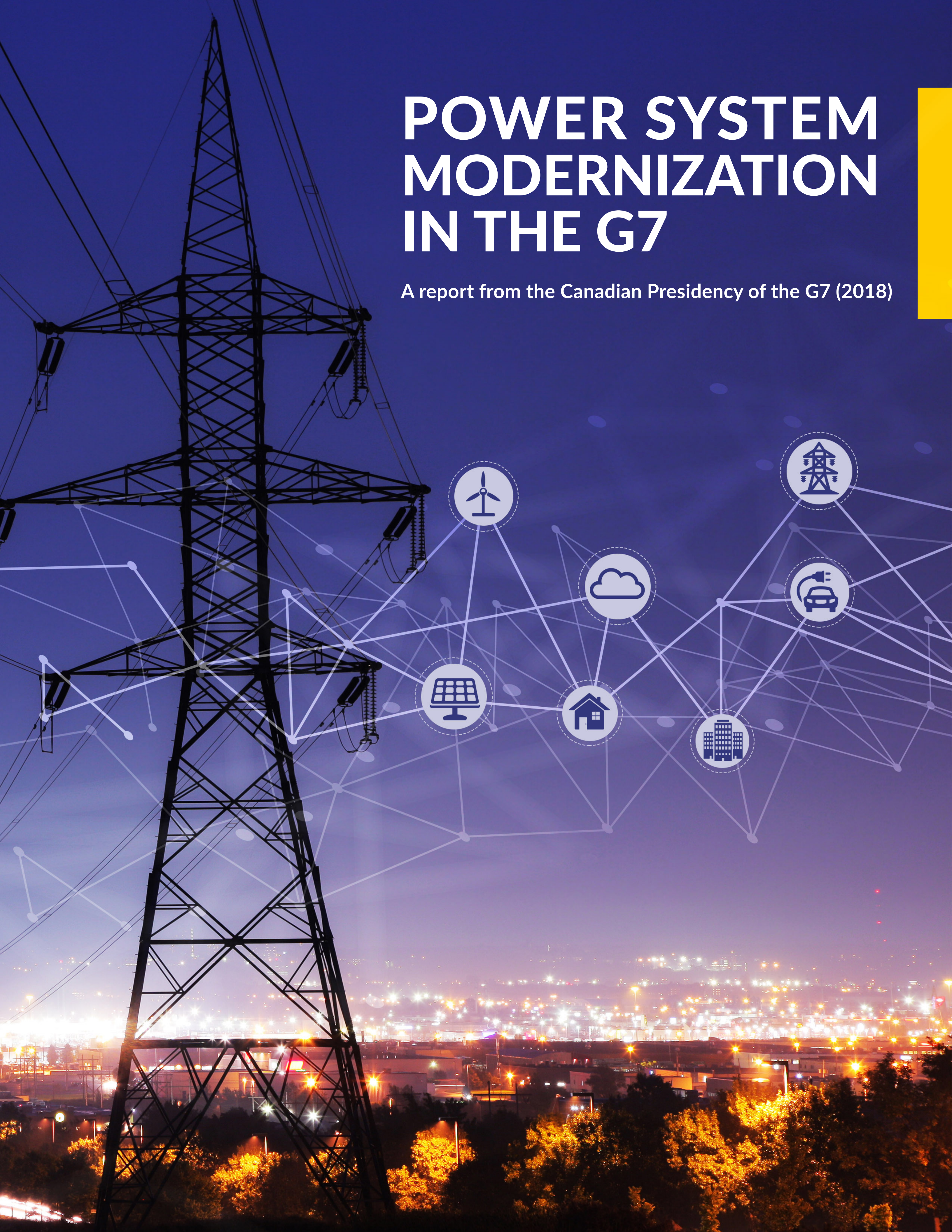
# POWER SYSTEM MODERNIZATION IN THE G7

A report from the Canadian Presidency of the G7 (2018)



# POWER SYSTEM MODERNIZATION IN THE G7

A report from the Canadian Presidency of the G7 (2018)

## AUTHORS

This report is the result of contributions from G7 members. Although many people were involved in the report's development, one primary country contact is identified in the Acknowledgments section for ease of reference.

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Below are the primary contact points for each country's report. Questions about the common sections can be directed to the Canadian contact.


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# EXECUTIVE SUMMARY

Under Canada's 2018 G7 Presidency, G7 members agreed to concrete actions to advance the modernization of power systems that deliver economic growth, ensure energy security and improve environmental protection. One critical way they are doing so is by investing in cleaner, more reliable and more affordable energy sources and technologies. Power systems that are efficient, secure, sustainable, resilient, and which afford opportunities to a diverse array of workers and industries are critical to country-driven energy transitions. To modernize the energy systems of tomorrow, it is essential to promote innovation in power system technologies.

G7 members are well positioned through various international engagements to share technical and policy insights related to the modernization of power systems. They are all members of multilateral forums, such as the International Energy Agency (IEA), the International Electrotechnical Commission (IEC), the International Smart Grid Action Network (ISGAN), the International Renewable Energy Agency (IRENA), and Mission Innovation — Innovation Challenge #1 on Smart Grids (MI-IC1). They also collaborate through regional activities, such as the North American Renewable Integration Study (NARIS) and the European Energy Research Alliance (EERA), as well as through myriad bilateral activities. International organizations and initiatives have strengthened clean energy technology innovation and significantly reduced power system emissions in all G7 members.

G7 members are transforming their power systems as per the current trends of emissions reduction, digitalization and decentralization, while also addressing the perpetual need for reliable, affordable, and secure electricity production to sustain economic growth and prosperity. While circumstances vary, common aspects of these transformations include increases to renewable energy supply, regulatory reforms, the search for financing, pressures to modernize infrastructure and the electrification of sectors like transportation, building and industry. Across G7 members, there are common challenges and opportunities in power system modernization relating to evolving technology, customer behaviour, data and multilateral collaborations.

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# INTRODUCTION

The G7 Report on Modernizing Power Systems outlines progress made by G7 members in transforming their power systems and electrical grids. It discusses G7 members' power system collaborations at all levels (multilateral, bilateral and domestic) and provides the status of power system modernization in each member country and the EU, including key drivers for each of their energy transformations and accompanying case studies. Lastly, the report discusses common challenges and opportunities facing the G7 members' transformation efforts, including evolving technologies, customer behaviour, data-enabled value creation and the aforementioned multilateral collaborations. By examining the lessons learned and common challenges and opportunities presented in this report, G7 members will strive to pursue further collaboration and share their best practices for advancing power system modernization.

# 1. MULTILATERAL COLLABORATIONS OF POWER SYSTEMS

## MULTILATERAL ORGANIZATIONS

G7 members are well positioned through various international engagements to share technical and policy insights related to the modernization of power systems. They are all members of multilateral forums such as the International Energy Agency (IEA), International Electrotechnical Commission (IEC), International Smart Grid Action Network (ISGAN), International Renewable Energy Agency (IRENA), and Mission Innovation — Innovation Challenge #1 on Smart Grids (MI-IC1).

### International Energy Agency

The IEA was created in 1974 to help coordinate a collective response to major disruptions in the supply of oil. While oil security remains a key aspect of its work, the IEA has evolved and expanded significantly since its foundation. Taking an all-fuels, all-technology approach, the IEA advocates policies that enhance the reliability, affordability and sustainability of energy. It examines a full spectrum of energy issues including renewables, oil, gas and coal supply and demand, energy efficiency, clean energy technologies, electricity systems and markets, access to energy, demand side management and much more.

In 2015, the IEA expanded its engagement with major emerging countries to extend its global impact, and deepen cooperation in energy security, data and statistics, energy policy analysis, energy efficiency and the growing use of clean energy technologies.

For more than a decade, the IEA has been examining smart grids and system integration issues, including through the Grid Integration of Variable Renewable Program and, since 2016, a dedicated unit on System Integration of Renewables. The IEA has published a smart-grid technology roadmap (2011) and a "How2Guide for Smart Grids in Distribution Networks" (2015). In 2017, the IEA published a flagship report on "Digitalisation and Energy," which included an analysis on the fundamental ways electricity networks are being transformed via digitally interconnected systems.

The IEA oversees a broad network of member-driven Technology Collaboration Programmes (TCPs), many of which focus on aspects of power systems (e.g. ISGAN on smart grids, the User-Centered Energy Systems TCP on demand side issues; the HTS TCP on high-temperature superconductivity; etc.). The TCPs collectively involve over 6,000 experts worldwide who represent nearly 300 public and private organizations located in 55 countries, including many from IEA Association countries such as China, India and Brazil.

The IEA is a key contributor to the G7, G20, Clean Energy Ministerial (CEM) and many other international energy and economic organizations. For example, the IEA provides the scene-setting presentation for the annual CEM, drawing from its influential annual publication, Tracking Clean Energy Progress. It also works closely with a number of power system-related CEM work streams like ISGAN and the 21st Century Power Partnership, and coordinates others such as the Electric Vehicles Initiative.

## International Electrotechnical Commission

Founded in 1906, the IEC is the world's leading organization for the preparation and publication of International Standards for all electrical, electronic and related technologies, in which power system technology is heavily implicated.

The IEC provides a platform to companies, industries and governments for meeting, discussing and developing International Standards. All IEC International Standards are fully consensus-based and represent the needs of key stakeholders from every country participating in IEC work. IEC publications serve as a basis for national standardization and as references when drafting international tenders and contracts.

## International Smart Grid Action Network

ISGAN is an international collaborative initiative that seeks to accelerate progress on key aspects of smart grid policy, technology and investment. Bringing together 25 member countries and the European Commission, ISGAN operates as both a CEM initiative and an IEA TCP, and works closely with other organizations and stakeholders involved in grid modernization. Members periodically report on progress and projects to the CEM, in addition to satisfying all IEA TCP reporting requirements.

ISGAN provides an important channel for the development and exchange of knowledge and expertise to support high-level government attention and action for the accelerated development and deployment of smarter, cleaner, more flexible and resilient power grids around the world. ISGAN is largely organized around an evolving set of working groups (or "Annexes") that are driven by national experts from participating members.

- Annex 1 (Global Smart Grid Inventory – complete) gathered information on various smart grid priorities and activities of member countries to better define ISGAN's objectives and work programme.
- Annex 2 (Case Studies) develops and collects case studies on smart grid deployments and supports focused knowledge exchange through structured workshops held in conjunction with Annex 4.
- Annex 3 (Cost-Benefits) has developed analytical tools to inform stakeholders' investment and regulatory decisions related to smart grid technologies, practices and systems.
- Annex 4 (Policy Insights) organizes the lessons learned, best practices and practical insights from other ISGAN Annexes and packages the knowledge into forms which are useful to specific target audiences.
- Annex 5 (Testing Labs), also known as the Smart Grid International Research Facility Network, brings together leading research facilities on smart grid testing to evaluate testing protocols (i.e. "test the tests") and emerging state-of-the-art testing practices.
- Annex 6 (Power Systems) takes a longer-term view on the development of future sustainable power systems, focusing on system-related challenges relating to technologies, market solutions and policies.
- Annex 7 (Smart Grids Transitions) investigates the institutional changes associated with smart grid deployment to support policymakers, focusing on non-technical aspects and conditions such as the direction, efficacy and efficiency of energy system transitions, and innovative practises like regulatory sandboxes.

- Annex 8 (Training), also known as the ISGAN Academy, offers the ISGAN community and other stakeholders professional development in the field of smart grids, through a set of e-learning modules and webinars focusing on power system fundamentals to more specialized courses on breakthrough smart grid solutions.

## International Renewable Energy Agency

IRENA is an intergovernmental organization which includes 160 member states and the European Union that supports countries with their transitions to a sustainable energy future, and serves as the principal platform for international cooperation, a centre of excellence, and a repository of policy, technology, resource and financial knowledge on renewable energy. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity. The organization has steadily evolved into an international organization with a diversified program of work and significant contribution to the global climate change and clean energy agendas.

IRENA has analyzed the innovation landscape for the integration of variable renewable energy, mapping and categorizing innovative solutions and on-the-ground examples along four key dimensions: enabling technologies, business models, market design and system operation. The resulting report — *Innovation landscape for a renewable-powered future* — and associated briefs provide a structural framework to approach innovation and a guide to current innovations, notably those related to the modernization of power systems.

IRENA is a key contributor to the G7, G20, CEM and other international energy and economic organizations. For example, IRENA has engaged with the G20 on the subject of energy transitions since 2015 and provides guidance on increasing the share of renewables in power systems. IRENA submitted a report to the 2019 G20 in Japan on innovative solutions to integrate high shares of variable renewable energy into the grid. IRENA also acts as an operating agent for a number of CEM campaigns and initiatives, including the Multilateral Solar and Wind Working Group.

## Mission Innovation — Innovation Challenge #1 on Smart Grids

Launched in 2015 on the margins of the 21$^{st}$ Conference of Parties to the United Nations Framework Convention on Climate Change (COP21), Mission Innovation (MI) is a global partnership of 24 countries and the European Commission (on behalf of the European Union) seeking to double government investment in clean energy research, development and demonstration (RD&D) over five years, while encouraging greater engagement from the private sector in bringing transformative clean energy technologies into the market. These efforts aim to dramatically accelerate the availability of the advanced technologies that will define a future global energy mix that is clean, affordable and reliable.

MI members identified eight Innovation Challenges (IC) designed to accelerate innovation in priority areas that could accelerate the global transition to low-carbon economies; MI-IC1's focus is smart grids. Co-led by Italy, India and China, 21 participating members are advancing the RD&D of electric grids that are powered by affordable, reliable and decentralized renewable electricity systems. All G7 member countries, with the exception of Japan, are participating in MI-IC1.

For this challenge, members identified four main sub-challenges and selected six RD&D tasks to help build a shared understanding of the gaps and opportunities in smart grid fields worldwide. The sub-challenges are regional grid innovation, distribution grid innovation, micro grid innovation and cross innovation, and the tasks are described below.

- Task 1: Improve storage integration at all time scales (in operation for system services but also when performing planning studies as an additional degree of freedom) as a source of flexibility.
- Task 2: Use of demand response for system services with well-defined interactions between the market players and the network operators (and information exchange between the transmission system operator [TSO] and the distribution system operator [DSO]).
- Task 3: Develop regional electricity highways with both alternating current (AC) and direct current (DC) technologies (e.g. long transmission systems, high voltage direct current [HVDC]).
- Task 4: Identify and support improvements of suitable flexibility options (renewable energy generation, flexible thermal power generation, load, network, storage, integration with other energy networks) to ensure adequacy and security.
- Task 5: Study and demonstrate new grid architectures both at the transmission and distribution levels as a source of flexibility.
- Task 6: Introduce novel/advanced power electronics technology to improve the efficiency and controllability of smart grids.

# EUROPEAN COLLABORATIONS

## European Strategic Energy Technology Plan

Since 2007, the European Strategic Energy Technology Plan (SET Plan) has been the research and innovation backbone of the EU's energy and climate policy. It aims to accelerate the development and deployment of low-carbon technologies. It promotes cooperation among private sector and research institutions from European Union (EU) countries as well as Iceland, Norway, Switzerland and Turkey (32 countries). The SET Plan comprises the SET Plan Steering Group, the European Technology and Innovation Platforms (ETIPs), the EERA and the SET Plan Information System (SETIS).

## European Energy Research Alliance

The EERA represents the largest energy research community in Europe with more than 50,000 experts from nearly 250 public research centres and universities across 30 countries. Through 17 Joint Research Programmes, the EERA coordinates low-carbon energy research along shared priorities of the SET Plan. As part of its mission, the alliance works closely with industry and decision makers to ensure efficient technology transfer to industry and market. Italy coordinates the Joint Research Programme on Smart Grids, which involves 40 Research Organizations representing 17 European countries, including France, Germany and the UK.

## European Technology & Innovation Platform — Smart Networks for Energy Transition

A revision of the SET Plan in 2015 led to a new Integrated Roadmap and a merger of the European industrial initiatives and the European technology platforms to create nine European Technology & Innovation Platforms (ETIPs). The ETIPs were created by the European Commission in the framework of the new Integrated Roadmap Strategic Energy Technology Plan. They represent the industrial branch of the SET Plan and bring together a multitude of stakeholders and experts from the energy sector. Their role is to guide research and development (R&D) to support Europe's energy transition, from the private sector point of view.

The ETIP Smart Networks for Energy Transition (SNET), focuses its work and policy advice on research and innovation (R&I) in the areas of smart networks and energy systems, with a focus on reaching a fully integrated "systems of systems." In June 2018, the ETIP SNET published its "Vision 2050—Integrating Smart Networks for the Energy Transition: Serving Society and Protecting the Environment" aiming to pave the way towards low-carbon pan-European integrated energy systems by 2050. In January, the ETIP SNET R&I roadmap was released. It identifies future R&I needs to achieve the goals set by Vision 2050 regarding an Integrated Energy System with electricity as its backbone.

## NORTH AMERICAN COLLABORATIONS

### North American Renewable Integration Study

The United States Department of Energy's (DOE) National Renewable Energy Laboratory's (NREL) NARIS will analyze pathways to modernize the North American power system through the efficient planning of transmission, generation and demand. As wind, solar, hydropower and natural gas continue to grow, the NARIS will highlight power system possibilities for the future and explore how the United States, Canada and Mexico can collaborate to enable economic competitiveness and reliability. The Study is a collaborative effort between NRCan, the Mexican Secretariat of Energy's (SENER) and the DOE's Grid Modernization Initiative. Stakeholders from all three countries with expertise in power systems planning and operations are helping to guide and review the study, including a Canadian Stakeholder Committee consisting of representatives from industry associations, academia, consultants and non-government organizations. The study aims to examine the interconnection of American, Canadian and Mexican power systems, from planning through operation and balancing at a 5-minute resolution. Geographically speaking, the NARIS is the largest study of its kind. It also explores the potential to increase the use of clean power across the continent.

