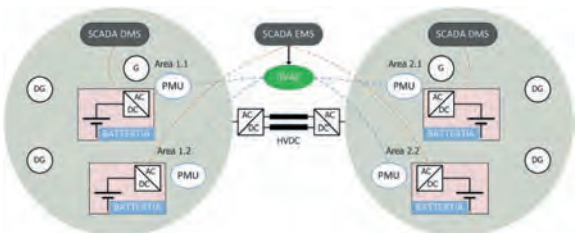
- Applying the DVAC concept to the model of REE's grid.
- Demonstrating that DVAC works with a manufacturer's HVDC control technology (General Electric).

Major milestones:

- PhD Juan-Carlos GONZALEZ "Transient stability of high voltage AC-DC electric transmission systems".
- Rotor angle stability enhancement using dynamic control of embedded HVDC links, J-C. Gonzalez, EPRI 2019 HVDC & FACTS.
- See the related publications on page 60.

Value for energy transition:

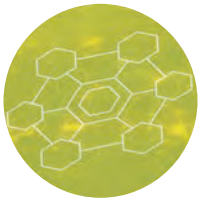
The two concepts developed as part of the RITSE project (DVAC - SuperGrid Institute and BATTERCIA - IMDEA) will undoubtedly contribute to the increase of renewable energies in the grid by helping to boost the stability margins of low inertia networks.



Project partners

SUPERVISORY CONTROL OF HVDC GRIDS BASED ON DISCRETE EVENT SYSTEMS (DES)

Managing operation methods, coordination and control of a multi-terminal HVDC system.



Duration: 6 years
Launched: 2016

Objectives:

- Controlling the system automatically to return to a normal operational state as quickly and safely as possible.
- Changing the HVDC converter control modes when there is a disturbance in the system.

Scientific and technical scope:

- Developing expertise and tools that make it possible to design a supervisory control adapted to HVDC systems that respects manufacturer's specifications, therefore reducing the number of necessary acceptance tests.
- Design and integration of control architectures.
- Identifying a system's operating modes in order to automate its supervisory control.

Accomplishments in 2019:

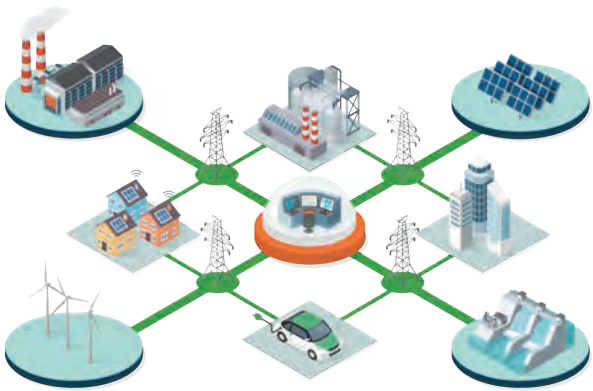
Development of a supervisory control based on Discrete Event Systems (DES) methods (real-time testing with realistic hardware elements and communication protocols).

Major milestones:

- Patent pending: FR1908975 - HVDC installation supervision process.
- PhD Miguel ROMERO RODRIGUEZ "Supervisory control synthesis for MMC-based HVDC systems"
- See the relevant publications on page 60.

Value for energy transition:

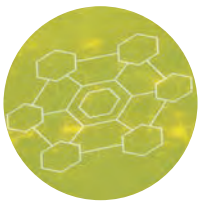
The supervisory control function will coordinate future electricity grids' numerous technological building blocks and their interoperability. It will therefore be a key element for ensuring grids' operational safety and continuity. The supervisor will be required to accurately identify the state of the system based on the data provided and act quickly and automatically to rectify any problems. The increased presence of power electronics in grids will require faster supervisor reactivity.



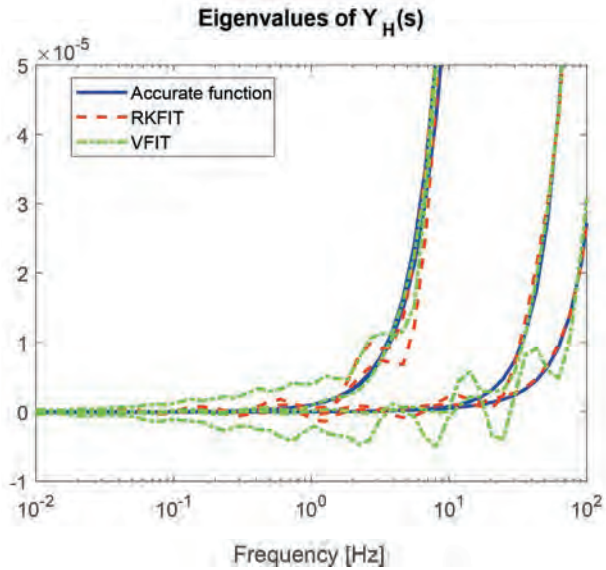
Project partners

CONTRIBUTION TO THE MODELLING OF HVDC CABLES FOR ELECTROMAGNETIC TRANSIENT SIMULATIONS

Cable models for electromagnetic transient simulations.



Duration: 3 years
Launched: 2017



Objectives:

Improving existing cable models to deliver a more accurate and stable simulation result, thereby making it easier to manage the network when faults occur.

Scientific and technical scope:

- Developing a mathematical method to guarantee the cable model's passivity.
- Improving the fitting method: a mathematical method used to reduce the scale of cable models more accurately.

Accomplishments in 2019:

PhD Amjad MOUHAIDALI "Contribution to the modelling of HVDC cables for electromagnetic transient simulations"

Major milestones:

- Patent pending: FR1874052 - High fidelity rational fitting of frequency transfer function with time delay.

Value for energy transition:

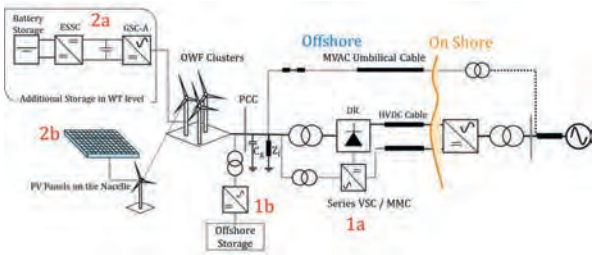
Cable models are the building blocks of electromagnetic transient simulations. The large-scale integration of renewable energies into the network depends on these simulations because they are essential for the development of protection and control strategies for multi-terminal DC networks (MTDC).

Project partners

HVDC TRANSMISSION WITH DIODE RECTIFIER UNITS (DRU) FOR OFFSHORE WIND FARM CONNECTION

Connecting offshore wind farms via an HVDC transmission link.

Duration: 3 years
Launched: 2017



Objectives:

- Reducing the costs of offshore high voltage AC/DC conversion for use with HVDC transmission (mainly point-to-point connections).
- Highlighting the constraints of this DRU technology and suggesting solutions to some of these constraints.

Scientific and technical scope:

- Grid forming:

  - Challenge: managing the MVAC power collection system's voltage magnitude and frequency in the absence of an offshore HVDC voltage source converter and without the MVAC cable which usually connects the collector system to the shore in the DRU solution.

  - Solution: using converters at the wind turbine outputs to manage this voltage – synthesising and implementing the related control laws.

- Black Start: Implementing a process whereby offshore wind farms can power up by themselves (using local energy storage and wind power) without a connection or dependency on the continent/onshore grid via an MVAC cable. Managing the steps of this start-up process with a dedicated supervisory control.