The NARIS is expected to:

- Analyze opportunities for clean energy;
- Develop state-of-the-art methods, scenarios and datasets for future analysis;
- Assess coordinated grid planning and operation, cross-border transmission, grid flexibility and other strategies and technologies needed to enable higher market penetration of renewables.

Final results are slated for late 2020.

### Arctic Council

As part of the United States' chairmanship of the Arctic Council, the U.S. and Canada co-lead the Arctic Remote Energy Networks Academy Project (ARENA) and the Arctic Renewable Energy Atlas (AREA). The Arctic Council is an intergovernmental forum that promotes cooperation, coordination and interaction among the Arctic States (Canada, Denmark, Finland, Iceland, Norway, Russia, Sweden and the United States). The ARENA project was designed to share knowledge and establish professional networks to support Arctic communities' transitions to include more renewable energy. The project provided fundamental knowledge from electrical energy storage to solar energy through a webinar series and on-site sessions. The AREA project aims to provide better access to information for Arctic communities looking to modernize their power systems, by including baseline assessments of renewable energy potential, energy efficiency standards and practices, and community success stories. The member states developed a website in 2017 to share collected renewable energy supply and demand data. The website is continuously populated, includes Arctic-wide local community energy success stories, and an online atlas that provides solar, wind, geothermal, marine and hydrokinetic resource maps in an easily accessible format. The Arctic Council completed Phase II of the project in May 2019.

## EXAMPLES OF BILATERAL COLLABORATIONS

### Canada-UK

**The Power Forward Challenge** is a CAD 20M/£11.5M bilateral initiative led by NRCan and the UK Department for Business, Energy and Industrial Strategy (BEIS) that seeks to increase collaboration between innovators from Canada and the United Kingdom. The Challenge was launched in October 2018 and innovators were asked to develop solutions that integrate distributed energy resources such as renewables, storage, and electric vehicles (EV) to develop cleaner and more resilient power grids. Between October 2018 and March 2019, over 300 business-to-business engagements were facilitated between Canadian and UK innovators through a series of trade missions and virtual events. In March 2019, 44 teams submitted project proposals that were evaluated by experts from Canada and the UK to select a group of 7 “finalist teams.” NRCan and BEIS are currently funding a series of demonstration projects (three in Canada and four in the UK) developed by these finalist teams. In January 2021, the finalists’ projects will be evaluated to compete for a grand prize of CAD 1M.

### UK-South Korea

The UK and South Korean Governments have committed up to £6M to deliver a bilateral competition on smart energy innovation, providing grant funding to companies and other organizations for the development and demonstration of smart energy technologies and services. Projects supported by this competition include a pilot energy flexibility trading platform, gamification of EV charging/Vehicle-to-Grid (V2G) charging/ discharging and a liquid air production and storage system.

### Italy-Austria

Italy and Austria coordinate Implementation Working Group 4 of ETIP-SNET, which is related to SET Plan Action 4, “Increase the resilience and security of the energy system.” This working group defines its member countries’ R&I Roadmaps at the national level, with the involvement of national operators, with the aim of achieving the innovation objectives of SET Plan Action 4.

# 2. STATUS OF POWER SYSTEMS IN G7 MEMBERS

All G7 members are undergoing electrical system transformations related to the current trends of emissions reduction, digitalization and decentralization, while addressing the perpetual need for reliable, affordable and secure electricity production to sustain economic growth and prosperity. While circumstances vary, common aspects of these transformations include increasing renewable energy supply, the electrification of sectors (e.g. transportation, building and industry) and pressures to modernize infrastructure. International organizations and initiatives have also strengthened clean energy technology innovation as well as G7 members' efforts to reduce their power sectors' greenhouse gas (GHG) emissions.

In the following section, G7 members describe the status of power systems in their jurisdictions, including the status of grid modernization, current initiatives, future directions and case studies.

Please note that the status reports from each country were compiled over the period of late 2018 to early 2020, and therefore may contain information and analysis that has further evolved since the reports were submitted. For current updates on any of the country reports below, please reach out to that country's primary point of contact (available in the acknowledgments section of this report).

# CANADA

## Grid modernization — framework and overview

As part of its commitments under the Paris Agreement, Canada committed to reducing its GHG emissions by 30% below its 2005 level of 732 megatons of carbon dioxide equivalent (Mt $CO_{2\,eq}$) by 2030.[1] To meet this target, the Government of Canada, in collaboration with provinces and territories, developed the Pan-Canadian Framework on Clean Growth and Climate Change (Pan-Canadian Framework). The framework identifies clean, non-emitting electricity systems as the cornerstone of a modern, clean growth economy and mentions that Canada's approach to electricity will include the modernization of its electricity systems.

Canada is the world's third-largest producer of hydroelectricity, generating approximately 382 terawatt hours (TWh) in 2018. Overall, 67% of Canada's total electricity generation comes from renewable sources, 60% being hydroelectric. When taking into account nuclear power, nearly 82% of electricity generation in Canada is from non-GHG emitting sources. Moreover, from 2005 to 2018, the fastest-growing sources of electricity generation were wind and solar photovoltaic (PV) energy, collectively accounting for around 6% of the total electricity generation.

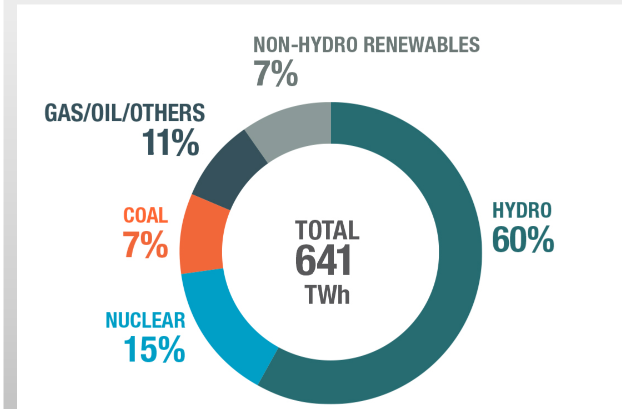

**Figure 1: Electricity generation by source, 2017**

The energy mix varies significantly from region to region. For example, of Canada's ten provinces and three territories, the provinces of British Columbia, Manitoba, Quebec, Newfoundland and Labrador, and the territory of Yukon generate over 90% of their electricity from hydro sources. The remaining provinces and territories rely on various combinations of nuclear, fossil fuels, hydro and other renewables such as wind, solar PVs and biomass.

Through the Pan-Canadian Framework, all the provinces and territories agreed to take action to reduce their GHG emissions, decarbonize their electricity supply and electrify end uses. To achieve their goals, they will need to integrate more renewable energy into the power supply, which will in turn drive the need for modernized, more flexible and better connected grids. To accelerate this transition, the Government of Canada plans to phase out traditional coal-fired generation by 2030, which represented 9% of total electricity generation and 77% of electricity sector emissions in 2017, and implement regulations setting increased performance standards for gas-fired generation. The provinces implicated in coal phase out are Alberta, Saskatchewan, Nova Scotia and New Brunswick.

Historically, Canada's electricity interconnection infrastructure capacity has developed more along a north-south axis with the United States than the east-west axis between provinces. Through the Pan-Canadian Framework, the Government of Canada conducted the Regional Electricity Cooperation and

[1] https://www.canada.ca/en/environment-climate-change/services/environmental-indicators/progress-towards-canada-greenhouse-gas-emissions-reduction-target.html

Strategic Infrastructure (RECSI) initiative to identify the most promising electricity infrastructure projects between provinces and territories.[2] The RECSI initiative, studying the Western and the Atlantic regions, has identified promising transmission options between provinces and represents a building block in a regional dialogue to develop a Clean Power Roadmap for Atlantic Canada.[3]

Under the terms of Canada's Constitution, the provinces and territories have jurisdiction over the pace and extent of resource development, including electricity generation, transmission and distribution. The federal government, however, has jurisdiction over interprovincial connections, making cooperation fundamental. In the majority of provinces, electricity is provided by vertically integrated electric utilities through regulated markets, but Alberta and Ontario have a deregulated wholesale electricity market and a hybrid market, respectively. Depending on the market, utilities can be either publicly or privately owned.

Canada's aging electricity infrastructure is a key driver for grid modernization. The majority of the electricity system was built more than fifty years ago, and some elements are reaching the end of their service life. In addition, with the increasing electricity demand from the electrification of other sectors (e.g. transportation), the electricity system must be upgraded to maintain reliability and be responsive to customers' needs.

For Canada's Northern and remote communities,[4] reducing the reliance on diesel generation is the key driver for grid modernization and represents one of the Government of Canada's commitments under the Pan-Canadian Framework. Because of geographical isolation and lower population levels, many of these communities cannot be connected to the continental grid in economically viable ways. In these cases, developing self-sustaining, local, clean energy solutions, and connecting them to smarter, autonomous grids could be more cost-effective.

The emerging dynamics between decarbonization, digitalization and decentralization are also key to the modernization of Canada's electricity systems. In addition to the need to decarbonize the grid, digitalization, through the deployment of smart grid technologies, contributes to improving grid efficiency, reliability, control and flexibility, while reducing system costs. However, it will require strong and sustained investments over the coming years. Digitalization also enables decentralization, through which small-scale, distributed generation sources and flexible loads known as distributed energy resources (DERs) are better supported by the grid. Decentralization can give customers and remote communities more options and is a means to add resiliency, stability and flexibility. These three emerging dynamics are also creating an opportunity for Canadians to play an active role in electricity systems and markets by producing electricity and selling it on the grid and participating in demand response mechanisms.

[2] Natural Resources Canada—Regional Electricity Cooperation and Strategic Infrastructure Initiative https://www.nrcan.gc.ca/climate-change/canadas-green-future/clean-energy-and-electricity-infrastructure/21294

[3] Atlantic Canada Opportunities Agency—Atlantic Growth Strategy Maps Atlantic Canada's Clean Energy Future https://www.canada.ca/en/atlantic-canada-opportunities/news/2019/03/atlantic-growth-strategy-maps-atlantic-canadas-clean-energy-future.html

[4] Natural Resources Canada, The Atlas of Canada—Remote Communities Energy Database https://atlas.gc.ca/rced-bdece/en/index.html

## Modernization initiatives

**Canadian electric utilities and companies have worked with all levels of government to invest in innovative solutions** that improve the reliability, sustainability and affordability of electricity systems across Canada. In 2018, capital expenditures for electric power generation, transmission and distribution in Canada were $24.4B, representing an increase of 66% compared to 2008.[5] These expenditures are expected to rise to maintain aging infrastructure and to meet rising demand. Launched in 2016, the Investing in Canada Plan is providing CAD 180B over 12 years to support infrastructure projects across Canada, including green infrastructure projects such as plans to modernize electricity grids.[6]

Many elements of the Canadian electricity sector are in transition, including generation sources, customer and utility interactions, and the regulatory framework. In 2016, for instance, Ontario, through the Independent Electricity System Operator (IESO), launched a set of initiatives **to redesign Ontario's wholesale electricity markets**. The Market Renewal Program supports "structural changes to market design, greater market competition and a more flexible procurement process that is better aligned with system needs."[7] System needs include renewable energy integration, the increase of small-scale, decentralization and digitalization. Numerous grid modernization initiatives like this one are taking place as Canada becomes increasingly electrified, decentralized and digitalized.

Through measures including electrification, **the Pan-Canadian Framework is supporting the decarbonization of various sectors of the Canadian economy**, particularly industry, power generation, buildings and transportation. For instance, in 2016, the transportation sector accounted for 21% of energy use and 25% of GHG emissions.[8] In 2018, electric vehicle (EV) sales made up 2.2% of total vehicle sales. Indeed, more than 44,000 EVs were sold in 2018, representing an increase of 137% in EV sales from 2017.[9] Through the Transportation 2030 Initiative, green infrastructure programs and other initiatives, the Government of Canada is investing in EV fast-charger demonstration and deployment projects across Canada to support the wide adoption of EVs. For example, the Government of Canada provided funding, in collaboration with a consortium of ten electric utilities, to address concerns regarding potential grid overload due to EV charging.[10] Additionally, the Government of Canada is investing up to $312.5M to support the deployment of EV chargers, demonstration of next generation charging technologies, and enabling of

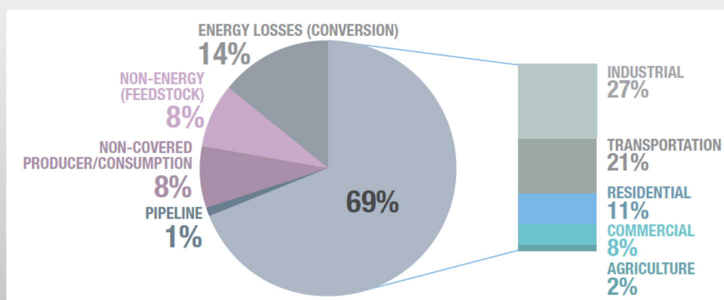


**Figure 2: Primary and secondary energy use, Canada, 2016**

[5] Statistics Canada. Table 34-10-0036-01 capital and repair expenditures, non-residential tangible assets by industry (x 1,000,000) https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3410003601
[6] https://www.infrastructure.gc.ca/plan/about-invest-apropos-eng.html
[7] http://www.ieso.ca/en/Learn/Ontario-Power-System/Electricity-Market-of-Tomorrow
[8] canada.ca/en/environment-climate-change/services/environmental-indicators/greenhouse-gas-emissions.html
[9] nrcan.gc.ca/science-data/data-analysis/energy-data-analysis/energy-facts/20061
[10] https://www.nrcan.gc.ca/science-and-data/funding-partnerships/funding-opportunities/current-investments/enhanced-charging-infrastructure-vehicle-side-data/19496

new EV and alternative fuel vehicle codes and standards across Canada. The governments of British Columbia and Quebec offer EV financial incentives and the Government of Canada started providing such incentives in May 2019. Electric utilities also accelerate EV adoption by facilitating access and modernizing their infrastructure.

Renewable energy generation increased by 18% between 2010 and 2017 in Canada and this proportion will grow as many provinces and territories are taking ambitious measures to increase renewable energy generation. For example, the Province of Alberta has set a target to meet 30% of its electricity needs from renewable sources by 2030 and contracted nearly 1.5 gigawatts (GW) of renewables in 2018 and 2019.[11] The established competitive bidding process enabled Alberta to secure the lowest bid price for wind power in Canada: $0.037 per kilowatt hour (kWh).[12] Saskatchewan is committed to doubling the percentage of renewable electricity capacity to 50% by 2030, up from 25% in 2015.[13] The provinces of New Brunswick[14] and Nova Scotia[15] both plan to meet 40% of demand with renewables in 2020, up from 30% and 22% respectively in 2015.[16] In addition, the **Government of Canada is supporting the deployment of demonstrated emerging renewable power technologies that reduce GHG emissions** from the electricity sectors through the $200M Emerging Renewable Power Program.

To manage the integration of variable renewable energy, electrical utilities and governments across Canada have been **investing in grid flexibility and adaptability through digitalization projects**. In Alberta, for instance, ENMAX, a municipally owned utility, is demonstrating technologies that accommodate bidirectional power flows on secondary networks within urban electrical grids.[17] This will permit greater deployment of solar PVs in cities.

Grid digitalization is also unlocking new opportunities for demand-side management projects. All the provinces and territories with a climate action plan are **investing in smart grid technologies**. Over 80% of electricity meters in Canada are smart meters, and all provinces have a net-metering plan. Ontario, which has fully deployed smart meters, adopted time-of-use pricing.[18] Intelligent automated management solutions are also increasingly deployed throughout Canada's electricity systems to facilitate the continued integration of variable renewables, energy storage, electric vehicles and other distributed energy assets. For instance, NB Power and NS Power, provincially owned utilities from New Brunswick and Nova Scotia, have partnered with Siemens on a $93M smart grid project that will leverage data analytics to better manage the grid.[19] This project is part of the $100M invested through NRCan's Smart Grid Program to support smart grid projects that increase the penetration of renewables into power systems and enhance grid reliability, resiliency and flexibility.

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[11] https://www.alberta.ca/renewable-electricity-program.aspx

[12] https://www.cbc.ca/news/canada/calgary/renewable-energy-program-electricity-alberta-bidders-contracts-1.4446746

[13] https://www.saskpower.com/about-us/media-information/news-releases/2018/03/the-path-to-2030-saskpower-updates-progress-on-renewable-electricity

[14] https://www2.gnb.ca/content/gnb/en/departments/erd/energy/content/renewable.html

[15] https://www.novascotia.ca/just/regulations/regs/elecrenew.htm#TOC2_7

[16] Statistics Canada. https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=2510002001

[17] https://www.nrcan.gc.ca/science-and-data/funding-partnerships/funding-opportunities/current-investments/integrating-distributed-generation-secondary-networks-large-urban-centres/21322

[18] The Government of Ontario temporarily suspended time-of-use (TOU) pricing during the COVID-19 pandemic.

[19] Siemens - Siemens partners with Canadian Utilities to research and develop the electrical grid of the future

Canada has nearly 300 Northern and remote communities that are not connected to the continental grid and rely on diesel as their main source of generation. To improve the affordability, reliability and sustainability of the electricity supply in these communities, the Government of Canada, in collaboration with provincial and territorial governments, is **supporting the deployment of microgrid solutions by leveraging smart grid technologies and renewable energy**. For example, in Colville Lake, a community located near the Arctic Circle in the Northwest Territories, the regional electric utility, in partnership with the territorial government, built a solar/battery/diesel hybrid system that improved service reliability and reduced operating and maintenance costs. The annual energy contribution from the PV system reached 17.6% overall. In Nunavik (northern Quebec), the federal government supported a first-of-its-kind microgrid that combines a 3 megawatt (MW) wind turbine, a flywheel, lithium ion batteries and a hydrogen fuel cell to power the local mining activities.[20] The Government of Canada is also investing up to $220M through the Clean Energy for Rural and Remote Communities program to fund projects that reduce the reliance on diesel fuel, support the use of renewables, increase energy efficiency and build capacity in rural and remote communities, including in Indigenous communities. Besides ensuring service reliability, energy storage such as this is used to increase system flexibility, notably by managing demand fluctuations and regulating voltage and frequency. Recognizing the important role of storage in grid modernization, the Independent Electricity System Operator of Ontario initiated an energy storage program, which procured 50 MW of storage for testing at 20 different locations in two phases (2014, 2019) and which is now becoming operational.[21]

## Future directions

A key process that continues to guide Canada's power system modernization began with "Generation Energy," a national dialogue conducted in 2017 on Canada's energy future that involved more than 380,000 Canadians and international experts. Building on this conversation, a council of energy experts was created with the mandate to advise the federal government on how Canada can transition to a low-carbon future. One of the four pathways identified by the council to lead Canada to an affordable, sustainable energy future is switching Canada's economy to clean power, in alignment with the Pan-Canadian Framework. In this regard, the report indicated that cleaning the power supply should be pursued in tandem with improving the infrastructure and shaping electricity demand. Improving the infrastructure requires deploying more DERs, and the microgrids and smart grid technology to support them, as well as managing demand, including both energy efficiency measures and the electrification of sectors like transportation, buildings and industry.

Recognizing the importance of the clean power transition, in December 2018, Canada's First Ministers agreed to discuss the development of a framework for a clean electric future, including hydroelectricity, aimed at using clean, reliable and affordable electricity and to promote access to domestic and international markets. To inform investments in grid modernization and the broader energy transition, the Government of Canada established the Energy Modelling Initiative,[22] a national forum to convene the modelling community. The Initiative produced an inventory of tools and developed recommendations for a long term plan to establish a sustainable capacity for energy modelling in Canada.

[20] https://www.nrcan.gc.ca/energy/funding/current-funding-programs/eii/16662
[21] Independent Electric System Operator of Ontario - Energy Storage Procurement at the IESO
[22] https://emi-ime.ca/national-forum/

These various commitments, including the federal government's target of net-zero emissions by 2050, are addressing Canadians' expectations regarding Canada's energy future and supporting grid modernization by investing in research, development, demonstrations and deployment. As Canada's utilities operate new energy networks that are more decentralized, with two-way energy flows and increased flexibility, they will also have to adapt by developing new business models, finding new ways to manage networks, using existing infrastructure more effectively and offering more options to customers.

Advanced distribution management and leveraging data for value creation are key drivers in ensuring the grid's reliability and efficiency, and innovation in artificial intelligence (AI) is catalyzing the transition. Canada's federal and provincial governments and utilities are also investing in resiliency to mitigate cyber security threats and respond to climate change adaptation. Investments are required to ensure electricity systems can withstand more frequent extreme weather events and increased stress resulting from climate change. Additionally, increased cyber security vulnerabilities, brought on by the drive towards digitalization, reinforce the need to ensure that the security of Canada's electricity systems keeps pace with their modernization.

Finally, the traditional electric system architecture, with its large centralized power plants, is not likely to disappear in the near future. However, modernization will leverage the opportunities that digitalization and decentralization bring to increase its flexibility and to reflect new customer expectations. Part of this modernization transition will involve higher levels of distributed energy resources (DERs) that require significant decentralization and bidirectional transmission capacity. To adapt to this new paradigm in power system design, utilities will have to make use of myriad tools and approaches, including:

- **Artificial Intelligence**— algorithms to improve load forecasting and optimize the control of DERs.
- **Digitalization** — use of information and communication technologies to manage, monitor and/or control distributed energy resource (DER) elements in a coordinated fashion with or without direct utility input.
- **New business models** — novel methods for utilities, manufacturers and installers, and property managers to both facilitate consumer engagement and increase cost-benefit.
- **Regulatory sandboxes** — the ability of utilities and other related entities to conduct pilots outside the normal regulatory requirements, particularly with respect to the buying and selling of energy.
- **Smart communities** — will be the integration point of energy and data systems across heat, transport, electricity and other increasingly digitalized services.
- **Virtual net-metering** — the ability to apply net-metering to an entity's assets spread across a number of physical meters.

In addition to the normal differences in resources/loads from one utility to another, Canada has the challenge of electric systems operating in both deregulated and vertically integrated environments; thus a large, diverse set of solutions and options is currently being explored.

## Case studies

### Case study #1 — PowerShift Atlantic: the Maritime provinces' customer load control demonstration for wind integration

| Electricity system segment |
|---|
| Wind generation and distribution system |
| **Current status** |
| Completed |
| **Project duration** |
| 2010–2015 |
| **Project lead** |
| The New Brunswick Power Corporation (NB Power) is a vertically integrated Crown corporation wholly owned by the government of New Brunswick. NB Power is responsible for the generation, transmission and distribution of electricity. |
| **Project partners** |
| *Utilities: Maritime Electric Company Limited, Saint John Energy, Nova Scotia Power Incorporated*: recruited customer participants in their service area and managed third-party providers/installers of end-use control technologies.<br>*University of New Brunswick*: led methodologies for wind forecast, wind power production forecast and the estimation of forecast uncertainties. |
| **Project cost (CAD)** |
| Project cost: $33.4M<br>Public/private $ ratio: $15.6M public/$17.8M private<br>Government of Canada, through NRCan (Clean Energy Fund): $15.6M |
| **Project location** |
| The project deployed technologies across the Maritime provinces of New Brunswick, Nova Scotia and Prince Edward Island. |
| **Project website** |
| [http://www.powershiftatlantic.com/](http://www.powershiftatlantic.com/) |

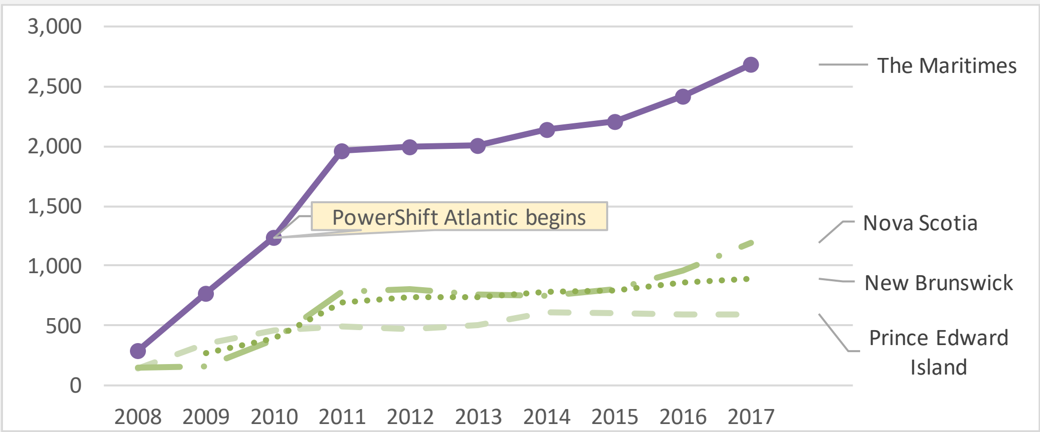
#### Context

Wind generated electricity increased six fold between 2008 and 2011 in the Maritimes as a result of several programs to increase wind generation capacity and to reduce reliance on fossil fuels and nuclear generation. Both Nova Scotia and New Brunswick have goals to provide 40% of their electricity consumption through renewable generation by 2040. In 2017, wind powered 11% of the region's electricity generation compared to 54% and 20% for fossil fuels and nuclear, respectively.

The increase of variable wind electricity presented grid system operators in the Maritimes with a fundamental challenge of balancing supply and demand in the event of sudden changes in generation. In cases of undersupply, the grid was balanced by calling on reserve power from fast-start generators, often resulting in increased costs and emissions.

In 2010, a consortium of Maritime utilities, system operators, companies, associations and universities, with financial support from federal and provincial governments, launched the PowerShift Atlantic project to address this challenge using innovative smart grid technologies.

**Table 1: Wind Electricity Generation in the Maritime Provinces, in gigawatt hours (GWh), 2008–2017**




Source: Statistics Canada, Table 25-10-0020-01

## Objectives

The project sought to address grid balancing by demonstrating one of the world's first fully grid-integrated virtual power plants (VPPs). This novel real-time load shifting solution used customer aggregation and wind forecasting to manage the consumption of over 1,700 residential and commercial devices, adjusting their power demand to the wind power supply.

This demonstration project had three objectives: 1) to evaluate the performance of this demand-side solution for grid balancing with increasing wind generation; 2) to evaluate the role of the customers and their acceptance of remote-controlled devices, and; 3) to assess the costs, benefits and technical feasibility of wider grid implementation.

This demand-side management solution could reduce the need for natural gas powered generation reserves.

## Project description

PowerShift Atlantic was a customer-focused project that aggregated and remotely controlled residential and commercial end-use devices across three provinces, creating VPPs that could be called upon to modify demand, much like dispatchable generators, however, with the effect of increasing or lowering demand rather than supply. By doing so, utilities could *shift* electricity demand according to the variable wind generation availability on the grid. An Intelligent Load Management (ILM) system automated the control of the two VPPs.

Project participation was voluntary and without incentives. Utilities recruited customers using a variety of methods such as home shows, targeted customer emails and phone call campaigns. They explained that the project would support the efficient deployment of greater regional wind generation.

Three third-party aggregator companies applied their *off-the-shelf* technologies to aggregate, monitor, and control participants' end-use devices, thus creating two VPPs (one for NB Power, one for Nova Scotia Power). The aggregators were in regular communication with an ILM system providing forecast load control capability and following dispatch instructions.

The project proponents developed an ILM software to automate the VPP control to: 1) offset or reduce the impact of wind generation grid variability through continuous smoothing; 2) provide the equivalent of a 10 minute bidirectional reserve ancillary-like service to the system operator (i.e. used as real-time generation dispatch).

The ILM received real-time grid data and short-term wind generation forecasts, as well as hourly available load shifting capability information from the aggregators. When necessary, it sent dispatch instructions to the VPPs (i.e. the aggregators) to shift demand. The ILM performed this analysis, decision and dispatch process every 15 minutes.

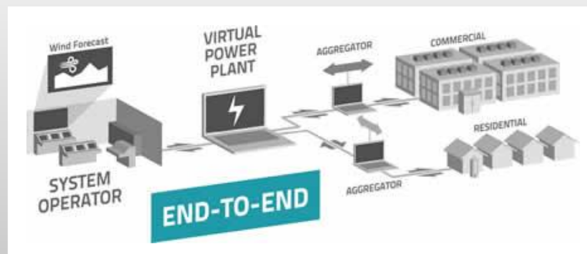



**Figure 3: The PowerShift Atlantic high-level system architecture**

## Project outcomes

The utilities recruited 1,357 residential and 69 commercial customers, connecting 17.3 MW of end-use devices. The automated monitoring and demand shifting of the VPPs started in October 2013 and lasted 12 months. The ILM and VPPs successfully demonstrated near real-time continuous load shifting by shedding load during peak demand and restoring load during demand valleys. In addition, for two weeks, the system was tested solely for its potential for real-time generation dispatch.

**Table 2: Connected end-use device details**

| End-use device | # of devices | MW connected |
|---|---|---|
| Domestic electric water heaters | 1,102 | 3.7 |
| Space heaters | 504 | 2.0 |
| Residential air furnaces | 15 | 0.4 |
| Commercial storage heating | 86 | 4.6 |
| Commercial HVAC, refrigeration, water pumping stations | 26 | 6.6 |
| ***Total*** | **1,733** | **17.3** |

Over the project year, the ILM *requested* 1,888 MWh of demand down shifts and 2,369 MWh of demand up shifts. The aggregators responded with 2,334 MWh of *actual* down shifts and 1,880 MWh of *actual* up shifts.

Utilities frequently surveyed participating customers. Approximately 80% of residential respondents were satisfied with their experience and 2% were dissatisfied. Importantly, most noticed no change in service or comfort during the project, nor did they have to change their behaviour. Surveys of commercial customers had lower response rates and received slightly higher rates of dissatisfaction. Nonetheless, overall, they were satisfied with their experience.

## Lessons learned

**This case study identified four technological lessons**: 1) non-proprietary open-standard interfaces between the ILM and aggregators can benefit research and development as well as vendor participation; 2) device communication using an internet connection is challenging due to the specifics of network architectures and unstable connections; 3) remote software updates on devices are necessary, and equipment must resume normal service provision at appropriate set points following communication interruptions; 4) since each device presents a range of risks and load shape potentials, targeting specific devices with low complexity and high load-adjustment potential (e.g. residential water heaters with smart controls) is favourable.

**This project presented three lessons on customers**: 1) since the time and effort required to recruit, educate, retain and respond to customers was significant and underestimated, sufficient resources and time should be allocated; 2) commercial customers accounted for two thirds of connected loads but only 5% of participants; therefore, utilities should emphasize the low risk to normal business operations for commercial customer recruitment; 3) engaging with decision makers as early as possible and providing financial incentives would likely encourage participation.

**This project highlighted two system-level lessons:** 1) the aggregator's forecast of available load control was often conservative because they prioritized customer comfort and satisfaction, and; 2) the available load control was significantly higher in the winter, corresponding with increased wind power availability and variability.

Overall, PowerShift Atlantic demonstrated the technical feasibility of using VPPs for load smoothing and as an alternative to natural gas fired power plants for real-time generation dispatch. At the time, however, the utilities did not see a viable business case due to technical immaturity and high costs. Nonetheless, PowerShift Atlantic put a spotlight on Maritime utilities, and helped inform their future transformations.

## Next steps

In January 2019, Siemens announced a $93M smart grid pilot project in partnership with NB Power and Nova Scotia Power. This Smart Grid Atlantic project will develop an Energy System Platform to enable the continued integration of variable renewable generation and more customer-focused grid applications and services.[23] The Smart Grid Atlantic project has many similarities to the PowerShift Atlantic project (e.g. aggregation, control and extensive customer management). The relevant experience gained during PowerShift Atlantic was instrumental in Siemens' decision regarding project location. The Government of Canada, through the Strategic Innovation Fund, contributed $36M towards this initiative,[24] and an additional $10.2M was contributed to a related project by NRCan's Smart Grid Program.[25]

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[23] Siemens - Siemens Canada, NB Power and Nova Scotia Power announce $92.7 million project to develop the electrical grid of the future
[24] Government of Canada – Strategic Innovation Fund
[25] Government of Canada – Smart Grid Program

## Case study #2 — British Columbia Electric Vehicle Smart Infrastructure Project

| **Electricity system segment** |
| --- |
| Distribution system |
| **Current status** |
| Completed |
| **Project duration** |
| 2012–2016 |
| **Project lead** |
| BC Hydro is a provincial Crown corporation owned by the Province of British Columbia (BC) which supplies electricity to 95% of the province's population, representing 4 million customers from residential, commercial and industrial sectors |
| **Project partners** |
| Government of Canada: financial support<br>BC government: financial support<br>Greenlots, AddÉnergie, SMPC and CrossChasm: in-kind support<br>Suppliers and service providers to the electric vehicle market |
| **Project cost (CAD)** |
| Project cost: $8.39M<br>Public/private $ ratio: $6.8M public/$1.59M private<br>Government of Canada through NRCan's ecoENERGY Innovation Initiative: $4.1M[26]<br>BC Government through Clean Energy Vehicle for BC: $2.7M[27] |
| **Project location** |
| Vancouver, BC |
| **Project website** |
| https://www.bchydro.com/powersmart/electric-vehicles/bc-hydro-electric-vehicles.html |

### Context

In 2012, the transportation sector accounted for 38% of $CO_{2e}$ emissions in the province of BC. With 92% of electricity generated from clean and renewable sources, mostly hydro, electrifying transportation was a key component of BC's low carbon economy transition. This electrification will reduce GHG emissions, improve air quality, support technology innovation and create new business opportunities.

The BC Electric Vehicle Smart Infrastructure project leveraged a broader provincial clean energy vehicle (CEV) program that provided CEV adoption incentives and widened access to charging infrastructure

[26] https://www.nrcan.gc.ca/plans-performance-reports/dpr/2015-2016/19036
[27] https://www.cevforbc.ca/

across the province. The infrastructure part of this provincial program was established to deploy 1000 EV charging stations including 30 direct current fast chargers (DCFCs). This project was designed to deliver at least 300 public charging stations, including DCFCs, to help achieve the CEV infrastructure program goals.