Accomplishments in 2019:

- Execution of a Grid forming method.
- Execution of a Black Start method.

Major milestones:

- PhD Ragavendran RAMACHANDRAN "Control and Power Management of an Offshore Wind Power Plant with a Diode Rectifier based HVDC Transmission".
- See the related publications on page 60.

Value for energy transition:

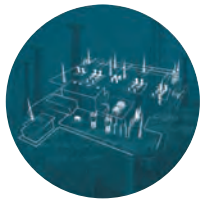
An innovative, lower-cost solution (less complex AC/DC conversion, fewer losses and increased reliability due to the passive nature of the DRU) for connecting high-power offshore wind farms located far from shore.

Project partners

EDF · G2Elab · GE · L2EP

DC GAS INSULATED SWITCHGEAR (DC GIS)

DC gas insulated substations (converter stations, cable/overhead transmission line networks) and high-voltage DC switchgear using solid and/or gas insulation.



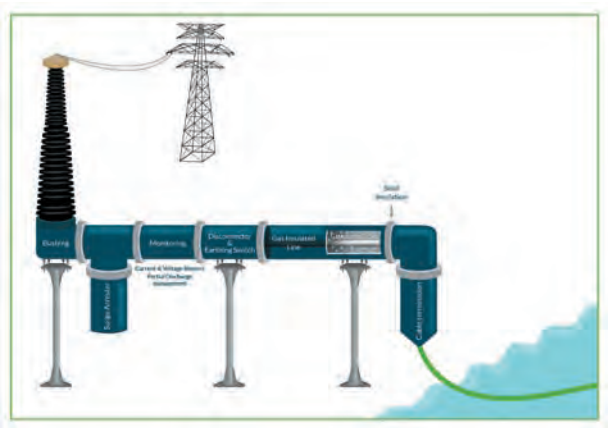
Duration: 7 years
Launched: 2014

Objectives:

- Design HVDC equipment using multi-physics simulation.
- Test HVDC equipment in accordance with IEC and CIGRE standards.

Scientific and technical scope:

- Improve knowledge of solid and gas insulation.
- Develop a complete simulation methodology that takes material electrical conductivity, space charges and temperature into account.
- Determine the design criteria.
- Design products ready for manufacture (busbar-disconnector).



- Define the future standards for electric power systems by participating in international working groups (IEC, CIGRE).

Accomplishments in 2019:

- Manufacturing and testing 320kV and 500kV busbars.
- Developing a methodology for calculating dielectric constraints specific to direct current and designing isolation systems thanks to the criteria identified using this methodology.

Major milestones:

- Patent pending: FR2001456 - Disconnector switch enabling the transfer of power from one line to another.
- See the relevant publications on pages 60 - 61.

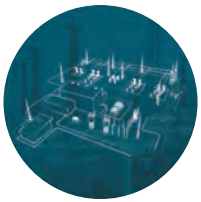
Value for energy transition:

DC Gas insulated switchgear reduces the amount of space required to build HVDC offshore wind farms, therefore bringing down the cost. It is also an inherent component in multi-terminal DC networks. These networks will facilitate the wide-scale integration of renewable energy sources while minimising losses.

Project partners

DC CIRCUIT BREAKER

Protection equipment for high voltage direct current networks.



Duration: 6 years
Launched: 2018

Objectives:

Develop a circuit breaker for multi-terminal DC networks making it possible to interrupt a fault current of 20 kA in less than 10 milliseconds.

Scientific and technical scope:

- Characterisation of the high current, high frequency breaking arc.
- Withstand of the transient interruption voltage in metallic plasma in a vacuum.
- Optimise the fault clearing time.

Accomplishments in 2019:

- Characterisation of arc-quenching chambers.
- Validating the forced commutation interruption principle.
- Developing an ultra-fast electro-mechanical actuator.
- Creating a techno-economic model of HVDC circuit breaker solutions.

Major milestones:

- Patent pending: FR1874217 High-voltage direct current cut-off device with an adaptive oscillation circuit and control method.
- Patent pending: FR1903008 – High-voltage direct current cut-off device with resonator and switching.

Value for energy transition:

One of the technical barriers facing Multi-terminal Direct Current (MTDC) networks is the ability to interrupt faults in the network. These networks will facilitate the large-scale integration of renewable energies, notably offshore energy. In addition to addressing the issue of interrupting faults on MTDC networks, this circuit breaker has been designed using environmentally friendly technologies.

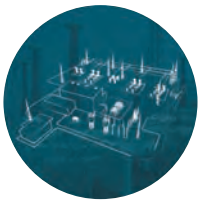
Project partners

EDF

GE

PARTIAL DISCHARGE MEASUREMENT SYSTEM

DC gas insulated substations (converter stations, cable/overhead transmission line networks).



Duration: 1,5 years
Launched: 2019

PROMOTioN
PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS

Objectives:

Evaluate the performance of partial discharges sensors under DC voltage with SF_6 gas and alternative gases.

Scientific and technical scope:

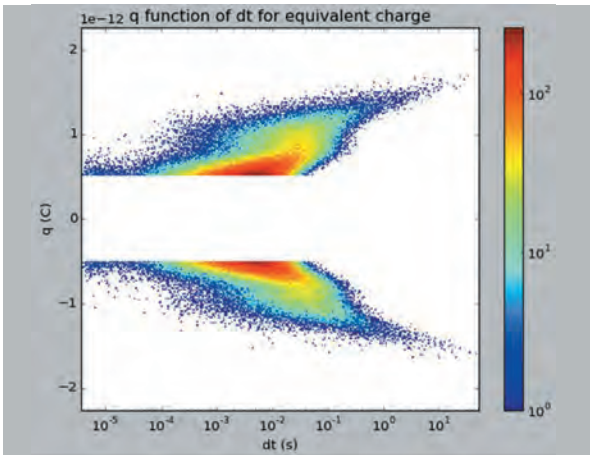
- Analyse short and long term partial discharge behaviour under DC voltage, according to the type of fault and gas (SF_6 gas and alternative gases).
- Develop monitoring and diagnostic methods for HVDC GIS equipment to ensure the switchgear can be operated safely.
- Evaluate the performance of SF_6 gas alternatives
- Use long-term testing, monitoring, and diagnosis to improve models and develop an understanding of failure modes.

Accomplishments in 2019:

- Completing a series of DC tests to determine fault signatures, using different measuring systems and on different gases.
- Installing a test loop for long-term tests with a background noise of less than 1 pC.

Value for energy transition:

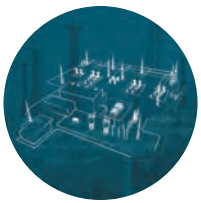
This technology helps minimise the risk of electric arcing which in turn reduces the amount of greenhouse gases, used to insulate high voltage switchgear, that leak out when the safety devices open.



Project partners

VACUUM SWITCH DESIGN AND MANUFACTURING

Vacuum or low pressure switches for AC and DC networks.



Duration: 5 years
Launched: 2016

Objectives:

- Commission a test platform with the capacity of manufacturing small series of vacuum switches.
- Define design guidelines for these vacuum switches.

Scientific and technical scope:

- Commission the manufacturing test platform.
- Define surface treatment and brazing acceptance tests.
- Define the specifications for and commission a test bench to develop the technological aspects of vacuum switch key components.
- Develop plasma characterisation tools to support the technological development of vacuum switches.
- Design, manufacture and test electrical contacts and their magnetic structure.
- Assess the dielectric qualities of vacuum or low pressure switches.

Accomplishments in 2019:

- Commissioning the manufacturing platform.
- Manufacturing a 36 kV vacuum interrupter

Major milestones:

- See the relevant publications on pages 60 - 61.

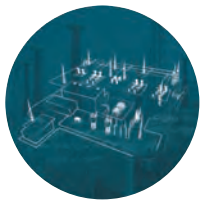
Value for energy transition:

The development of environmentally friendly circuit breaker technologies makes it possible for manufacturers to stop using greenhouse gasses such as SF_6 for insulation. With our manufacturing capabilities up and running, we are able to design, manufacture and test specific prototypes that can be used in DC circuit breakers.

Project partners

COST-EFFECTIVE FCL USING ADVANCED SUPERCONDUCTING TAPES FOR HVDC GRIDS

Protecting multi-terminal HVDC grids by combining a resistive superconducting fault current limiter (RSFCL) and a circuit breaker (CB).



Duration: 3,5 years
Launched: 2017

FastGrid

Objectives:

- Significantly reduce the cost of the RSFCL.
- Propose a reliable RSFCL design for high voltage.
- Validate the RSFCL's performance when combined with a DC circuit breaker.

Scientific and technical scope:

- Develop a structure for the conductor with significantly improved electrical properties in order to drastically reduce the RSFCL's cost.
- Produce long lengths of the conductor on an industrial scale without it losing its electro-thermal properties.
- Study the dielectric properties of nitrogen in its liquid and two-phase form (liquid + gaseous phase) and propose design rules that apply to high voltage.
- Design and produce windings and the RSFCL.
- Propose methods for testing the RSFCL in high voltage.
- Design and test the related CB.
- Assess the cost of the RSFCL + CB solution.

Accomplishments in 2019:

- Defining the conductor structure.
- Testing samples of the conductor.
- Commissioning the cryostat platform.
- Producing the conductor in long lengths and performing a demonstration of the RSFCL's elementary module windings.

- Carrying out a series of dielectric tests to characterise the liquid and two-phase nitrogen.
- Completing functional performance tests of the CB components.

Major milestones:

- See the relevant publications on pages 60 - 61.

Value for energy transition:

The RSFCL + CB solution offers a cost-effective, reliable design for use in high voltage networks. By addressing the issue of fault current management, one of the technical barriers facing multi-terminal networks, this solution is helping to facilitate the large-scale integration of renewable energies into the grid.

Project partners

cnrs · G2Elab · ELU · EPFL · ICMAB CSIC · KIT · OXOLUTIA · Polytechnique Montréal Université d'ingénierie · RSE · STU · Tel Aviv University אוניברסיטת תל אביב · THEVA

LARGE LINEAR PHOTOVOLTAIC POWER PLANT PROJECT (LARGE LINEAR PV)

Linear photovoltaic power plant on the banks of the Rhône (France).

Duration: 1 year
Launched: 2019

Objectives:

- Carry out a feasibility study for the project and confirm the appeal of using a medium voltage direct current (MVDC) electrical architecture for producing solar energy over long distances of up to 20 kilometres.

Scientific and technical scope:

- Carry out a study of an MVDC network architecture that makes it possible to efficiently transport the energy produced by photovoltaic panels to the mains via two hydroelectric power plants.
- Complete a study of control and protection principles for the MVDC network.
- Study energy conversion solutions to connect the photovoltaic panels to the MVDC network (DC-DC conversion) and to connect the MVDC network to the AC mains network (DC-AC conversion).
- Perform a study of MVDC network equipment (cabling & switchgear).
- Complete a techno-economic study of the solution.

Accomplishments in 2019:

In-depth needs analysis and detailed technical specifications for the following phases of the project.

Value for energy transition:

This project will provide the Compagnie Nationale du Rhône (CNR) with a solution that takes the constraints of collecting solar energy from a large linear set-up into account.

Project partners

CNR

Working in collaboration with

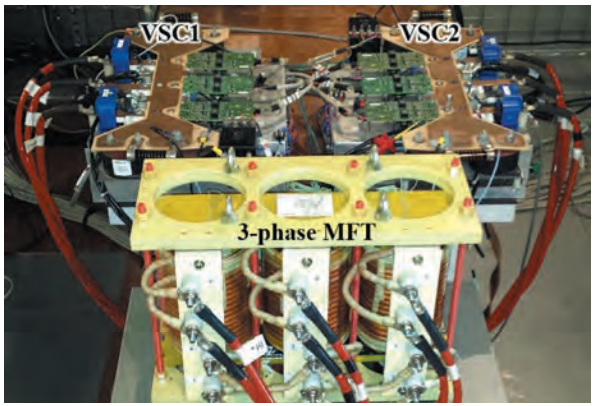
cea

ines2s

100KW DC-DC ISOLATED CONVERTER

Modular isolated DC-DC power converter for use in transport (maritime or rail) or to interconnect renewable energy sources in a DC distribution network.

Duration: 5 years
Launched: 2014



Objectives:

Design, prototype and test a 100 kW medium voltage, compact (power density > 1 kW/kg), and highly energy efficient (> 98%) DC-DC converter.

Scientific and technical scope:

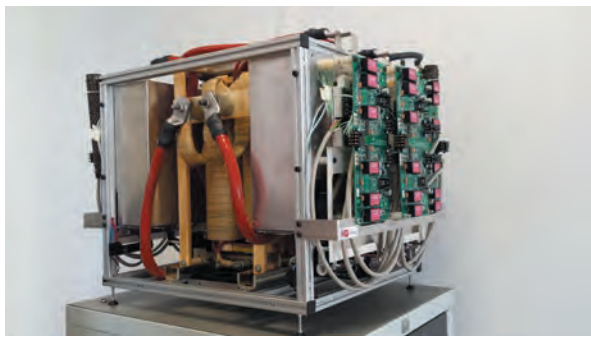
- Study and sizing of the converter: Single-phase and three-phase Dual Active Bridge (DAB) operating at 20 kHz.
- Design a Medium Frequency Transformer (MFT) operating at 20 kHz.
- Multi-physical design of power modules including silicon carbide (SiC) switches.
- Design and implementation of Rapid Control Prototyping (RCP).
- Prototyping and testing the complete converter.

Accomplishments in 2019:

- Producing and testing an innovative three-phase Medium Frequency Transformer.
- Testing the DC-DC converter using the three-phase transformer: measured performance is greater than 99%.
- Optimising the converter performance by mitigating the electromagnetic interference

Major milestones:

- Patent pending: WO2017187045 - Control process for a dual-active-bridge DC-DC converter.
- See the relevant publications on pages 61-62.



Value for energy transition:

This technology facilitates the integration of renewable energies into DC distribution networks or mixed AC and DC urban networks.

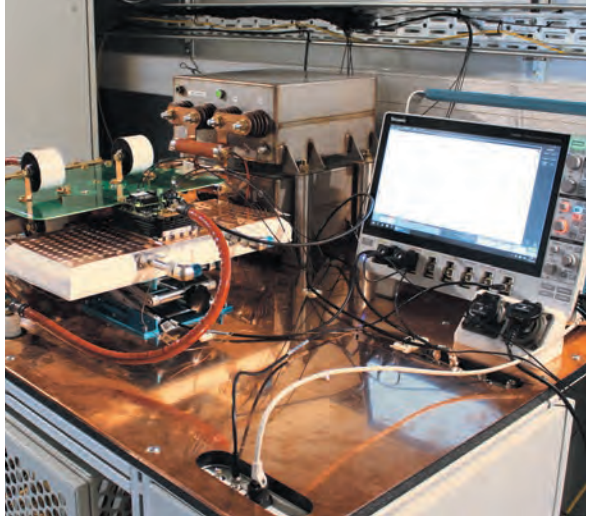
Project partners

ALSTOM · Ampère · EDF · G2Elab · GE

HIGH CURRENT POWER SEMICONDUCTOR SWITCH CHARACTERISATION TEST BENCH (HCSW)

High voltage and current power converters.