## Objectives

The project aimed to address technical and non-technical EV adoption barriers. It did so by expanding access to charging infrastructure, thus reducing drivers' range anxiety (related to battery capacity), and by democratizing the use of EVs. On the technical side, as an early technology adopter, BC Hydro expected to harmonize a network of EV charging infrastructure, a communication network, and a framework for data collection and energy management. In a longer-term view, the project aimed to evaluate grid impacts from an increasing electricity demand and to catalyze smart grid solutions. Through the deployment, the project intended to inform infrastructure business models and best practices including standards and policies, to facilitate future provincial and national deployments across Canada.

## Project description

The project supported the installation of 456 Level 2 charging stations across the province and 30 DCFCs for the general public. For the DCFCs only, a distance of 75 km was established as the maximum between charging stations that were installed along a corridor loop in the south of the province. An existing exemption was identified in the BC Utilities Commission Act that allowed the project to partner with local and regional governments to operate the fast chargers outside of the regulatory confines of a public utility and receive compensation for the provision of electricity. This project established the first by-the-kWh fee EV charging network in Canada.

During the project, BC Hydro tested a series of smart charging demonstrations, both business-to-business (B2B) and direct utility pathways for controlling EV charging. All demonstrations successfully validated the management of demand response systems. In B2B pathways, EV suppliers acted as demand response aggregators and responded to utility demand response requests with load curtailment of charging stations on their network. Using a local gateway controller, a demonstration validated the management and smart charging control of five charging stations based on historical or real-time building demand. In direct utility pathways, utilities maintain customer relations and use their digital metering network to directly control EV charging loads. Few demonstration sites tested direct utility pathway communications for supporting smart charging using Advanced Metering Infrastructure. Those direct utility pathway demonstrations were more attractive for EV load control but required more integration effort. All demonstrations aimed to prepare BC Hydro and the utility industry for an eventual larger-scale adoption of EVs.

As a project deliverable, a harmonized data network (i.e. evCloud) collected EV charging data across all deployments in the project. The evCloud consolidated valuable real-world data from a variety of sources to enhance understanding by academics and government of the impact of public infrastructure on EV adoption. Through the project and evCloud, BC Hydro explored greater opportunities for further integration of EV into the smart grid.

## Project outcomes

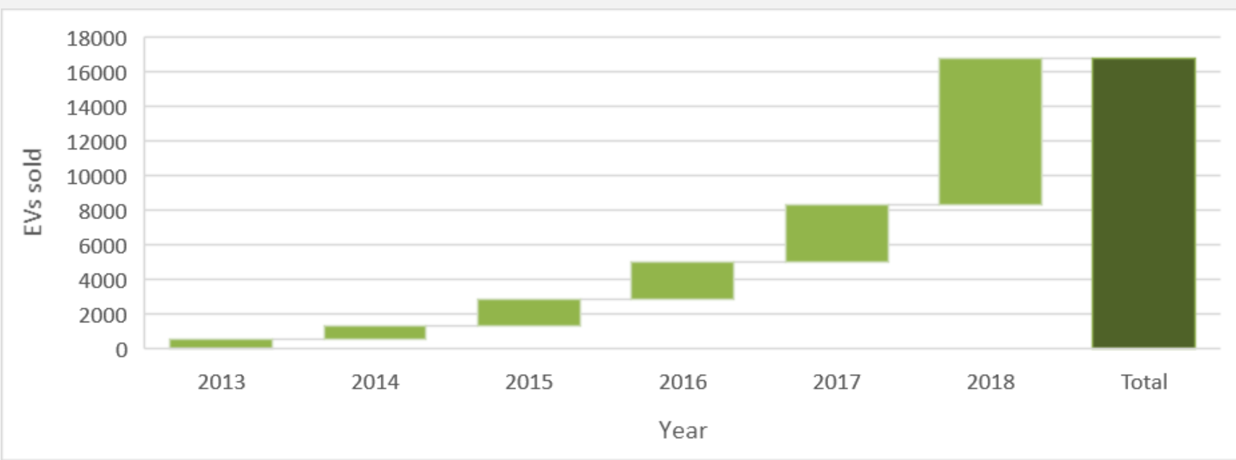
The project deployed 300+ Level 2 charging stations and 30 DCFCs across the province to identify key barriers to accelerating EV adoption. It leveraged the CEV program and accelerated the provision of adequate charging infrastructure across the province for CEV owners and potential owners. The success of this project secured funding for BC Hydro from partners for the deployment of an additional 20 DCFCs through a Phase II CEV program. At the end of 2018, through the CleanBC program, the government of BC expressed an ambitious goal to sell only zero-emission vehicles by 2040 and committed to expanding the province's DCFC network to 151 stations, with 76 already completed or underway as of the end of 2018.

As a project deliverable, the harmonized data network — evCloud — was developed to collect EV charging data gathered from all participating EV service providers. The evCloud website, still active and updated regularly, consolidates valuable real-world data and is available publicly.[28] The general public can access aggregated data such as total tons of GHG emissions avoided to date as a result of EV charging (e.g. over 7,050,000 kg of $CO_2$ saved since late 2019), while government and academic partners can reference the dataset to support policy and program development as well as to better understand the resources that will play a role in the smart grid. Simon Fraser University, the University of Victoria, and the University of British Columbia have already used the data as have various levels of government, including Metro Vancouver. For example, from late 2013 to early August 2019, the general public can see that there were more than 831,000 charging events, more than 6.3 GWh dispensed and over 2.54 megalitres (ML) of fuel saved as a direct result of the EV chargers publicly funded since 2013, most of which were deployed by this project.

Since the development of the communication and data network, evCloud has proven its value by meeting consistent requests from government and academia to access the data. BC Hydro used evCloud to plan future EV infrastructure deployments and to assess the effectiveness of existing deployments such as the Phase II CEV program. evCloud has also proven useful through its capability to analyze and report on the initial project's beneficial outcomes by way of avoided GHG emissions. Throughout the project, signage at charging stations informed and alerted passing pedestrians about the benefits of EVs.

On the environmental front, from 2013 to 2018, nearly 17,000 EVs were sold in the province. Throughout the project, EV sales rose exponentially, from 567 EVs in 2013 to 1,546 in 2015, and 8,449 in 2018. Moreover, the "Life Cycle Analysis of Electric Vehicles" produced by the University of British Columbia in 2018, shows that an EV emits less than half the $CO_{2e}$ emissions of a conventional car given the clean electricity mix in BC.[29] Annual GHG emission reductions through accelerated EV adoption measures, including the implementation of this project, reached nearly 35,000 tonnes in 2018.

**Table 3: EVs on the road, based on yearly EV sales, in British Columbia, 2013–2018[30]**




[28] https://www.fleetcarma.com/evCloud
[29] Kukreja, B. (2018), *Life Cycle Analysis of Electric Vehicles*, UBC Sustainability Scholar, Vancouver
[30] https://www.fleetcarma.com/electric-vehicles-sales-update-q3-2018-canada/

## Lessons learned

When the project started in 2012, the province of BC was an early adopter of EV technology. Since then, BC took several actions to develop the EV market such as a study on the impact to the grid and an inquiry into the business models for EV charging stations.

For infrastructure deployment, the lesson learned was to collaborate with fewer host entities or facilities in multiple locations of interest for EV charger deployments. Subsequent DCFC deployments mostly targeted large grocery store chains. In the Phase II of the CEV program, the deployment locations were targeted through the British Columbia Electric Vehicle Direct Current Fast Charger gap analysis, a report prepared by the Fraser Basin Council based on public consultations, surveys and an EV mapping tool. In this regard, the report mentioned some gaps that were reviewed for later projects including the locations and the type of connector. On the location recommendation, as the first 30 DCFCs were installed along major transportation corridors, back filling the urban regions with more fast charging stations was recommended to support EV adoption for a greater number of drivers. Chargers now incorporate multiple connector types to accommodate a larger variety of vehicles, such as the Japanese (CHAdeMo) and North American (SAE Combo) standards, which was not the case when the project started in 2013.

For the regulation of EV charging services (phase one), the British Columbia Utilities Commission (BCUC) explored in 2018 the potential regulatory issues in the market which could have broader stakeholder impacts. The BCUC found that the public EV charging market was not a monopoly hence there was no need to regulate price and terms of service. This regulatory framework caused a misunderstanding for some EV charging station providers because they are not considered a public utility, and the BCUC determined that most EV charging stations were to be supplied by public utilities. Therefore, it recommended that an exemption be given from the BCUC regulation to multi-dwelling buildings, landlords and EV charging station providers like Tesla.

## Next steps

The BCUC started phase two of the inquiry at the end of 2018. This phase focuses on the regulatory framework for EV charging service providers that are public utilities and have not been recommended for an exemption in phase one such as BC Hydro and Fortis BC, the two main public utilities in the province of BC. The inquiry will focus on the coexistence between exempt and non-exempt public utilities and will set out a market structure for EV charging stations such as the costs of EV charging services and electricity rates.

## Case study #3 — Empowering the digital utility customer via an open data platform using smart meter data

| **Electricity system segment** |
| --- |
| Distribution system |
| **Current status** |
| Ongoing |
| **Project duration** |
| 2016—present |
| **Project lead** |
| London Hydro is a local distribution company (LDC) with a peak load of 719 MW, serving electricity to over 157,000 customers from residential, commercial and industrial sectors in the City of London, Ontario. London Hydro envisioned and designed the original cloud-based, scalable customer energy management platform to support 153,000 electricity and 115,000 water customers leveraging the open Green Button Energy Data Access and Secure Data Sharing standard. |
| **Project partners** |
| Festival Hydro and Whitby Hydro: support in testing the scaleability of London Hydro's Green Button platform in addition to joining IT efforts for a better integrated online solution for customer energy management and back-end utility systems. |
| **Project cost** |
| Entirely funded by the utility consortium of Festival Hydro, London Hydro and Whitby Hydro. |
| **Project location** |
| Implemented for customers in the province of Ontario for the cities of London, Stratford and Whitby. |
| **Project website** |
| https://www.londonhydro.com/site/binaries/content/assets/lhcontent/news/mediarelease_collaborationaward_march2017.pdf |

### Context

As an early adopter of advanced metering infrastructure (AMI), the Province of Ontario has deployed over 5 million smart meters as a key technology enabler for time-of-use (ToU) rate structure. AMI monitors and records customers' electricity consumption, for billing and grid operation. ToU rates are more expensive during on-peak hours when the power system is constrained whereas they are less expensive during off-peak hours. This rate structure incentivizes customers to adjust their electricity consumption to save money and provide relief to the grid during peak times; ToU rates during on-peak hours is a little over double the energy rate as compared to off-peak hours.

Creating user-friendly tools for customers to better understand and reduce their electricity consumption is a way for electric utilities to maintain a positive relationship with their customers. This project was inspired by a few innovative utilities in Ontario keen on evolving this very interaction between customers and LDCs. Energy data from the LDCs' AMI is leveraged by a user-friendly format known as Green Button in an effort to help customers better understand and manage their energy consumption. The Green Button energy data standard is an efficient and effective way to store, manage, analyze and share energy data (or any data with a time series like water or gas metering). It also allows customers to make better use of the data collected by utilities and facilitates data sharing in an open data setting. While establishing the Green Button standard under the North American Energy Standards Board, London Hydro set out to be the Canadian Green Button champion and adopted the standard to create an energy management platform for its customers.

## Objectives

The objective of the project was to provide more residential, commercial and industrial customers with a digital solution to encourage better self-management of their consumption and improve their energy literacy through a cost-effective platform. A centralized, robust and secure data management platform was piloted by London Hydro where customers were able to view and share their consumption data using the Green Button standard. The existing platform was created and designed based on London Hydro customer input and included functions like access to Green Button data, online billing, automated data transfers when customers move within the LDC's service territory, and loyalty programs. This project involved modifying the existing London Hydro platform to ensure scaleability for an increased number of customers across the utility consortium: London Hydro, Whitby Hydro and Festival Hydro. Festival Hydro and Whitby Hydro had to consolidate their utility data systems in order to use London Hydro's designed platform. This was also an opportunity to develop innovative solutions leveraging each LDC's unique experience and customer base in one platform.

This project acts as a way for the utility consortium to transition to a modernized power system. It serves as a way to explore future proofing initiatives to offer customers a platform to better integrate behind the meter loads within a smart grid. Furthermore, the utility consortium can maximize benefits from existing data within utility core operation systems and integrate this data into a platform that will empower customers to make better decisions to reduce their bills, and relieve the system at critical times to help with grid operation like asset and outage management. This will also set a good precedent for the utility consortium to continue to build functional modular systems that leverage cloud computing to create solutions with added business value on a large scale, across jurisdictions.

## Project description

This project builds upon the customer energy management platform designed by London Hydro with 70,000 additional customers from Festival and Whitby Hydro. The original platform used the Green Button standard for access to energy data. The Green Button standard outlines a standardized format to download energy data, known as the Download My Data function, and an interface known as Connect My Data, where customers can choose and authorize third party aggregators to gain automated access to their energy data (revocable at any time) in order to provide insights and strategies to save money.

This project included updating Festival Hydro and Whitby Hydro's corporate websites to host a web portal named MyAccount. Once customers login to the utility portal, a dashboard displays several functions including energy data reports, billing information and behaviour-based analytics. The customer energy data is extracted and processed into the standardized Green Button format using AMI metered data. This user-friendly data format helps customers see valuable and relevant data, allowing them to better understand their consumption, and find ways to save energy and money by coming up with their own strategy or by leveraging the Connect My Data functionality via third party application-provided analysis and insights. Through MyAccount, customers can authorize solutions developed by a third party to activate additional functions if desired.[31] The system is based on software-as-a-service in the cloud with an emphasis on privacy, secure data security, scaleability, regular patches and performance.

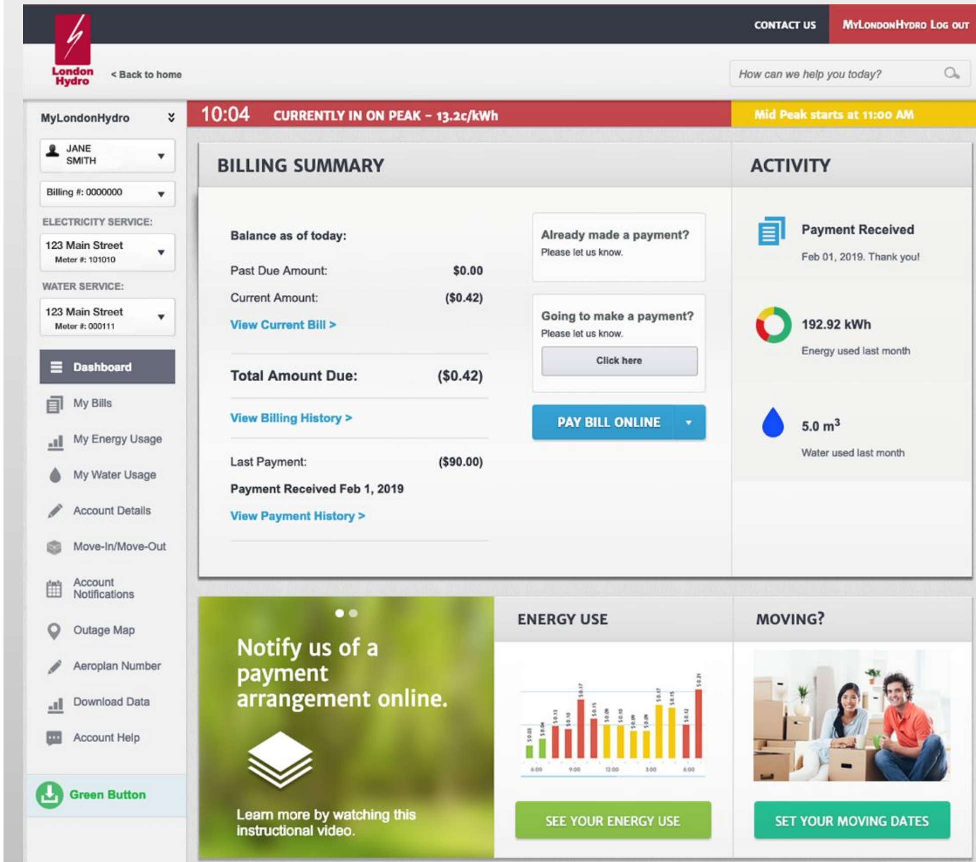



**Figure 4: London Hydro platform using the Green Button standard**

## Project outcomes

The project succeeded in extending the customer engagement portal by about 40% (from 153,000 customers to over 215,000 customers) and achieving a better return on investment on smart meters. The utility consortium has reduced approximately 60,000 hard copy billing invoices per year, saving the utilities $10 per customer per year since the beginning of the project. To date, more than 1/3 of London Hydro customers have opted for paperless billing and over 50% of customers with an online account subscription. Festival Hydro increased their portal and paperless billing adoption by more than 50% over the past two years which can be directly attributed to delivering a new customer portal. Similarly, Whitby Hydro is experiencing a 1% monthly growth in both portal subscriptions and paperless billing.

[31] There are several different apps developed with different objectives. There are 30 alone registered on this site: https://openei.org/wiki/Green_Button_Apps

The energy management platform proved to be a scalable, easy to deploy low-cost solution given the shared services business model with the utility consortium. The utility consortium observed an improvement in business processes for Customer Information Systems (CIS) and Outage Distribution Systems; this included forms, data entry templates that eliminate fraudulent and incomplete data record sources, and a data validation standard. The shared IT services between the LDCs formed stronger teams for security, cloud computing and application program interface (API) integration purposes.