Duration: 5 years
Launched: 2014



Objectives:

Characterisation and modelling of power electronics components.

Scientific and technical scope:

- Static characterisation of power components.
- Dynamic characterisation of power electronics components (hard and soft switching).
- Robustness and reliability tests.
- Modelling of power electronics components.

Accomplishments in 2019:

- Continued in-depth characterisation and modelling of power electronics components for high voltage and current levels.
- Automating the launch of test sequences.

Major milestones:

- Performance of tests as part of the SeTT project
- ECPE presentation: T. LAGIER, "Design of a 1200 V, 100 kW Power Converter: How Good are the Design and Modelling Tools?", The Future of Simulation in Power Electronics Packaging for Thermal and Stress Management - ECPE Workshop, Nuremberg 2018.

Value for energy transition:

Power electronics converters are the interface between production and storage facilities (wind, solar, batteries, etc.) and the grid. In order to optimise the efficiency of these converters, decrease their mass and reduce losses, it is important to characterise the power switches, especially when the switching frequency increases.

Project partners

ALSTOM Ampère EDF GE

SUPERGRID INSTITUTE
E-TRANSFORMER FOR TRACTION (SETT)

Electronic transformers for use in railways.

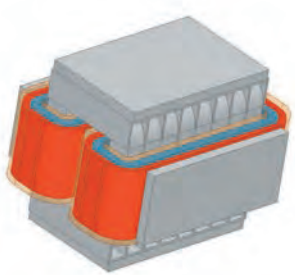
Duration: 3 years
Launched: 2017

Objectives:

Design an optimal single-phase AC/DC converter for trains that improves performance and reduces on board weight and volume by replacing the main transformer and rectifiers.

Scientific and technical scope:

- Hard and soft switching characterisation of 3.3 kV silicon carbide (SiC) MOSFETs, and creating a behavioural model for the switch.
- Study, calculate the optimal size, compare and optimise the converter topology.
- Design a Medium Frequency Transformer (MFT) with reinforced insulation between the primary and secondary windings.
- Design and produce a reduced scale model of the converter including its control solution (hardware and software).



Accomplishments in 2019:

- Implementing the control software into the reduced scale model of the converter.
- Defining the specifications for the Litz cables and acoustic measurements on a scale 1 magnetic nanocrystalline core for the MFT.

Major milestones:

- Patent pending: WO2018172671 - Multilevel AC/DC converter control process.
- Patent pending: WO2019162608 - On-board electric power conversion system.
- See the relevant publications on pages 61 - 62.

Value for energy transition:

This technology improves traction chain energy performances and reduces the overall size and weight of on board train equipment.

Project partners

ALSTOM · Ampère · EDF · G2Elab · GE · Laplace

Working in collaboration with deeP Concept

ENERGY STORAGE SYSTEM INTEGRATED INTO POWER CONVERTERS FOR HVDC TRANSMISSION SYSTEMS

Providing auxiliary services thanks to the integration of an energy storage system in the power converters used for DC links.

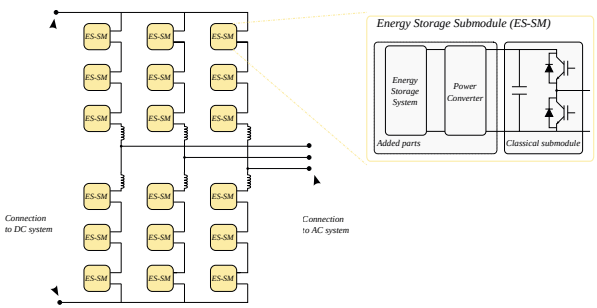
Duration: 3 years
Launched: 2017

Objectives:

- Improve the stability and management of the electrical grid by integrating energy storage systems that are capable of compensating for temporary differences in energy production and demand.
- Design an energy storage system that can be integrated into HVDC transmission system power converters.

Scientific and technical scope:

- Identify ancillary services that could be supplied by these new converters and pinpoint relevant energy storage technologies.
- Calculate the size requirements for an energy storage solution integrated into a multi-level modular converter (MMC).



- Suggest a suitable structure for the converter acting as an interface between the MMC and the energy storage system.
- Validate the concept on a reduced scale model.
- Study the reliability of the complete system, the probability that the expected service will be provided and the cost of this solution.

Accomplishments in 2019:

- Patent pending: FR1904790 – Multi-level voltage converter with optimised additional energy storage.
- Creating the reduced scale model, commissioning it and running tests.

Major milestones:

- See the relevant publications on page 61 - 62.

Value for energy transition:

Unlike traditional electrical production methods, new renewable energy sources (wind and solar) are connected to the grid via a power electronics converter. This means they have no inertia so connecting them to the grid causes problems for grid stability. There are two challenges linked to integrating renewable energy sources into the grid: transporting energy over long distances, via underwater or underground cables, and the generators' lack of inertia. Introducing energy storage in DC link converters offers a solution to both of these issues.

Project partners

Ampère · ALSTOM · GE · G2Elab · EDF

SIC COMPONENTS
10 KV - PIN DIODE AND BJT

Medium and high voltage power converters made from 10-kV semi-conductors using silicon carbide (SiC) technology, for use in railways, electrical grids and the medical sector.

Duration: 5 years
Launched: 2014

Objectives:

- Study and produce the first 10-kV SiC chip samples: PIN (Positive Intrinsic Negative) diode and BJT (Bipolar Junction Transistor).
- Static and dynamic characterisation of these samples to validate the design.

Scientific and technical scope:

- Component specification.
- Simulating the physical design of these components (e.g. thickness of the materials).
- Producing wafers (made with semi-conductor materials for chip manufacturing).
- Packaging.
- Performing static, dynamic and short circuit tests to validate the design.

Accomplishments in 2019:

- Static characterisation of the chips (PIN diodes and BJT) made from the latest wafer.
- Designing a 10 kV switch mock-up for the dynamic characterisation of PIN diodes.
- Performing dynamic characterisation and repetitive short circuit withstand tests on the BJTs.

Major milestones:

- 10kV Silicon Carbide PIN Diodes and Bipolar Junction Transistors for High Voltage Current applications, B. Asllani, ECPE Workshop: Power Semiconductors in Medium Voltage Applications -SiC vs. Silicon-, 2019.
- See relevant publications on pages 61 - 62.

Value for energy transition:

Converters that use these components benefit from fewer losses thanks to the component's faster switching behaviour. These components can function in high operating frequencies, making it possible to reduce their size, and therefore mass, and to use less energy (e.g. in railway rolling stock). They can also withstand higher temperatures and voltages than standard silicon (Si) components.

Project partners

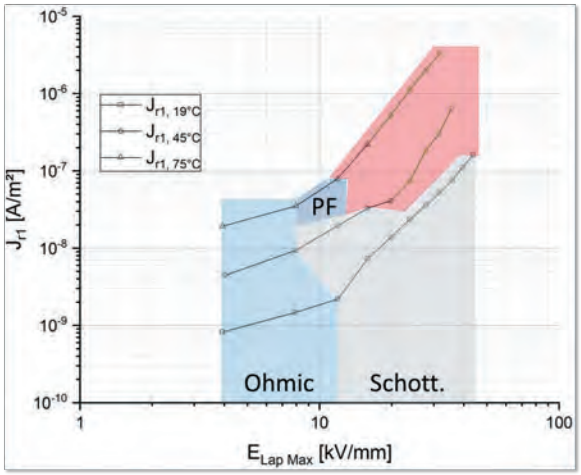
ALSTOM · Ampère · EDF · GE

Working with the support of CALY TECHNOLOGIES

CONDUCTION MECHANISM CHARACTERISATION FOR HVDC CABLES

Cable monitoring and diagnosis.

Duration: 3 years
Launched: 2018



Objectives:

- Map conduction mechanisms in HVDC cable insulation: classify the different physical mechanisms that transport electrical charges according to voltage and temperature.
- Acquire a better understanding of how cables behave as they age.

Scientific and technical scope:

- Develop a "low-cost" system to measure the current passing through the cable insulation in the 100 pA – 25 µA range.
- Develop and validate a methodology for separating stray currents from useful ones in maps.
- Validate a time-saving procedure for determining the cable's conduction mechanisms from transient current measurements.
- Understand the injection and transport mechanisms of electrical charges in cable insulation.

Accomplishments in 2019:

- Validating the procedure for determining the cable's conduction mechanisms from transient current measurements.
- In-depth mapping of conduction mechanisms in HVDC cable insulation according to voltage and temperature.

Major milestones:

- See the relevant publications on page 60 & 62.

Value for energy transition:

By monitoring conduction mechanisms, this project will help increase the reliability of cable systems and make it easier to manage scheduled maintenance work. It will make it possible to detect the most appropriate moment for carrying out cable maintenance, ultimately ensuring that a maximum power supply is maintained at all times.

Project partners

OFFSHORE HVDC NODES

Subsea technologies:
building offshore HVDC networks.

Duration: 4 years
Launched: 2016

Objectives:

- Perform a techno-economic analysis of a Tee-In connection (subsea nodes) in an offshore network.
- Study the electrical requirements and protection strategies needed for a Tee-In connection.
- Present the Tee-In concept as a new means of interconnecting HVDC subsea cables and demonstrate its feasibility.

Scientific and technical scope:

- Electrical network studies.
- Dielectric design studies.
- Mechanical design studies.

Accomplishments in 2019:

Results of the feasibility study:

- Simulation of a subsea node installation that takes weather conditions into account.
- Specification of the Tee-In control communication and power supply.
- Analysis of sealing technologies.
- Cost-benefit analysis.

Major milestones:

- Patent pending: EP3526868 – Subsea connector for high voltage direct current.
- See the relevant publications on page 60 & 62.

Value for energy transition:

Offshore Tee-In nodes make it possible to rationalise the investments needed to build an offshore network. They reduce the number of HVDC cables needed to maintain a maximum level of transmission between offshore production hubs and areas of consumption.

Project partners

AN EFFICIENT FLARED PUMP-TURBINE DESIGN TO REDUCE INSTABILITIES

Improving the stability of
Pumped Storage Power Plants (PSPP).

Duration: 5 years
Launched: 2014

Objectives:

- Improve turbine coupling stability.
- Develop new numerical simulation tools.
- Demonstrate the concept on a reduced scale model.

Scientific and technical scope:

- New numerical methodologies (unsteady 3D fluid dynamics).
- Optimising methods for automating turbine design.
- Observing instability phenomena on a reduced scale model.
- Validating the new design on a reduced scale model.

Accomplishments in 2019:

- Testing a reduced scale model of a new pump-turbine design to measure its efficiency and check its stability.
- Tracing minute particles to take highly accurate measurements of the water flows in the turbine.

Major milestones:

- Patent pending: FR1909861 - Francis-type wheel for hydraulic machines with improved stability.

Value for energy transition:

The demand for electricity does not always coincide with the periods when renewable energy is available. If, when renewable energy is available the demand or means of storing electricity are insufficient, this energy becomes unusable. Renewable energies are therefore often referred to as “unavoidable energy”. As such, the integration of these renewable energies requires a flexible means of storing energy on a large scale.

Hydropower energy storage (PSPP) currently represents between 94 and 99% of the world’s total energy storage capacity. It is also the most efficient and economically viable means of storing energy.

Improving turbine stability makes it possible to optimise hydropower energy storage performance, thereby facilitating the large-scale integration of renewable energy into electricity grids.

Project partners

CREMHyG

08 | FINANCIAL SUMMARY

SUPERGRID INSTITUTE'S FINANCIAL STRUCTURE

SuperGrid Institute is owned by public and private minority shareholders which ensures the company's independence and imposes a mutual decision making process.

Since 2014, the company has been financed through:

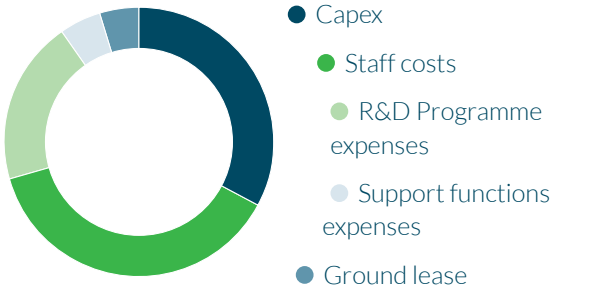
- Funding from the French State's Investments for the Future programme (PIA)
- Subsidies from local authorities (Auvergne-Rhône-Alpes Region and Greater Lyon)
- Investment from industrial shareholders, either as capital or subsidies
- Contributions from academic shareholders, including staff secondment to SuperGrid Institute
- European funding through new collaborative projects
- Self-financing through the company's commercial activities

This financial structure is guaranteed for the first 10 years of SuperGrid Institute's activity. After the first decade, the company will be self-sufficient, covering the cost of its R&D activities with the revenues generated from its technologies and services. Additionally, certain research projects will be eligible for subsidies from the French State and/or European Union.

SuperGrid Institute Funding - over 10 years

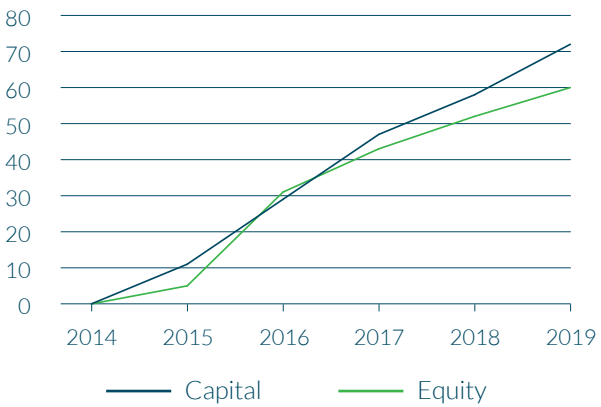
Two thirds of the Institute's overall funding is allocated to R&D expenses, with staff representing roughly 50% of these costs. The remaining third is dedicated to a capex investment plan which allows SuperGrid Institute to differentiate itself through its operational assets.

SuperGrid Institute Expenses - over 10 years

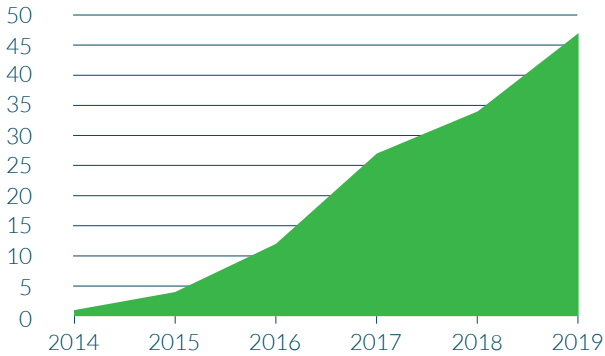


SuperGrid Institute's ambitious R&D investment plan will stimulate innovation over a long term period. The Institute's capital and equity are reinforced every year through capital increase which is made possible by the confidence our public and private shareholders place in us. SuperGrid Institute is expected to make a loss during its first decade. However, the initial funds invested in the company will ensure that the Institute has all the necessary resources to become self-sufficient after this start-up period.