The Made-in-Ontario Environment Plan, the Province of Ontario's environmental policy released at the end of 2018, sets out an action to increase the availability and access to information that will allow homes and businesses to conserve energy, and supports the implementation of Green Button by utilities on a voluntary basis.[32] Ontario is considering ways to implement Green Button to increase the availability and accessibility of information on energy and water consumption in the province.

## Lessons learned

A key lesson was to enable third party developers to help utilities innovate different solutions on online and mobile platforms, a functionality included in the Green Button standard with Connect My Data. Presenting third party developers with a standardized data format allowed for apps to be designed for budgeting, tracking sustainable targets, comparing consumption to similar establishments and identifying where phantom loads exist. This results in creating additional jobs, increased innovation, and less burden on utilities to maintain these solutions. Customers want a seamless interaction between utility data and the novel smart devices they are purchasing. The Green Button data standard facilitates this type of interaction enabling customer choice to various energy management software solutions, easy and secure access to energy data in a user-friendly format, in addition to privacy and secure transmission of data. In addition, ensuring a seamless customer experience increases customer engagement in new energy efficiency programs. The risks associated to the implementation of the platform and back-end automation were reduced by using a data ingestion adapter which works well with the common CIS systems used in Ontario. A more robust utility data model was able to leverage both Tier 1 and Tier 2 CIS systems, and cloud computing resources were optimized for data storage and computational power.

Residential and commercial customers were able to effectively manage their energy in near real time with the given platform. The utility consortium brought together diverse customer experiences to help design a better platform to bring value to customers using the Green Button standard. This sets an example to help other LDCs and other electric utilities to empower their customers across the province and country who are interested in a similar platform. Deployments in Europe and Korea have further proven that the Green Button standard is universal and can be leveraged internationally if time series datasets are available. This allows for tools to be designed and shared to create added value for all customers with access to Green Button data across utility boundaries. Broad adoption of utility-enabled, accessible, and digital energy data-enabled solutions increases benefits to customers and the environment, while improving the reliability of the grid for the future.

[32] *A Made-in-Ontario Environment Plan*, Government of Ontario 2018

## Next steps

The collaboration between the LDCs created an environment of experience sharing and looking for further benefits to customers and other stakeholders (e.g. regulators) that could bring additional value to the 5 million smart meters deployed across Ontario. This evolving platform is in the process of being tested by additional utilities across the province and country. Recently, one utility from Western Canada has started a pilot to showcase the value of another Green Button platform in other jurisdictions across Canada. London Hydro has also tested advanced analytics related to appliance consumption and neighbourhood comparison which will be tested among the other utilities. The London-to-London consortium is another initiative London Hydro is working on as a finalist in the Canada-UK Power Forward Challenge. The consortium, which includes London Hydro, Electron UK, ENMAX, the University of Western Ontario, Navigant and Gowling WLG, is working on an open scalable DER platform leveraging the Green Button standard.[33]

Furthermore, the platform content has expanded to include water and gas metered data given the inclusive structure of the Green Button standard which uses time series data. The Green Button standard provides the foundation to unify all utility data to support the customer experience, which will be key to support a smart city of the future. The Green Button standard continues to present the opportunity for developers to innovate and create options for customers in addition to flexibility and security solutions for LDCs.

[33] londonhydro.com/site/binaries/content/assets/lhcontent/news/mediarelease_lhteamfinalistpowerforwardchallenge.pdf

# FRANCE

## Grid modernization — framework and overview

### Main energy and climate objectives, legal framework

The Energy Transition Act (2015) has set ambitious energy and climate targets to reach at different points in time. By 2030, GHG emissions should be cut by 40% compared to 1990, whereas carbon neutrality should be reached in 2050. Renewable electricity generation should reach 40% by 2030 and nuclear will be capped at 50% of the electricity generation by 2035. Currently active coal power plants will be shut down by 2023.

Those targets are set in the law and translated into actions via the Multi-annual Energy Programming (PPE). The second PPE, currently under consultation, covers the country's objectives until 2028. It defines trajectories and means of reaching national targets such as financial incentives, new regulations to be implemented and a cross-sectoral approach. The French islands and non-interconnected territories are considered energy transition pilots, as they should reach energy independence using only renewables by 2030.

### Current status of France's power system

The national TSO Réseau de transport d'électricité (RTE) is responsible for electricity transmission, except overseas where there is no separation between generation, transmission and distribution. RTE operates over 100,000 km of lines with five levels of voltage: 45,000 km of very high voltage lines [400 kilovolts (kV), 225 kV] and 55,000 km of high voltage lines (150 kV, 90 kV, 63 kV). Under this level of voltage, the network is operated by the DSOs. France has over 130 DSOs, but the biggest one, Enedis, operates 95% of the total distribution network (more than 1,300,000 km of lines).

Transmission and distribution prices are regulated at a national level according to a principle of equalization: every consumer pays the same price for transmission and distribution regardless of location.

France is part of the European electricity market. Its interconnections with six European countries have an influence on its national market prices since France's export and import capacities are respectively of 17.5 GW and 12.5 GW.

Overall, the power system is not yet heavily constrained in continental France thanks to a reliable and well-sized grid, and a relatively low share of variable renewable electricity sources. Flexibility is ensured by pumped storage hydroelectricity (5 GW) and developing interconnections.

### Evolution of the electricity mix

France's current electricity mix is dominated by nuclear power, which provided 72% of national production in 2018 (549 TWh). France's net exports totalled 60 TWh in 2018, making it the biggest electricity exporter in Europe that year.

The electricity mix will change drastically in the years to come. Renewables will rise from 21% in 2018 to 40% in 2030, the additional capacity being mostly based on solar PV, onshore and offshore wind. In the meantime, plants running on coal will be shut down and the nuclear share will decrease.

All of these changes are decentralizing power system management — with most of the new production sites connected to the distribution network — and increasing the need for flexibility. Consequently, the main issue for the French power system in the years to come will be the integration of massive distributed and variable renewable energy, which will require adaptations both in the grid and in terms of supply and demand balancing. Many solutions can be used to reach this objective and the challenge is to prepare the right strategies to optimize the technical and economic aspects of the long-term management of the French power system.

## Major projects led by the national TSO and DSOs

The transmission network operated by RTE is already well equipped with sensors and supervision centres to ensure a real-time balance of supply and demand. New equipment is being progressively tested and deployed (see for example the second case study).

The distribution network directly faces most current evolutions with a large number of renewables connected at low voltage levels, the integration of electric vehicles and the development of demand-side management. New equipment is being rolled out progressively. Electronic systems are already able to restore electricity to 70% of customers in less than a few minutes. Over 150,000 of the 780,000 medium to low voltage substations from the distribution network operated by Enedis are equipped with sensors.

Thirty-five million smart meters, covering more than 95% of the population, will be rolled out by 2021. The deployment of the Linky smart meter began in late 2015 and over 23 million have been installed to date. Linky meters are connected to substations through power line communication. They provide many features, including data collection for the purposes of grid management, incident solutions without physical intervention, the remote measurement of consumption, coupling with devices directly plugged on the meter, customer access to a free website to visualize their consumption, and load curves with a 30 minute time scale. Linky also facilitates PV self-consumption and allows pricing to be fine-tuned for distribution and supply to facilitate energy consumption behaviour.

Regarding local flexibility, the national DSO Enedis is currently leading new experiments with a call for tenders announced in November 2019, targeting six locations where any kind of flexibility could help solve local issues or congestion.

In order to facilitate the renewable connection to the grid, regional connection schemes (called "Schémas régionaux de raccordement au réseau des énergies renouvelables") gather all stakeholders (project developers and producers, TSO, DSOs, public authorities) to better plan, optimize and share the costs of grid adaptations and connections.

Experiments have been conducted to test new ways to connect renewables to the grid, possibly with little curtailment but limited investments.

## National grid-related programs

France is supporting both R&I and the deployment of the first mature solutions.

R&I projects are funded by the National Research Agency (ANR) or the National Innovation Fund ("Programme des Investissements d'Avenir," PIA). Through its operator the energy agency ADEME, the PIA has provided a total of €120 M in funding to 28 demonstrators since 2011, involving more than 120 private and public partners.

Another important investment is the SuperGrid Institute, a collaborative research platform which develops new technologies for electricity transmission networks, including HVDC, with public and private investments. The SuperGrid Institute benefits from more than €80M in public support.

Overall, research is very active on grid technologies and power system issues, with major French public research institutions, such as the Alternative Energies and Atomic Energy Commission and the National Centre for Scientific Research, being involved.

Beyond specific technological issues, particular attention is currently being paid at a national level to the economic costs and benefits assessment of smart grid solutions, and to multi-energy systems modelling. The aim is to define optimal public policies.

### International programs

France is involved in 17 TCPs hosted by the IEA, including the ISGAN TCP on smart grids. France is also part of CEM and is involved in most MI Challenges, including the co-leadership of the Off-grid Access to Electricity Challenge (IC2) with India. Many French public and private organizations regularly participate in European programs regarding smart grids.

## Future directions

It appears that electric mobility is not a threat to the power system if charging is sufficiently piloted. A reference in France is electric water heaters which have been piloted since the 1970s (they charge at night only). With piloting and the possible use of the energy stored in the batteries (Vehicle-to-X), electric mobility could even be an opportunity to add flexibility to the power system.

Among all other existing and foreseeable solutions and challenges, there remains much uncertainty as to how to best adapt the power system to the many evolutions involved in distributing new energy sources and new electricity uses: the first being the evolution of the cost of technologies in the fields of production (especially solar PV and offshore wind) and storage (batteries, hydrogen), and the second regarding the choices that customers and citizens will make (e.g. concerning solar PV self-consumption) and their willingness to change their habits to facilitate the necessary and major energy transition which lies ahead.

To explore all these fields and prepare for the best choices, the French government is making use of all available tools: public research, public funding for demonstrators, financial incentives, evolutions of the regulatory framework — with, for example, a regulatory sandbox recently set in the law and widespread consultations with all stakeholders.

International cooperation is and will remain a very precious tool to progress together towards quicker and relevant innovation, and to achieve efficient and sustainable power systems in the long term.

Further information:

- A summary of the current PPE can be found at https://www.ecologique-solidaire.gouv.fr/programmations-pluriannuelles-lenergie-ppe
- The Think Smart Grids association website (https://www.thinksmartgrids.fr) offers information in English about the smart grid solutions provided by the French industry and an overview of implementations in France
- First results from smart grid demonstrators, by the energy and environment funding agency ADEME: https://www.ademe.fr/smart-grids-first-results-from-french-demonstrators; this study will be updated in 2019
- A repository of the demonstration and research projects is available online (in French) on the website of the French energy regulator: http://www.smartgrids-cre.fr

## Case studies

### Case study #4 — Smart Grid Vendée

| **Project title** | |
|---|---|
| Smart Grid Vendée | |
| **Electricity system segment** | |
| Distribution grid (medium voltage) | |
| **Current status** | |
| Completed | |
| **Project duration** | |
| 5 years (2013–2018) | |
| **Project lead** | |
| SYDEV (Service public des Énergies vendéennes) — local authority for energy in Vendée (French Department) | |
| **Project partners** | |
| Actility — demand side management (DSM) company/technical and commercial aggregation<br>CNAM — including research on acceptance topics related to DSM<br>Enedis (main French DSO, covering 95% of the territory)<br>Engie Ineo — DSM and equipment supplier for substations | GE Grids — in charge of developing two demand side platforms for the DSO and for the local authority to use all flexibilities available in the territory (to solve local constraints on the distribution grid)<br>Legrand — DSM/smart home company<br>RTE (TSO) — mainly in charge of economic studies in this project |
| **Project cost** | |
| Project cost: €27.7M<br>Public/private € ratio: €9.5M public/€18.2M private<br>Government program: Investment for the Future | |
| **Project location** | |
| Vendée department | |
| **Project website** | |
| French: http://smartgridvendee.fr/<br>English: https://www.ademe.fr/sites/default/files/assets/documents/smart_grid_vendee_veng.pdf | |

## Context

This project was funded in the third wave of the call for projects under the Investments for the Future program. It was part of France's innovation policy to support large-scale demonstration projects in the field of smart grids, notably projects including a DSO like this one. Moreover, this was an opportunity to test the idea of having a load balancing mechanism at the local level (i.e. the department level). The aim was to examine market needs and describe all technical points to be addressed to deal with local grid constraints. This project involved and is coordinated by a local authority, which is crucial for the project to be selected for financing.

## Objectives

The Smart Grid Vendée project aimed to test, within the Vendée department, new solutions for controlling and modernizing electricity distribution. The project aimed to test new concepts while ensuring the optimization of the public distribution grid in collaboration with all stakeholders of the electric system. The demonstration project aimed to show the relevance and viability of new business models by considering technical, economic and societal aspects. Optimization at regional and local levels requires greater upstream coordination (planning and forward-looking management) between stakeholders thanks to new interfaces, new information and calculus systems.

## Project description

*Physical demonstration*

- Technical development of sensors and actuators to provide a demand-side response in 120 public buildings and 40 street lights
- Update of technical equipment on PV and wind farm sites (4 wind farms and 4 PV sites) to enable them to pilot their production
- Digitalization of five distribution grid substations; deployment of sensors in substations
- Smart meters roll out in that zone (before national roll out)
- Installation of weather stations to improve local renewable production predictions

*Technical chain of flexibility activation (flexibility from the demand OR production side)*

- During three winters, this technical and communication chain was tested in real conditions. The interactions between all the stakeholders were tested (technical aggregator, commercial aggregator, demand site, production site, DSO, TSO).
- A new way of connecting renewables to the grid was tested ("Offres de raccordement intelligentes"/"Smart Connecting offers" allowing limited production curtailment).

*Economic studies*

- A new cost benefit analysis method for smart grids was developed during the project by the TSO and the DSO, and data was provided by all project partners to conduct this study on the flexibility value.

*Social studies*

- Interviews of public building users (involved in the flexibility tests) and popularization work on smart grid issues were conducted.

## Project outcomes

In this project, the Offres de raccordement intelligentes (new ways of connecting renewable production) were tested on two production sites. The idea is to curtail production for a few hours per year and, in exchange, to establish connections to the grid in a more cost effective and timely manner. Overall, the economic assessment shows that this could be more efficient in some cases.

This offer was tested for a production site in Vendée. Savings totalling €300,000 were assessed when 4% of the production was curtailed, which is a significant benefit for the producers as the projected cost of connecting the PV production site was €494,000.

A new cost benefit analysis for smart grid solutions was developed and conducted by RTE (the TSO) and Enedis in this project. This analysis was expanded to the national level and contributed to the publication of a national socio-economic analysis on smart grid solutions (document in French only — Valorisation socio-économique des Réseaux électriques intelligents;

https://www.rte-france.com/sites/default/files/rei_synthese-commune_2017.pdf).

## Lessons learned

Trying to create a local market helped to:

- develop a tool to better identify the constraints on the distribution grid, and the different flexibility solutions to solve these constraints (demand side, production side or flexibility coming from the grid);
- think about the rules between stakeholders and a DSO, and between the TSO and DSO on how to use flexibility in the most economically favourable way for the entire power system; and
- question the level of the end user's implication (depending on the DSM technical solution).

## Next steps

DSO-TSO cooperation was a major issue in the project. Discussions will follow, notably on the use of flexibilities connected to the DSO used at the TSO level (market level) and also on related issues of production on the distribution grid when they can lead to an electric backflow on the transmission grid.

Regarding local flexibility, the national DSO Enedis is now leading new experiments with a call for tenders announced in November 2019, targeting six locations where flexibility could solve local issues or congestion.

Discussions on the opportunity to generalize new ways of connecting renewables to the grid (with little curtailment) are ongoing and the project lead in Smart Grid Vendée offers highly valuable input for these discussions.

## Case study #5 — Postes intelligents (Smart substations)

| **Project title** |
| --- |
| Postes intelligents (Smart substations) |
| **Electricity system segment** |
| Transmission system/substations |
| **Current status** |
| Completed |
| **Project duration** |
| 2013–2018 |
| **Project lead** |
| RTE (French national TSO) |
| **Project partners** |
| GE Grid (developing the digitalized substation)<br>Enedis (DSO)<br>Schneider Electric (equipment in the DSO-TSO part of the substation)<br>Nokia (telecommunications works)<br>Neelogy (SME developing a new sensor) |
| **Project cost** |
| Total project cost: €32M<br>Public/private cost: €9.7M public/€22.3M private<br>Government program: Investment for the Future |
| **Project location** |
| Picardy region, France; two substations are concerned (Blocaux 225 kV/90 kV and Alleux) |
| **Project website** |
| More information (in English) here:<br>https://www.ademe.fr/sites/default/files/assets/documents/postes_intelligents_veng.pdf |

### Context

This project was funded in the third wave of the call for projects under the Investments for the Future program. It was part of France's innovation policy to support big demonstration projects in the field of smart grids, notably projects involving RTE, the national TSO.

The area surrounding the two substations features a large amount of wind generation which occasionally causes transmission line congestion. To integrate new levels of flexibility (in order to operate the system to benefit from new techniques and technologies), TSOs needed to shift their assets towards more flexible and smart solutions.

## Objectives

This project aimed to operate two demonstrator substations [90 kV and 225 kV]. This new high and low voltage equipment helped to achieve:

- A better overview: thanks to new information and communication technologies that collect more accurate data on the grid's status and its environment in real time.
- Greater efficiency: thanks to the use of digital technologies to operate and maintain the system's compatibility when faced with the new constraints imposed by the integration of renewable energy sources and their effect on demand side management.