Capital & Equity (M€)



Tangible, intangible and financial assets (M€)



2019 FINANCIAL OVERVIEW

In 2019, SuperGrid Institute saw a considerable increase in its commercial activities. The 2019 turnover of €3.1 M exceeded expectations by 15% thanks to a significant order of g3 gas research results in addition to revenues from platform rental and services.

Private subsidies are in line with industrial shareholders' commitments and funding from the Investments for the Future programme (PIA) covers a significant proportion of our research costs. Funding is allocated to 15 research projects that are already underway and also covers the 3 new projects launched in 2019.

New funding rules from the PIA laid out in 2019 will make SuperGrid Institute eligible for additional funding for new R&D projects.

SuperGrid Institute's costs were 13% lower than expected in 2019 due to lower depreciation expenses, giving a positive result when compared to the initial budgeted costs.

In 2019, the combination of additional revenues and lower costs was a positive outcome, reinforcing confidence in our capacity to run our R&D programmes effectively while securing a robust financial structure for the company's future.

09 | CORPORATE SOCIAL RESPONSIBILITY

At SuperGrid Institute we empower our employees and believe in the value of corporate social responsibility. It has many guises, but its goal is always the same: to improve employee well-being and create a working environment that is responsible, ethical, sustainable and respectful.

PROMOTING DIVERSITY

We are constantly seeking highly-qualified, proactive individuals who are keen to contribute to the company's growth and help us build SuperGrid Institute's future. The Institute is proud of the diversity in its workforce, with team members from all over the world representing a total of 28 different nationalities.

Respect and equal opportunity

At SuperGrid Institute, we respect and value the diversity of our teams, their origins, experiences and career paths, and are committed to offering equal opportunities for all.

SuperGrid Institute is an equal opportunities employer. We believe in equality and take affirmative action to ensure that discrimination has no place in our recruitment process nor our company. All positions at SuperGrid Institute are accessible to people living with a disability.

Gender equality

SuperGrid Institute is committed to ensuring equality in the workplace. The company assesses all job applications based on a candidate's qualifications, skills, professional experience and education. We are committed to offering equal pay for equal work according to each employee's responsibilities, education, experience and professional skills.

WELL-BEING IN THE WORKPLACE

Transparency

At SuperGrid Institute, we value transparency in the workplace. We have introduced a procedure that allows our workforce to raise concerns about possible improprieties or misconduct in complete confidence.

The right to disconnect

We strive to promote the well-being of our employees and protect their work/life balance by respecting their right to disconnect, as is formalised in our employer policies.

COMMITTED TO ENVIRONMENTAL ISSUES

As an Institute for Energy Transition, respect for the environment is one of our core concerns; a value shared by our staff. From using 100% renewable energy in our facilities to increasing awareness of energy-saving behaviour amongst staff, SuperGrid Institute is fully committed to sustainable development. One action taken in 2019 was introducing measures to reduce the use of single-use plastics at the company.

SuperGrid Institute organises a Climate Collage

In December 2019, we organised our first Climate Collage; a fun, interactive workshop intended to raise awareness of climate change issues. This initiative was led by a group of employees who organised the in-house event for their colleagues. The thoroughly enjoyable evening was filled with rich dialogue and thought-provoking exchanges.

Promoting greener modes of transport

In 2019, SuperGrid Institute took part in the Mobility Challenge for the first time. We asked our teams to use a greener mode of transport to get to work and invited two companies to our headquarters site to give cyclists advice and offer bike repair workshops. On the day in question, a total of 108 employees took part in the event at our Villeurbanne and Grenoble sites, covering a total distance of 3,822 kilometres between them on their journeys to and from work.

SPORTING ACTIVITIES EVERYDAY OF THE WEEK

SuperGrid Institute's Sports Association was established in 2016. This proactive organisation offers employees a wide range of activities during the week at lunchtime, including yoga, running, indoor football and combat sports. It also organises outings and trips. In 2019, a number of employees went for a day's skiing in the Alps, while in May a team got together to take up the MaxiRace challenge: a race around Lake Annecy. These activities are sponsored by the company.

The Défi Inter-Entreprises: inter-business sports challenge

Every year, multiple teams from SuperGrid Institute participate in Villeurbanne's annual sports event for local businesses, the Défi Inter-Entreprises. This exciting challenge is always highly appreciated by those who take part. The highlight of the 2019 edition was one of our women's teams winning first place on the podium, a first-time victory for SuperGrid Institute!

STAFF COHESION

SuperGrid Institute's teams are the heart and soul of the company. We strive to create a unified and cohesive working environment for all. Twice a year, we organise events to share the company's achievements, development and vision with the staff and promote social interactions between team members. Every January we celebrate the New Year in a cultural setting. In 2019, our celebration took place at the Musée Lugdunum, a museum focusing on the city's Gallo-Roman heritage, set in the hills above Lyon. We also hold a mid-year review every year in June on our premises. These events provide a valuable opportunity for management and staff to connect, exchange and share.

10 | EXCITING NEW CHALLENGES FOR THE COMING YEAR

The main challenge for SuperGrid Institute's teams moving forward will be to deliver on the promise of the past year. To achieve this we must forge a strong relationship with our clients and be attentive to their needs and those of the market. The transformation that began in 2019 must therefore continue. **We are sure to succeed, as long as the technologies we develop continue to bring concrete solutions to the industry, our clients, partners and shareholders.** From the beginning, SuperGrid Institute positioned itself as a driving force for the development of energy industry players. Therefore, it is together that we must move forward, ever faster, ever farther.

AIMING FOR THE ISO 9001 CERTIFICATION

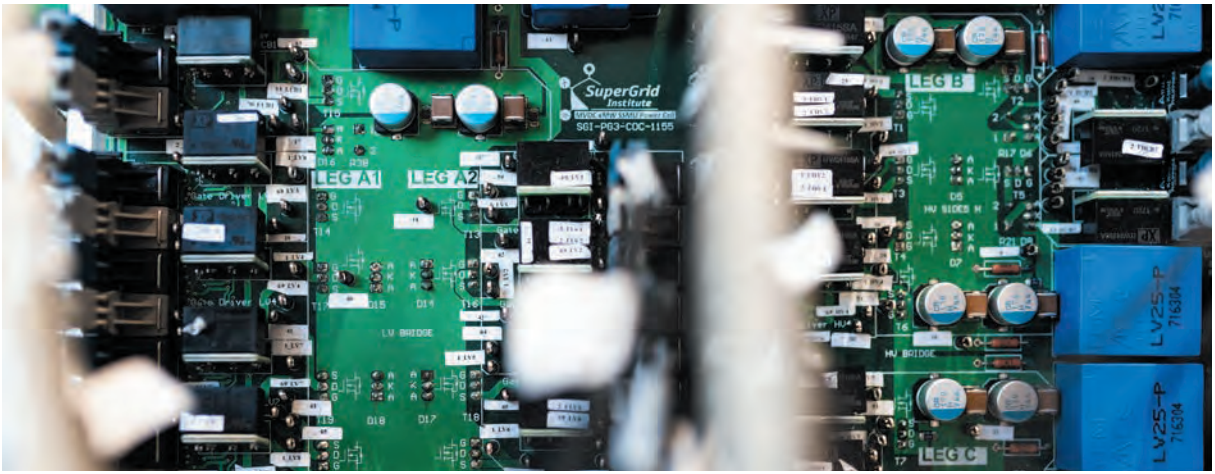
To achieve this goal, we must continue the fundamental work that began in 2019. **The test facilities we use to carry out our services are widely recognised for their efficiency. However, to guarantee the quality of our services for our clients, we need to go even further. The ISO 9001 certification will be a major milestone in this objective.** This process is already underway and we aim to be certified within the year.

REINFORCING OUR INFRASTRUCTURE AND COMPETENCIES

In the coming year, we will continue enhancing the facilities at our Villeurbanne headquarters that were inaugurated in 2019. In addition to the building that was commissioned late last year, dedicated to testing equipment subject to very high voltages, **our third building that will house our High Power Source will be completed in the second half of 2020.** The Auvergne-Rhône-Alpes Region supported this project by contributing €10 M of funding towards this installation. This new facility will allow us to perform both AC and DC short circuit tests. **The High Power Source will supply the energy needed for the High Power Hall, providing us with a truly unique testing facility.**

The first trial tests of this installation are planned for the latter half of 2020. **We will then be able to perform High Voltage DC breaking tests for our research and customers.**

In the coming year, we plan to reinforce our workforce with increased skills and competencies. Drawing on these new talents and skills, we will work together to improve our organisational performance and ensure the successful transformation of our company. **In 2020 we will create value from our research results on a wider scale** by improving our engineering capabilities and putting ourselves in an even better position to meet our clients' needs.



PURSUING NEW PARTNERSHIP OPPORTUNITIES

In parallel to our ongoing transformation, we will rise to the challenge of establishing new partnerships. **Broadening the range and scope of our various collaborations is essential.** To achieve this objective we need to enhance our visibility. We have already made significant progress in this area over the past few years, but now we need to go even further.

This year, we are organising the second edition of our event dedicated to Transmission System Operators (TSO), that will take place in early 2021 at our headquarters; an opportunity to present our vision of multi-terminal direct current grids (MTDC) and discuss the main challenges TSOs encounter in terms of grid interoperability, grid planning, grid engineering, and so on. **TSOs are at the forefront of MTDC grid construction, so it is imperative that we ensure our road maps are aligned and that we work to address the main issues they are confronted with.**

In 2020 we will take part in a certain number of major events in our fields of expertise, both in France and abroad. **We will participate in the PCIM 2020 conference, and later in the year we will be taking part in the CIGRÉ 2020 conference.**

In September, we will host EPE'20 ECCE Europe, a major power electronics conference, in our role as the local organisational committee. **We are also very honoured to have one of our staff, Dr. Abdelkrim Benchaib, appointed as the conference's General Chairman.**

2019 was a year of accomplishment and recognition and **we are sure that 2020 will prove to be another decisive year for the growth of our business. A Memorandum of Understanding is under discussion with the French Transmission System Operator RTE,** an important milestone of our shared commitment to working together. Numerous areas for collaboration have already been identified, pathing the way for a closer working relationship for research and development, services and professional training.

EUROPE: THE CATALYST FOR MTDC GRIDS

Today it is clear that there has been a paradigm shift at a European level. Until recently, it was unclear if the European Union was going to support the development of multi-terminal grids. Today, there is no longer any doubt about the advantages of MTDC. Discussions are finally turning towards how to move forward collectively to develop this technology while safeguarding power grids from risk. This shift in opinion is highly promising as it opens up opportunities for us in terms of European and international collaboration.

For SuperGrid Institute, 2020 looks to be filled with exciting new challenges and our teams are looking forward to shaping the future of power transmission.

11 | PUBLICATIONS 2019

SUPERGRID ARCHITECTURE & SYSTEMS

- A New Energy Management Control of Modular Multilevel Converters for Coping with Voltage Stress on Sub-Modules, K. Shinoda, A. Benchaib & J. Dai, **CIGRE-IEC 2019 Conference.**
- An Implementation Method for the Supervisory Control of High-Voltage Direct Current Transmission Systems, M. Romero-Rodriguez, R. Delpoux, L. Pietrac, J. Dai, A. Benchaib & E. Niel, **Control Engineering Practice Journal.**
- Comparison and assessment of implementation techniques for dynamics mmc type models, A. Zama, S. Bacha, A. Benchaib, D. Frey & S. Silvant, **EPE2019.**
- Effect of the Surge Arrester Configuration in MMC-HVDC Systems under DC and Converter Fault Conditions, N. Manduley, S. Touré, A. Xémard, B. Raison & S. Poullain, **IPST2019.**
- Fault behaviour of bipolar overhead line based HVDC grids, P. Torwelle, A. Bertinato, B. Raison, T. Dung Le, M. Petit, **IET ACDC 2019.**
- FMEA of a non-selective fault-clearing strategy for HVDC grids, G. Dantas De Freitas, A. Bertinato, B. Raison, E. Niel, O. Despouys, **IET ACDC 2019.**
- On the Black Start of Offshore Wind Power Plants with Diode Rectifier based HVDC Transmission, R. Ramachandran, S. Poullain, Abdelkrim Benchaib, Bacha Seddik & Bruno Francois, **EPE'19 ECCE Europe.**
- Pole-to-ground fault protection strategy for HVDC grids under symmetrical monopolar configuration, A. Bertinato, P. Torwelle, G. Dantas De Freitas, M. Colmenero, B. Raison, **POWERTECH 2019.**
- Power system stability enhancement via VSC-HVDC control using remote signals: Application on the Nordic 44-bus test system, J. C. Gonzalez-Torres, J. Mermet-Guyennet, S. Silvant & A. Benchaib, **IET ACDC 2019.**
- Tuning of Droop Parameters Using Virtual Capacitor Control to Improve Voltage Dynamics, K. Shinoda, A. Benchaib, J. Dai & X. Guillaud, **EPE '19 ECCE Europe.**
- Use of Unbalanced Insulation for the Limitation of Double-Pole Lightning Flashovers in Double Circuit HVDC Overhead Lines, N. Manduley, S. Pack, S. Touré B. Raison S. Poullain & A. Xémard, **CIGRE ICLPS 2019.**
- Virtual Capacitor Control for Stability Improvement of HVDC System Comprising DC Reactors, K. Shinoda, A. Benchaib, J. Dai & X. Guillaud, **IET ACDC 2019.**

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- Characteristics of creeping discharges along epoxy surface in fluoronitrile/CO_2 gas mixture under lightning impulse, A. Perez, A. Beroual, A. Girodet & F. Jacquier, **ISH 2019.**
- Design and validation tests of 320kV HVDC GIL/GIS, T. Vu-Cong, G. Ortiz, F. Jacquier, P. Vinson & A. Girodet, **MATPOST 2019.**
- Electric field computation for HVDC GIS/GIL spacer under superimposed impulse conditions, T. Vu-Cong, F. Jacquier & A. Girodet, **CEIDP.**
- Electro-thermal simulation methodology for HVDC cable GIS termination, C. Toigo, A. André, T. Vu-cong, A. Girodet, M. Henriksen, **Jicable 2019.**