The project included the design, testing and commissioning of RTE's first entirely digital substation.

## Project description

The activities of the project can be summarized as follows:

- Development of an optimized, fully digital command and control system incorporating new self-analysis and dynamic reconfiguration functionalities
- Development of testing platforms for the new generation of equipment being developed
- Development of a new alternating current sensor based on the Néel Effect®
- Development of hypervision software (remote human machine interface incorporating advanced functionalities)

## Project outcomes

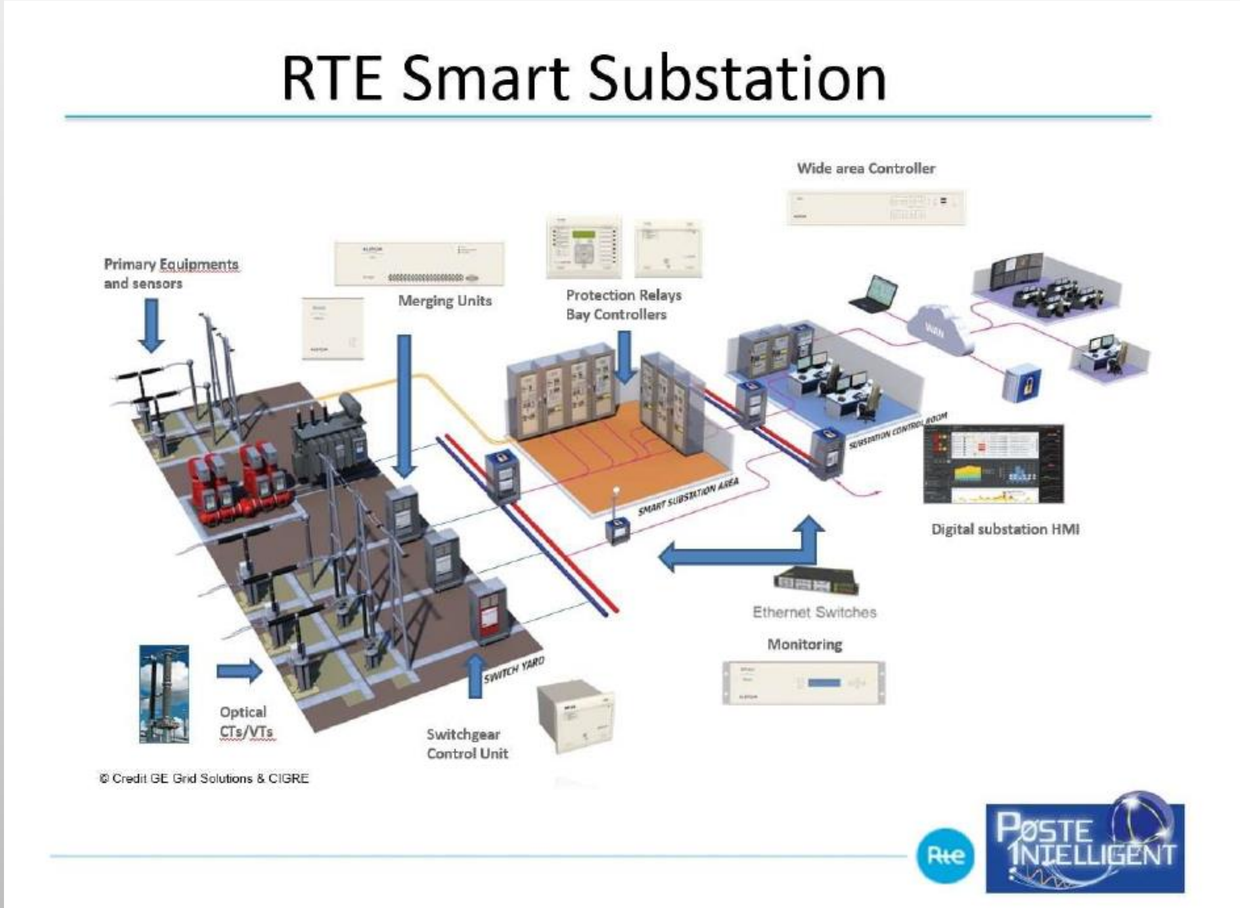
At the end of the project, Postes intelligents can be summarized as having a combination of the following features:

- Fully digitalized protection and automation system
- Extensive monitoring system
- Advanced functions implemented using local computing resources
- Reliable and resilient telecommunication networks

The development of intelligent electronic devices in substations opens the way to the deployment of advanced area automated functions such as Dynamic Line Rating (thanks to information sent by other local substations). Furthermore, this new substation is designed to operate an adaptive and coordinated protection scheme over a wide area.

Moreover, several environmental, economic and social impacts were identified:

- Integration of renewable energies and spatial planning aspects
- Reduction of electricity transportation costs
- Optimization of engineering, operating and maintenance costs for substation structures
- Improvement of electricity supply and security




## Lessons learned

Postes intelligents was a complex technical project to lead as it was experimented on real 90 kV/225 kV substations. The discussions on cyber security or doubling the new digital infrastructure were at the heart of the project. Developing such an industrial project led to some commissioning delays, but helped the TSO and the other partners to develop the best solutions for this substation and facilitated the development of new services (such as DLR) afterwards.

The use of mature Intelligent Electronic Devices using IEC 61850 protocols allowed the design of a new generation of Protection, Automation and Control System solutions, enabling the deployment of advanced area automated functions and coordinated upgrade actions over a larger area.

Piloting the transmission will not be as centralized as before with this new technology.

## Next steps

A roll out of six digitalized substations based on Postes intelligents developments in the French Brittany region is planned. RTE also has a program for the deployment of a next-generation substation called RSpace. Some of the functionalities developed in the Postes intelligents project will be used in the next generation substations deployed throughout France.

# GERMANY

## Grid modernization — framework and overview

The purpose of the German Energy Act is to secure an environmentally sound energy supply for society as a whole, based increasingly on renewable sources. This target can only be met by stepping up the expansion of the extra-high voltage grid. To assess the extent to which the transmission grid needs to be extended and to determine the precise location of these grid extensions, an efficient and streamlined five-step procedure has been established. This process is now conducted on a regular basis, whereby significant public involvement is ensured.

As specified in the Energy Act, every two years the transmission system operators draft a joint Scenario Framework, which is approved by the Federal Network Agency (Bundesnetzagentur). Based on this Scenario Framework, the transmission system operators then jointly calculate grid expansion requirements for the next decade. After rounds of participation allowing citizens, industry associations and public authorities to work together constructively, a Network Development Plan is confirmed by the Federal Network Agency.

The Scenario Framework is based on assumptions about how the electricity system will look in ten years. The actual Network Development Plan therefore targets the year 2030. The assumptions concern inter alia: renewable and conventional generation, load and consumption, flexibility (EV, Power-to-X, storage), and interconnection to neighbouring countries. The scenario also includes progressive assumptions concerning grid technology and innovations.

Together with the environmental report, the Network Development Plan serves as a draft for the Federal Requirements Plan (Bundesbedarfsplangesetz), which has to be presented to the legislator every four years. It contains a list of the necessary projects — including start and end points for each new construction project. The first Federal Requirements Plan was passed in 2013 and extended in 2015. The next amendment is scheduled for 2020.

The Government of Germany also ensured that efficient and streamlined consenting procedures for essential energy infrastructure are put in place. Certain measures and instruments are established in national law as a means of accelerating the approval procedure for energy infrastructure projects. A framework is established to ensure that consenting procedures are put in place correctly going forward, particularly the consenting procedures for essential energy infrastructure which are set out in the Grid Expansion Acceleration Act (NABEG).

The transmission grid expansion requires accelerated planning and approval procedures (specifically the Federal Sectoral Planning and Planning Approval Procedure), as provided for in the NABEG. To apply the NABEG, it was necessary to pass the Federal Requirements Plan Act which contains a list of required projects. Federal and state projects with the highest national significance are subjected to the new consenting procedures according to the NABEG. Furthermore, the Planning Approval Responsibilities Ordinance was passed. The Federal Network Agency decides which projects have high significance, ensuring a consistent and timely procedure.

In 2015, an amendment introduced more possibilities to use underground cables instead of overhead lines. It also introduced facilitations in the legal provisions, which should lead to greater acceptance and acceleration of procedures. Currently, another legislative process is in progress which should further facilitate underground cable installations. These acts also ensure an efficient and streamlined planning and consenting procedure.

As a result of Network Development Planning and to account for the rising need for electricity transportation, a substantial and legally binding grid expansion program was implemented. The program plans for an additional 7,700 km of power lines (new lines and enforcement). The German Federal Requirement Plan Act (BBPIG) was adopted in 2013 and amended in 2015. It now includes 43 connections to be completed in the upcoming years. In 2018, the "Electricity Grid Action Plan" was presented by the German Minister for Economic Affairs and Energy. This action plan consists of a dual strategy. On the one hand, grid expansion will be accelerated, e.g. through a general streamlining of approval procedures and a newly established controlling mechanism with agreed-upon timelines for the approval and construction processes. On the other hand, the utilization of the existing grid's capacity will be increased, e.g. using new technology and operating concepts.

Free market economies, such as the Federal Republic of Germany, rely on competition to ensure that prices are affordable, that there is a balance between supply and demand and that companies are constantly driven to seek out new products and cost effective production technologies. A few sectors of a national economy, however, may prove to be the exception. Electricity grids and gas networks are categorized as natural monopolies (in which competition is limited or does not exist at all). To prevent network operators from monopolizing profits and to keep them operating the networks in the most cost-efficient manner possible, electricity and gas network operators are regulated.

The operation of energy networks is a capital-intensive business. The "Energiewende" will therefore require investments from network operators. German network operators need a long-term planning horizon and reliable economic framework conditions for such investments.

The legislative framework for network tariff regulation comprises the Incentive Regulation Ordinance[34] (ARegV) and the Electricity[35] and Gas Network Charges Ordinances[36] (StromNEV/GasNEV). The underlying economic principle of incentive regulation is based on simulating competition and motivating a network operator to manage its operations more effectively and cost efficiently than comparable network operators in other regions.

A core element of the incentive regulation is a regulatory period of five years. The Bundesnetzagentur and the regulatory authority of the federal states determine in advance the maximum revenue the network operator may receive on a year to year basis during these five years. This requires extensive data collection and assessment to determine the costs of network operation. The audited costs for the operation of the network, as well as an efficiency benchmarking of network operators, provide the basis for determining the allowed revenues. The operator can freely employ and invest this predetermined revenue amount (budgetary approach). For the duration of the regulatory period, a network operator's actual costs and its revenue are decoupled. By setting a fixed amount of revenue, the network operator has an incentive to increase productivity and lower costs in order to increase its potential profits or reduce possible losses.

When an operator's supply obligations are extended, requiring the operator to invest in additional installations, for example, the regulatory regime would also allow for the revenue cap to rise over time.

## Modernization initiatives

Renewables have made significant progress in Germany in recent years, driven by robust policy support such as the Renewable Energy Sources Act (EEG), underpinning a strong increase in renewable electricity.

[34] http://www.gesetze-im-internet.de/aregv/
[35] http://www.gesetze-im-internet.de/stromnev/
[36] http://www.gesetze-im-internet.de/gasnev/

For the first time, in 2017, the total installed capacity of renewables (112 GW) surpassed fossil fuels and nuclear combined (105 GW). The share of renewables in electricity generation increased from 25% in 2013 to nearly 38% in 2018. The EEG supports additional RES capacity via auctions (wind, large PV installations and biomass) and via feed-in tariffs (mainly small-scale renewables for electricity generation).

## Congestion management

Renewable electricity should primarily be taken up by the grid and transported. However, challenges may occur if the network is over-dimensioned, as fluctuating renewable energy sources have low full load hours. Hence, renewable electricity generation plants can only be marginally curtailed if their influence on a network bottleneck is dominant. Smaller generating units such as PV systems can choose whether they reduce the feed-in power or, alternatively, have the grid operator cope with network bottlenecks.

## EV integration

One important element of integrating EV charging points into the power grid is smart grids. Smart grids require a communication infrastructure connecting all relevant actors of the energy system, enabling the management of charging processes and allowing for increased flexibility for EVs in the grid and the market. In 2016, the Act on the Digitization of the Energy Transition ("the Act")[37] was adopted by the German Parliament in transposition of Directive 2009/72/EC concerning common rules for the internal market in electricity and Directive 2009/73/EC concerning common rules for the internal market in natural gas. The Act provides the legal framework for the deployment and operation of intelligent metering systems ("smart meters") in Germany. It defines minimum technical requirements, in particular regarding their broad application, interoperability, data protection and cyber security.

Smart meters are designed as a communication infrastructure open for all use cases which are relevant to the energy transition and sector coupling, including the mobility sector. The Act sets out the fundamental requirements for the smart meter infrastructure and provides for common standards for the use of smart meters. Smart meters serve as the interface between generation, the grid and consumption, and provide a secure and standardized technical basis for the areas of grid operation, the electricity market and energy efficiency. Furthermore, the Act defines the rights and responsibilities of the actors involved (notably the metering operators, smart meter gateway administrators and the relevant public authorities) and rules on data communication in smart grids. Germany is currently working on establishing the necessary standards as well as a legal framework for demand-side management, including the integration of EV charging points.

## Grid monitoring and automation

In the course of the energy transition ("Energiewende"), Germany's energy supply network has been faced with substantial challenges. Induced by the rising share of fluctuating renewable energy sources on the national level, and the electricity market integration on the European level, there has been a steadily increasing demand for additional transmission capacities. Against this background, the German transmission network has been subject to extensive grid expansion and reinforcement measures.

In addition to these long-term measures, the optimization of the existing grid infrastructure has become increasingly important in both the short and long terms. By optimizing system operations, transmission

[37] https://www.bmwi.de/Redaktion/DE/Downloads/Gesetz/gesetz-zur-digitalisierung-der-energiewende.pdf

system operators may enhance the transmission capacities of the existing grid, which has a considerable impact on the level of so-called congestion management measures (e.g. re-dispatch).

First, grid optimization involves the wide-range application of state-of-the-art technologies such as phase shifters or the weather-dependent operation of overhead lines (overhead line monitoring). When applied in a comprehensive and coordinated manner, these measures will substantially lower the level of congestion management costs. In addition, innovative system operation concepts provide further potential for optimization. These concepts are subject to current R&D activities and will be implemented in pilot scale in order to gain practical experiences from real system operations. Due to their short-term response times, these concepts require real-time data in order to assess the actual state of the grid.

The implementation of innovative system operations concepts requires precise knowledge of the current state of the grid. By monitoring the grid's thermal and dynamic limits, planning and switching operations can be carried out closer to real time. Therefore, digitalization is of great importance in this context. This involves the rollout of appropriate sensors for real-time monitoring and the implementation of assistance systems in the control rooms, which allow for smarter and more efficient system operations.

## Future directions

At the end of 2017, electricity production plants with a total installed output of 216 GW were connected to the German grid. For the first time, more than half of the electricity production plants were based on renewable energy (112 GW), accounting for at least 36% of gross domestic electricity consumption. At the beginning of 2018, seven nuclear power plant units with a combined output of 9.5 GW were still connected to the grid. These will be successively shut down by the end of 2022. At the end of 2017, coal-fired power stations with a (net) output totalling 42.6 GW were active on the market (including 19.9 GW lignite fired and 22.7 GW coal fired). In 2017, coal-fired power stations covered a total of 37% of electricity production in Germany.

The growth of renewable energy is already well advanced, now accounting for at least 38% of gross domestic electricity consumption. The current coalition agreement has formulated a target bringing the renewable energy share to 65% by 2030 while the expansion of renewable energy will be grid-synchronized.

The electricity that is generated can only be used if it can be transported to the consumer. Further expanding and optimizing electricity grids and increasing the flexibility of the energy system are therefore prerequisites for ensuring system security in the future.

In June 2018, the federal government appointed the Commission on Growth, Structural Change and Employment to make proposals on phasing out coal production in Germany and establishing a concrete perspective for growth and employment in the affected regions. The Commission submitted its final report in January 2019. Concerning coal production, the report made recommendations to assure the step-by-step reduction and termination of coal-fired power generation, including reducing the overall coal capacity to 30 GW (15 GW hard coal and lignite) by 2022, 17 GW (9 GW lignite and 8 GW hard coal) by 2030, and a complete phase out of coal-fired power generation in Germany by 2038. The Commission's report also emphasized that the secure provision of electricity and heating as well as competitive electricity prices are of major importance for Germany's industrial sector. Therefore, the Commission made recommendations on flanking measures to address both aspects, such as developing a monitoring system focused on security of supply. The federal government is now working on implementing the Commission's recommendations.

## Case studies

### Case study #6 — “compactLine” space-optimized overhead lines

| |
|---|
| **Project title** |
| compactLine—space-optimized overhead lines |
| **Electricity system segment** |
| Transmission system |
| **Current status** |
| Completed |
| **Project duration** |
| 2013–2019 |
| **Project lead** |
| 50Hertz Transmission GmbH (TSO) |
| **Project partners** |
| SPIE SAG GmbH (overhead line design and conductor arrangement)<br>Forschungsgemeinschaft für Elektrische Anlagen und Stromwirtschaft (electromagnetic simulation and compatibility, acoustics)<br>Richard Bergner Elektroarmaturen GmbH & Co. KG (fitting design)<br>50Hertz Transmission GmbH (pilot line installation and line monitoring)<br>Rheinisch-Westfälische Technische Hochschule Aachen (tower design) |
| **Project cost** |
| Project cost: €3,075,967<br>Public/private € ratio: €1,836,283 public/€1,239,684 private<br>Government program: 6th Energy Research Programme |
| **Project location** |
| Saxony-Anhalt, Germany |
| **Project website** |
| https://www.50hertz.com/en/Grid/Griddevelopement/compactLine |

### Context

Transmission grid expansion plays a key role in the integration of renewable energies. Overhead lines form the backbone of the transmission grid and can be constructed cost effectively and operated reliably. If damage occurs, the lines can usually be repaired at short notice.