- Liquid spray injection in the expansion volume of a CO_2 high voltage circuit breaker, P. Errante, C. Corre & S. Makhlouf, **ILASS.**
- New challenges for High voltage transmission, D. Bachellerie, A. Girodet & F Jacquier, **Symposium Epoxy resin in electrical engineering.**
- Numerical modelling and influence of defects on space charges in epoxy resin under HVDC stresses, G. Ortiz, P. Mbolo Noah, S. Agnel, P. Notingher, C-T. Vu & A. Girodet, **ISH 2019.**
- Numerical Study of the Current Constriction in a Vacuum Arc at Large Contact Gap, B. Tezenas du Montcel, P. Chapelle, C. Creusot & A. Jardy, **IEEE transactions on plasma science.**
- Prebreakdown and Breakdown in Liquid Nitrogen under Pulsed Heating for Superconducting Applications, R. Chassagnoux, O. Lesaint, N. Bonifaci, O. Gallot-Lavallée, P. Legendre, C. Creusot & A. Girodet, **IEEE ICDL 2019.**
- Study of Turn-to-Turn Electrical Breakdown for Superconducting Fault Current Limiter Applications, R. Chassagnoux, O. Lesaint, N. Bonifaci, O. Gallot-Lavallée, S. Flury, P. Legendre, C. Creusot, A. Girodet, G. Escamez & J. Venck, **IEEE transaction on applied superconductivity.**

POWER ELECTRONICS & CONVERTERS

- 25 kV-50 Hz railway power supply system emulation for Power-Hardware-in-the-Loop testings, C. Stackler, N. Evans, L. Bourserie, F. Wallart, F. Morel & P. Ladoux, **IET Research Journals.**
- 3-phase medium frequency transformer for a 100kW 1.2kV 20kHz Dual Active Bridge converter, P. Dworakowski, A. Wilk, A. Michna, B. Lefebvre & T. Lagier, **IECON 2019.**
- Assessment of the Impact of Split Storage within Modular Multilevel Converter, F. Errigo, L. Chedot, P. Venet, A. Sari, P. Dworakowski & F. Morel, **IECON19.**
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- Classification of DC-DC Converters for HVDC Grids, J. Paez, D. Frey, J. Maneiro, S. Bacha & P. Dworakowski, **IEEE Power Delivery.**
- Cost-performance framework for the assessment of Modular Multilevel Converter in HVDC transmission applications, N. Evans, P. Dworakowski, M. Al-Kharaz, S. Hegde, E. Perez & F. Morel, **IECON19.**
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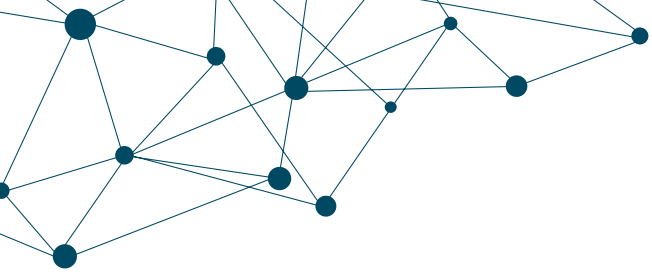
- Interest of using a micro-meter spatial resolution to study SiC semi-conductor devices by Optical Beam Induced Current (OBIC), C. Sonneville, D. Planson, L. V. Phung, P. Bevilacqua & B. Asllani, **ICSCRM 2019.**
- NPC assessment in insulated DC/DC converter topologies using SiC MOSFETs for Power Electronic Traction Transformer, C. Stackler, A. Fouineau, P. Ladoux, F. Morel, F. Wallart, P. Dworakowski & N. Evans, **20th International Symposium POWER ELECTRONICS Ee2019.**



- Packaging Solution for SiC Power Modules with a Fail-to-Short Capability, I. Dchar, C. Buttay & H. Morel, **APEC 2019.**
- Phase medium frequency transformer for a 100kW 1.2kV 20kHz Dual Active Bridge converter, P. Dworakowski, A. Wilk, M. Michna, B. Lefebvre & T. Lagier, **IECON19.**
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- Power electronic traction transformers in 25 kV / 50 Hz systems: Optimisation of DC/DC Isolated Converters with 3.3 kV SiC MOSFETs, F. Morel, C. Stackler, P. Ladoux, A. Fouineau, F. Wallart, N. Evans & P. Dworakowski, **PCIM Europe 2019.**
- Requirements for interconnection of HVDC links with DC-DC converters, D. Gómez A, P. Dworakowski, J. Páez, O. Gomis-Bellmunt, M. Cheah-Mane, F. Morel & J. Maneiro, **IECON19.**
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- Study of convective condensation in a thermosiphon loop, M. Moustaid, V. Platel & C. Buttay, **HEFAT 2019.**
- Study of the impact of DC-DC converters on the protection strategy of HVDC grids, J. Paez, J. Maneiro, D. Frey, S. Bacha, A. Bertinato & P. Dworakowski, **IET ACDC 2019.**

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- Comparaison de mesures de conductivité obtenues par spectroscopie diélectrique et mesure de courant sous tension continue sur une résine époxy, D. Bachellerie, L. Desmars, S. Haller, S. Iglésias, T. Lefort & T. Cong Vu, **SDM 2019.**
- Development and Set-up of a Non-intrusive Technique for measuring Space Charges in Specimens of dc cables, M. Jebli, L. Boyer, T. Martire, J-C Laurentie, P. Notingher, J. Castellonies, **Jicable 2019.**
- Follow up of space charge distributions in HVDC cable during a Pre-Qualification test using the Pulse ElectroAcoustic technique and the Thermal Step Method, L. Boyer, P. Mirebeau, K. Vershinin, A. Tzimas, J. Castellon, P. Notingher, **Jicable 2019.**
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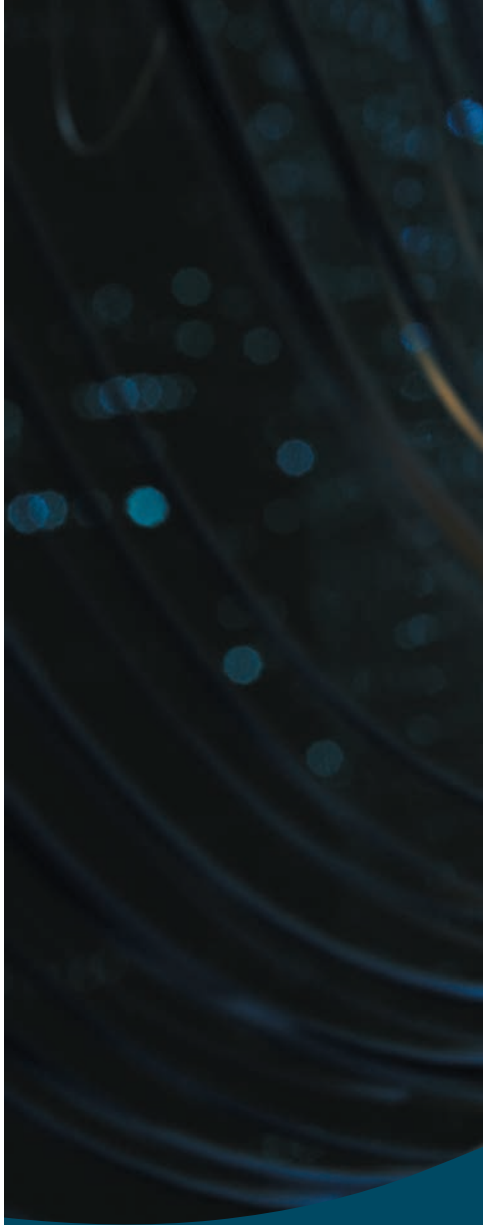

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Shaping power transmission

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