However, there is a problem of public acceptance towards grid expansion, due in part to the visual impact of the overhead lines. In particular, modern 380 kV overhead line systems are perceived as encroaching on spaces, impairing the landscape and reducing recreational value. With almost every new construction, citizens' initiatives are founded with the aim of preventing such lines, and approval processes are lengthy.

Finally, it is becoming increasingly difficult for the responsible authorities to approve new overhead lines. In addition to aspects such as the impacts on the landscape, they have to assess other effects of the line route, such as the risk of line collisions with migratory birds.

## Objectives

The space saving overhead line "compactLine" aims at enlarging the spectrum of technical solutions to use existing 220 kV corridors for the more powerful 380 kV overhead lines. In general, the compactLine needs a smaller corridor than a conventional overhead line design. With a total height of 30 to 36 metres, the compactLine towers are approximately 20 metres lower than typical Donau-type towers, which are generally used for conventional lines. Thus, compactLine is less visible in wide landscapes. Impacts on the local population's perception of the line have also played a role during technical design. Compactness and design reduce the level of impact, and they may have a positive influence on public acceptance of overhead line constructions. compactLine offers an alternative for future grid expansion projects in which:

- the space for corridors is very limited in width;
- the design of the towers could significantly impair landscapes; and
- existing corridors of 220 kV overhead lines will be used to increase the lines' capacity to 380 kV.

## Project description

The project started in 2013, with initial ideas for the concept and design having been developed in previous years. In 2014, the first theoretical discussions, field calculations and simulations took place, and prototypes were built for new line fittings. Since January 2015, the line components have been undergoing various mechanical and electrical tests. At the same time, the planning of the final tower structure began. As of early 2015, the company City Analytics began working on the accompanying acceptance research. From September 2017 to August 2018, a two-kilometre compactLine pilot installation was built at Jessen/Nord substation in Saxony-Anhalt, Germany. The pilot line was commissioned in the third quarter of 2018 and uses towers with a compact structure and lower height (approximately 36 metres). The line uses a narrow corridor (approximately 55–60 metres) which replaces the existing 220 kV overhead lines. Monitoring activities were carried out over a period of about a year to prove the practical suitability of the line.

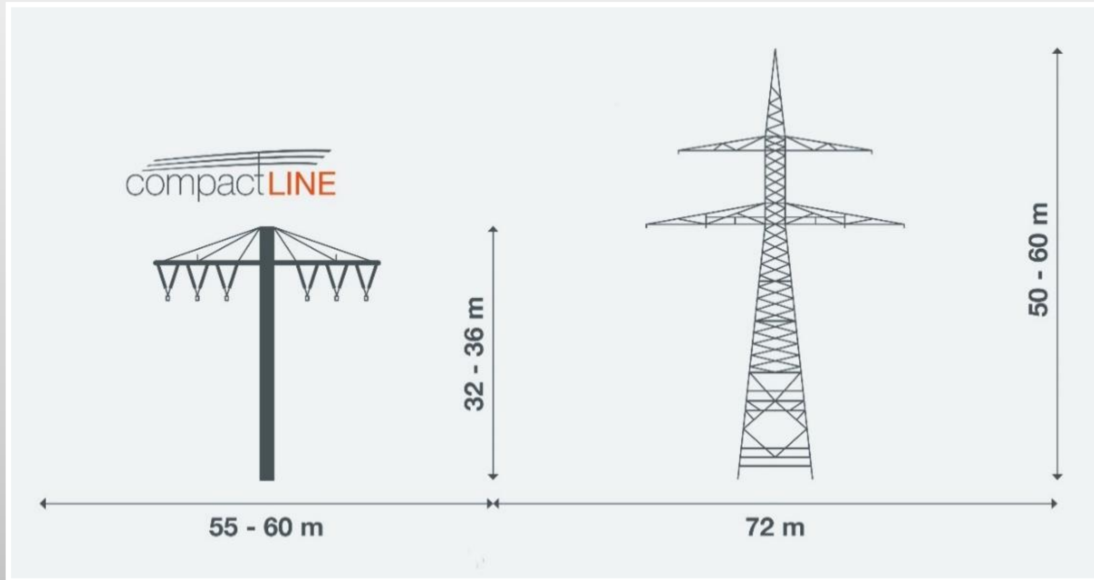



**Figure 5: compactLine concept and design compared to conventional overhead line design (COPYRIGHT 50Hertz)**

## Project outcomes

All required components for the new overhead line design were developed and successfully tested, e.g. tower, conductors, fittings and insulators. The tower is a conical solid wall construction with an innovative suspension system for conductors. The basic compactLine has a tower height of 30–36 metres and a corridor width of 55–60 metres. Distances between compactLine towers will reach up to 400 metres, just as for conventional overhead lines. The final distance depends on the terrain and the corridor route.

**Figure 6: Pilot line with suspension pole (COPYRIGHT 50Hertz)**

For compactLine, the way conductors are suspended at the tower level has been reimagined. Suspension ropes were installed between towers, attaching the conductors every 20 metres and thereby reducing their sagging and swinging. This also allows towers to be lower and corridors to be smaller.

Three new suspension types were studied and tested during the project. The pilot stretch was built with the Havel suspension system, wherein conductors are arranged on a single level. The other two types of suspension systems involved arranging conductors on two levels, which would affect the height and width of the towers and crossarms. Among other things, the acceptance study showed a preference among most respondents for the Havel suspension system.

The acceptance of the design was investigated in several studies, which showed that the tower design has a significant influence on the acceptance of overhead lines. Moreover, the dynamic between towers and the landscape plays an important role. With regard to landscape impairment, the dimensions of the towers are estimated to be of high to very high relevance for the majority of the respondents. The visibility of the overhead line is an important factor in its acceptance. In general, the new design is much more accepted compared to the conventional overhead line design.

**Figure 7: Pilot line—landscape usage in comparison to conventional design (COPYRIGHT 50Hertz)**

## Lessons learned

compactLine was a joint research project that aimed at optimizing the technology after executing and monitoring a pilot line. It intended to increase the acceptance of overhead lines and to expand the range of products and services offered by the project partners. An alternative overhead line design is finally available on the market and can be used to expand transmission grids or to strengthen measures in Germany. compactLine also intended to introduce an alternative to existing variants (overhead line and cable route).

Consequently, a communication system was developed to guarantee a later market launch and reach all stakeholders to:

- Make the project known to the stakeholders and the general public;
- Describe the new variant in the construction phase that complies with all technical and health-related threshold values; and
- Prove the increased acceptance compared to conventional overhead lines for transmission grid and restructuring measures.

## Next steps

Upon the completion of the joint project, plans include continuing the research and leveraging results in various forms. It is expected that the space-optimized overhead line will offer an additional technology option which simplifies and accelerates approval procedures for grid expansion or grid optimization actions. Although the pilot line was built in Germany, it is conceivable that this technology will also be implemented in other countries and for other voltages. Furthermore, the results of the space-optimized overhead line will be brought to suitable national and international committees (e.g. Energietechnische Gesellschaft im Verband der Elektrotechnik [VDE ETG], Deutsche Kommission Elektrotechnik [DKE] or Conseil International des Grands Réseaux Electriques [CIGRE]) for further discussions and dissemination.

## Case study #7 — DC gas-insulated lines (DC-GIL)

| **Project title** |
|---|
| DC gas-insulated lines (DC-GIL) |
| **Electricity system segment** |
| Transmission system |
| **Current status** |
| Ongoing |
| **Project duration** |
| 2012—approx. 2021 |
| **Project lead** |
| Siemens Aktiengesellschaft (large company) |
| **Project partners** |
| Siemens Aktiengesellschaft (GIL concept, component development, pilot installation)<br>Technische Universität München (electrostatic analysis)<br>Ostbayerische Technische Hochschule Regensburg (ground and mechanical stress investigations)<br>Technische Universität Darmstadt (high voltage investigations)<br>Technische Universität Berlin (partial discharge analysis)<br>Hochschule für Technik und Wirtschaft Dresden (heating investigations)<br>Within the framework of the project, the project closely cooperated with the four German TSOs, including experts from Cigré JWG D1/B3. |
| **Project cost** |
| Project cost: €23,583,518<br>Public/private € ratio: €11,550,341 public/€12,033,176 private<br>Government program: 6$^{th}$ Energy Research Programme |
| **Project location** |
| Pilot installation: Darmstadt, Germany |
| **Project website** |
| https://new.siemens.com/global/en/products/energy/high-voltage.html |

### Context

Germany's transmission grid must be expanded if 80 percent of the demand for electrical energy in the country is covered by renewable energy sources by 2050. For example, the electricity generated by wind power plants in northern Germany and offshore in the Baltic and North Seas must be transported as efficiently as possible to the load centres in southern Germany. For long-distance transmission, DC technology is superior to AC technology.

In 2016, German legislature introduced the rule that underground cables must take precedence over overhead lines for four of the country's long-distance DC projects under the Federal Requirements Plan. Thus, all DC links in Germany will be constructed using DC cables or DC gas-insulated lines. It is therefore immensely important that these technologies be reliable and affordable.

## Objectives

The basic idea is to apply the well-known gas-insulated line (GIL) technology from AC to DC. Materials and components from the AC GIL were analyzed and adapted to a DC setting in order to be tested in the field. In the underground DC GIL pilot installation, a high direct voltage of ±500 kV is applied simultaneously with a high direct current of 5,000 amperes (A). This novel transmission technology for high-voltage direct current (HVDC) transmission is analyzed with regard to its long-term behaviour, e.g. heating, electrical behaviour, mechanical stress and protection against electromagnetic pollution. With such a modern high-voltage transmission line, 5 GW of electrical power can be transmitted for an HVDC bipolar system. Dielectric, thermal and mechanical stresses are investigated under full system load and real conditions by suitable and novel measurement technologies.

## Project description

The project was created to research a new technology allowing high-power energy transmission with a high DC voltage of up to ±500 kV. The basic idea consists of transferring the gas-insulated line concept from AC to DC. All materials and components of the new DC technology were analyzed, developed and successfully tested in three development phases (materials analysis, component development and pilot tests).

**Figure 8: DC GIL tube cross section; copyright Siemens AG**

Insights were gained into the insulating materials and the insulator design for DC voltage applications up to ±500 kV, whereby the GIL's insulating gas (100% $SF_6$ gas) was substituted by an $SF_6/N_2$ gas mixture.

For validation purposes, long-term studies on DC GIL technology are being performed in two experimental setups in Darmstadt, Germany: a test setup for dielectric tests (above ground) and a test setup for mechanical and thermal tests (underground) with liquid soil bedding (without high voltage, but high current for thermal heating).

**Figure 9: Test setup for long-term verification of the DC GIL in Darmstadt (left: voltage and current supply; right: electrical test setup); copyright Siemens AG, see also Hallas *et al.* (2020)[38]**

## Project outcomes

The project was developed in a test facility for DC GIL with high direct currents and high voltages with the goal of studying the following:

- Long-term behaviour under an electrical load ±500 kV DC and 5000 A, as well as a superimposed surge voltage load
- Testing and quantifying partial discharge measurement technology under DC voltage on long cable lengths
- Heating behaviour of the underground endurance test facility and the surrounding ground
- Analysis of mechanically and thermally optimized liquid soils
- Thermally induced expansion of the DC pipeline under the continuous sectional electrical load of the underground test facility
- Testing of the novel welding technology (friction stir welding process)

In addition to the research possibilities listed here, on the long, buried endurance test facility, the project investigates a novel method of constructing the compact gas-insulated transmission line. This mobile installation platform can be used to implement underground installation in future projects using intelligent automated processes and welding methods in a cost-efficient, error-immune and environmentally friendly manner.

[38] Hallas, M, Hinrichsen, V, Neumann, C, Tenzer, M, Hausmann, B, Gross, D, Neidhart, T, Lerch, M, Wiesinger; D 2020, 'Cigré Prototype Installation Test for Gas-Insulated DC Systems — Testing a Gas-Insulated DC Transmission Line (DC-GIL) for ±550 kV and 5000 A under Real Service Conditions,' *Paper D1-107 (D1 – Materials and Emerging test techniques, PS 1 Testing, Monitoring and Diagnostics), Cigré 2020 Paris Session.*

**Figure 10: Pilot line (construction phase) for thermal and mechanical tests; copyright Siemens**[39]

Due to the high current carrying capacity of the GIL in heavy load points or sections of high load concentration, the DC GIL technology has obvious advantages over cable solutions and minimizes landscape consumption. Moreover, a technology acceptance study has shown that the acceptance of the DC GIL by citizens can be further increased with a broader transparent understanding of the technology. Finally, the DC GIL offers special solutions for overcoming obstacles such as motorways, railway lines and rivers.

**Figure 11: Pilot line (construction phase) for electrical tests; copyright Siemens**[40]

[39] Koch, H, Tenzer, M, Hinrichsen, V, Hallas, M 2019, 'DC Gasisolierte Übertragungsleitung (DC GIL) für ± 500kV: Dielektrische, bodenmechanische und thermische Langzeitversuche an einer Versuchsanlage' *Fachtagung des GIS Anwenderforums, TU Darmstadt, Darmstadt (https://www.hst.tu-darmstadt.de/gis/gis/gis_anwenderforum/index.de.jsp)*

[40] ibid

## Lessons learned

The investigations showed that several adjustments had to be made to the geometry of the GIL to transfer the basic line concept from AC to DC. Although simulations were helpful, they were not precise enough and could not reproduce all the effects from materials and components. Short and long-term tests were necessary to verify the DC GIL concept and the safe operation of the transmission system.

Based on the experiments conducted, it was determined that the arising issues must be separated for the purposes of the project. Two pilot installations were used for the long-term tests, decoupling the dielectric tests (above ground) from the thermal and mechanical tests (underground). Therefore, any downtimes or defects occurring in one test do not affect remaining tests.

Finally, the DC GIL technology provides a greater transportation capacity by width than DC cables and is suitable for grid sections and corridors of special demand, e.g. low landscape consumption or small transmission corridors.

## Next steps

In the two test setups, the developed materials and components will be tested under real conditions for more than one year in order to pre-qualify the DC GIL technology for grid installation. Afterwards, a new transmission alternative for DC links in Germany will be available for field tests. Cost-efficient and automated constructions technologies using autonomous robots will be developed simultaneously.

DC GIL technology can offer a useful and effective alternative for sections of the transmission grid which present problematic locations, such as tunnel sections with special fire-specific regulations (no introduction of additional fire loads by plastic cables) or underground or tunnel sections with sharp changes of direction or vertical sections.

If the project is finished, the TSO will have an alternative and cost-efficient technical solution for high load transmission using DC links.

## Case study #8 — Smart Energy Showcase: Digital Agenda for the Energy Transition (SINTEG)

| **Project title** |
|---|
| Smart Energy Showcase—Digital Agenda for the Energy Transition (SINTEG) |
| **Electricity system segment** |
| Transmission system, distribution system, remote microgrid |
| **Current status** |
| Ongoing |
| **Project duration** |
| 2017–2020 |
| **Project lead** |
| 5 project leaders for 5 showcases, most of them from large companies (network operators) |
| **Project partners** |
| More than 300 project partners are involved in the project, from the field of energy as well as the information and communication sectors, science and academia, industry and civil society. |
| **Project cost** |
| Project cost: €500M<br>Public/private € ratio: €200M public/€300M private<br>Government program: funding program by the Federal Ministry for Economic Affairs and Energy |
| **Project location** |
| The showcases span five model regions, each of which covers several regions in Germany; for more details on showcases: *https://www.sinteg.de/en/showcases/what-are-showcases/* |
| **Project website** |
| https://www.sinteg.de/en/ |

### Context

In the process of overhauling the German energy system, a great number of new challenges present themselves. We will be implementing an energy supply that is based on renewable energies. Feeding in a high level of renewables requires a better balance between the energy supply and demand. The funding program Smart Energy Showcases — Digital Agenda for the Energy Transition (SINTEG) comprises five large model regions, known as showcases, in which model solutions for the energy supply of the future are developed and demonstrated. The model regions — or showcases — are using digital technology to master the technical and business-related challenges linked to the energy transition. They are developing secure and efficient processes that are suitable for the mass market. Moreover, they are exploring innovative technologies and market mechanisms for flexible smart grids and markets. Due to the broad variety of topics involved, the work across the five showcases involves partners from the field of energy as well as the information and communication sectors.

## Objectives

The project partners develop and test model solutions that can be fed into blueprints for executing the transition in Germany. They aim to answer the question "How can an energy supply that is largely based on renewables be ensured for the entire country in an environmentally acceptable, secure and economically efficient manner?" SINTEG is addressing the technical, business-related and legal challenges involved. It is seeking to advance the development of a smart energy supply, the goals being:

- to ensure the efficient and secure operation of the grid, even as large parts of the electricity generated are renewables-based;
- to harness the potential of making the grid and the market more efficient and flexible;
- to ensure that all players of the smart energy system work together in an efficient and secure manner;
- to make more efficient use of existing grid structures;
- to reduce the need for grid expansion in the distribution network; and
- to develop new business models in the energy sector.

## Project description

The showcases span five model regions with specific challenges linked to supplying local businesses and residents with renewables-based electricity. The model solutions that have been tested in practice will be fed into blueprints for executing the energy transition throughout Germany. Another goal of the SINTEG program is to gain experience and use it to enhance the regulatory framework. The federal government has therefore adopted an ordinance that provides a temporary framework for experiments. The ordinance allows participants of the SINTEG program to test new technologies, procedures and business models — for example, in the areas of digitalization and the coupling of the electricity and heat sectors — and compensates them for the resulting economic disadvantages. This helps accelerate the process of moving innovations from the lab to practical testing and on to the market. SINTEG therefore acts as a regulatory testbed for the smart energy supply of the future.

## Project outcomes

The project is ongoing, therefore results are not available. We expect:

- blueprints and model solutions for the technical, business-related and legal challenges;
- synergies by working on cross-cutting issues; and
- international contact networks.

## Lessons learned

The project is ongoing.

## Next steps

A scientific study accompanying the SINTEG funding program is ongoing. We expect results in 2021.

The program will be evaluated to determine whether the goals have been met and to improve its effectiveness.

# ITALY

## Grid modernization — framework and overview

The electricity network is a highly strategic asset for the Italian economy, and its efficiency, reliability, modernization and continuous development are key. In 2018, within Europe, Italy had amongst the highest capacity for efficient power generation (118.1 GW), some of the longest transmission lines (66,350 km), the third-longest distribution lines (>1,140,000 km) and the fourth-highest yearly electricity demand (321 TWh). Since the liberalization of the electricity sector, the Italian electricity system has changed substantially. The ongoing transformation is driven by continuous objectives for improvements to end users' quality of supply, system management efficiency, and environmental and economic sustainability.

A first driver of the Italian grid modernization is the transformation of the electric energy mix. Centralized fossil fuel generation dropped steadily from nearly 85% of the electricity generated in 2007 to 64% in 2017. Distributed renewables (PV and wind), which were nearly negligible in 2007, accounted for 6% and 8% respectively in the electricity generation mix in 2017, drawn from more than 770,000 PV plants (19.7 GW) and 5,500 wind generators (9.5 GW). At the end of 2018, the gross efficient generation capacity by the over 835,000 installed renewable energy sources (RES) totalled 54.3 GW, which is 1 GW (+2.0%) higher than in 2017, thanks to 499 MW and 425 MW generated by new wind and PV installations, respectively. In 2018, the gross electricity production by RES totalled 114.4 TWh, representing 39.5% of the total electricity production in Italy. This represented a 10% increase with respect to 2017 owing to the improved performance of hydro power (+35%).

The evolution of RES's contribution to the Italian electricity generation portfolio is illustrated in Figure 12. On the distribution side, significant reverse power flows were observed in many primary high and medium voltage substations. These situations could have impacted the security of supply and the reliability of the network itself, but the rapid measures taken to modernize the grid's structure and management prevented any substantial issues. On the transmission side, the large power flows from regions with high concentrations of renewable generation (most of them located in the Southern regions of the country) and the high loads in the Northern regions raised potential congestion issues. Network modernization measures focusing on grid automation and improvements (increased observability, dynamic line ratings, etc.), together with the adoption of flexibility measures such as pilots for power- and energy-intensive storage systems, mitigated the disturbances which were likely to result from the ever-increasing penetration of variable renewable energy sources.

A second driver of grid modernization is the digitalization of the system and the progressive evolution of the interface with the user. Both public and private communication infrastructure is being deployed with the required capabilities in terms of data flow rate and quality. Cyber security and data privacy issues are being considered and advanced solutions are being implemented to guarantee the transparency and openness of the electricity market.

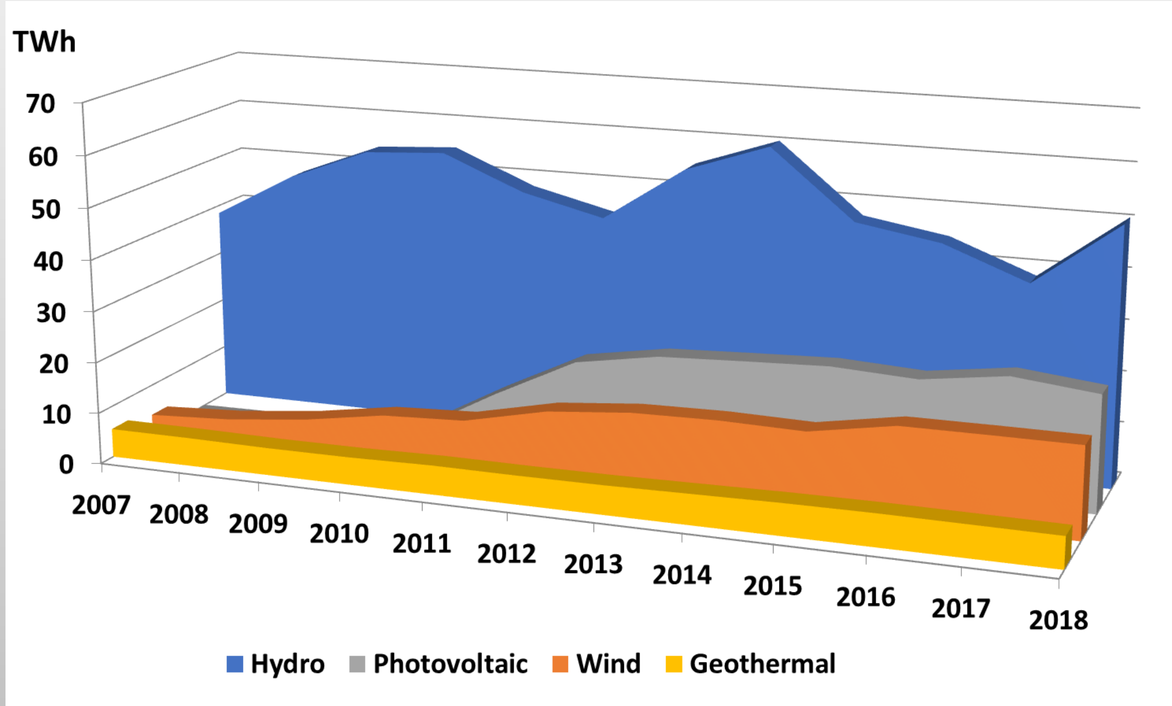



**Figure 12: Evolution of the renewable generation contribution [TWh] (drawn from Italian TSO [Terna] data)**

Digitalization and the need to advance final user interfaces are also driving factors in the adoption of smart meters, which began in the early 2000s with the deployment of a countrywide advanced metering infrastructure comprising 32 million first-generation electronic meters and related support (back office) systems. The progressive deployment of the second generation, which includes more advanced functionalities, is underway.

A third driver is the evolution of the roles of all parties in the electricity value chain, which can contribute to the adoption of the rules and features required to ensure the required level of flexibility and resilience within the system. New market rules have been established to allow the different parties to take part in resource dispatching, to promote the aggregation of generators into virtual power plants and to encourage users to explore new energy service opportunities and mixed aggregation. Distributed storage devoted to small PV plants to promote self-consumption and minimum grid involvement are incentivized and implemented, thus increasing flexibility from the market side.

A fourth driver is the increasing demand from a more sustainable mobility approach that includes the widespread adoption of electric vehicles (battery–BEV, hybrid—HEV, plug-in hybrid–PHEV). Although electric vehicles have yet to reach their full potential, the electricity infrastructure is progressively being adapted to host distributed private and public charging posts as well as concentrated fast charging stations. The national regulatory authority has considered the potential business models and related opportunities and responsibilities ranging from simple charging services to vehicle-to-grid features and interfaces. At present, most Italian cities are equipped with distribution networks which are able to host a great number of new electric vehicles whereas much still needs to be done in less integrated and rural networks.

## Modernization initiatives

- **The National Energy Strategy (NES)** is the ten-year strategy issued by the Ministry of Economic Development (MiSE) and the Ministry of Environment and Protection of Land and Sea on November 2017. It defines the national energy and climate targets necessary to drive the changes to the national energy system targeted by policy makers. In particular, the NES 2017 objectives are: to enhance Italy's competitiveness, by continuing to bridge the gap between Italian energy prices and costs and European ones, in a global context of rising energy prices;
- to attain Europe's environmental and decarbonization targets by 2030 in sustainable ways, in line with the future targets set by COP21; and,
- to continue to improve the security of energy supply and the flexibility of energy systems and infrastructure.

Completing the path started in December 2018, the final version of the Italian Integrated **National Energy and Climate Plan** (NECP) was presented by MiSE to the European Commission in December 2019, in accordance with the Governance of the Energy Union and Climate Action and will be binding for Italy. The plan describes and discusses energy scenarios towards 2030 with a longer-term goal of achieving climate neutrality by 2050 as proposed by the European Commission. The following keywords illustrate the approach adopted for the plan: decarbonization, energy efficiency, energy security, internal energy market, research and innovation, and competitiveness.

Italy plans for **30% of its gross final energy consumption to come from renewable sources by 2030** with an ambitious RES-E target of 55% (187 TWh). In 2018, renewables covered 33.9% of the demand in the electricity sector and 7.7% of the demand in the transportation sector. Moreover, renewables represented 19.2% of the final consumption in the heating sector, led by solid biomass with a significant contribution by heat pumps. New efficient biomass appliances can continue to grow without increasing total consumption.

Additional efforts are expected to increase energy efficiency and reduce GHG emissions. Italy plans to reduce emissions in the non-emission trading system sectors by 33% compared to 2005 values. For the ETS sector, there is no national target but the European target is a homogeneous 43% reduction (vs 2005).

R&I play a fundamental role in the achievement of the NECP targets. The main public actors involved in Italy are:

- the main funding ministries, such as MiSE, the Ministry of Education, Universities and Research and the Ministry of the Environment and Protection of Land and Sea;
- public research centres and institutions such as the National Research Council, the National Agency for New Technologies, Energy and Sustainable Economic Development, Ricerca sul Sistema Energetico (RSE S.p.A.), the National Institute of Oceanography and Applied Geophysics, and the Istituto Italiano di Tecnologia;
- many Universities throughout the country; and,
- the Italian Regions by means of the European Cohesion Funds for R&I.

**Public support mechanisms for grid modernization**

On the basis of the results of a few pilot demonstration projects financed through a tariff-based incentive, the Italian Regulatory Authority for Energy, Networks and Environment (ARERA) has adopted a new approach to regulating the development of smart power systems. The “output-based” incentives that were gradually phasing out the mechanisms in force until 2015 were based on the return on invested capital (“input-based” approach) for the deployment of large-scale smart grid pilot plants. In particular, the rollout of smart grids is developing following the ARERA act 646/2015/R/eel “*Integrated text of the output-based regulation of electricity distribution and measurement services for period 2016–2023,”* which focuses on the implementation of the smart functionalities “observability” (TSO-DSO data exchange) and “voltage control” in medium voltage (MV) networks.

Beyond the incentives tool, initiatives, programs and actions to modernize the grid, supporting plans and programs have been implemented at the regional and national levels:

- Regional governments are supporting smart grid research and fostering local R&D by means of **Regional Operating Plans (POR).** The projects proposed in the POR involve local industry and research entities, with regional funds associated to European funds (e.g. European Structural and Investment Funds [ESIF]).
- MiSE issued a decree at the end of 2016 under the **National Operation Program (PON)**, favouring investments in electrical infrastructure for less-developed Italian regions, supporting the implementation of smart grids for energy transmission and distribution. Another decree was issued on March 20, 2017; PON—I&C 2014–2020, Smart Grids Projects in the Distribution Network (medium & low voltage) focused on increased distributed generation based on renewable sources.
- The **“*Research fund for the Electrical System*” (RdS)** is among the most important support measures to drive the modernization of the electricity system**.** It is a national R&D program aimed at achieving technical and technological innovations of general interest for the electricity system in order to enhance competitiveness, security and environmental compatibility. Financing is obtained for this activity through a levy on consumer electricity bills (€0.08/kWh). The share of RdS funds dedicated to smart grids totals approximately €8M/year and is focused on the integration of distributed generation, energy storage, active distribution network control, automation and related ICT technologies. Smart grid-related RD&D activities carried out under the RdS are fully in line with MI, and specifically with the Innovation Challenge on Smart Grids IC#1.
- ***European-funded projects*** are another important tool in modernizing grids. Italy is among the highest performers within the European Programs, particularly Horizon 2020. Regarding smart grids, Italy is involved in projects devoted to the following themes: active distribution networks, AC and DC high energy corridors, new grid architectures, road mapping of future research/innovation needs for the energy system, integration of DER and energy storage into energy networks.

**Utilities’ commitments to R&D initiatives:** Utilities play a fundamental role in the achievement of a more sustainable energy system, providing services (energy, water, waste management, transportation) and contributing to the development of more efficient solutions through the synergies arising from cooperation with citizens, universities, research centres and policy makers. Italy’s public utilities are increasingly investing in R&D to support this transformation. In 2016, the top 100 Italian utilities entered into 120 agreements with universities, developed 461 innovative projects, deposited 60 patents, and generated approximately €4.6 billion in investments in plants, infrastructures, networks and equipment.

## Future directions

In the proposal of the Integrated NECP, Italy identifies the path towards a decarbonized energy system by 2050, with an important milestone set for 2030 characterized by very high shares of energy from renewable sources, in particular:

- 30% of gross final energy consumption;
- 55.4% of the electricity sector;
- 33.9% of the heating and cooling sector; and,
- 22% of the transportation sector.

To reach these goals, considering the growing importance of distributed generation, the role of smart grids will become more significant, including new architectures and management methods (e.g. forecasting and controlling generation from renewables, adopting all forms of storage and advanced demand response solutions) and fostering flexibilities in electricity networks, for example increasing the level of cross-border electricity interconnectivity up to 10% (capacity of nearly 14,375 MW).

Energy efficiency will be key for the system transformation, with expected cumulative savings from 2021 to 2030 totalling 51.4 millions of tonnes of oil equivalent. Energy efficiency will play a crucial role in achieving environmental protection goals and reducing foreign fossil fuel dependency, while sustaining economic growth. Energy savings are mostly expected in the building and transportation sectors, where electrification will also reduce air pollution.

Research, development and innovation activities are considered in the NECP as essential factors in reaching the objectives. Smart grids play a central role, particularly regarding the following key sectors:

- Development of management models for the electricity system and grids that favour the integration of renewable and non-programmable generation, self-production, storage, energy communities and aggregators;
- Application of advanced information technologies, the Internet of things (IoT), and peer-to-peer in the electricity system, to improve grid security and resilience;
- Development of models and tools to increase the penetration of electric mobility in the transportation sector and improve its integration and interaction with the electricity system;
- Upgrade of electricity grids and distribution grids, with a focus on hardware (e.g. to make networks bidirectional) and software (e.g. to enable demand response management initiatives); and
- Development of advanced clean energy materials enabling high performance and low costs for PV, energy storage, efficiency in buildings and industrial processes, and components of electric power transmission lines.

Due to the cross-cutting aspects of the NECP, a “Modelling and Scenarios” technical working group comprising public research centres dealing with climate, energy and economic issues has been established.

## Case studies

### Case study #9 — Puglia Active Network (PAN)

| **Electricity system segment** |
|---|
| Distribution system |
| **Current status** |
| Ongoing |
| **Project duration** |
| Ten years: 2014–2024 |
| **Project lead** |
| E-Distribuzione (Enel Distribuzione—main Italian DSO) |
| **Project partners** |
| Smart grid and energy technology providers |
| **Project cost** |
| Project cost: €170M<br>Public/private € ratio: €85M public/€85m private<br>Government program: New Entrance Reserve scheme of the EU-Emission Trading System; public cost co-financed by the European Union and the Ministry of the Environment |
| **Project location** |
| MV network located in Puglia, a southern region of Italy |
| **Project website** |
| https://ec.europa.eu/clima/news/articles/news_2016042501_en |

#### Context

The Puglia region includes a number of plants producing energy from renewable sources. It therefore needs to optimize the operation of its electrical network, which is characterized by heavy congestion. Thanks to new smart technologies, the management of this distributed generation can be optimized, allowing increasing amounts of renewable energy to be introduced into the electrical network and improving service quality.

#### Objectives

The Puglia Active Network (PAN) aims to boost the region's electric distribution network by integrating more than 3 GW of distributed renewable energy sources into the grid, impacting 80% of its MV network.

With the implementation of the PAN, about 50% of the region's medium voltage lines will become smart lines and over 8,000 secondary medium-to-low voltage substations will be able to communicate with each other through a rapid telecommunication network through Long-Term Evolution (LTE) Technology in areas of low/medium-density housing.

## Project description

The PAN is a demonstration of advanced network management solutions, funded under the European Project New Entrant Reserve scheme.

The project is based on three main actions:

- Strengthening of the power grid, to increase its efficiency and safety;
- Regional-scale development of an electric vehicle charging infrastructure integrated into the distribution grid, to implement a new model of eco-sustainable mobility with zero emissions; and,
- Monitoring of energy consumption with the Smart Info + kit to develop a greater awareness of the use of electricity (in homes and small businesses).

In particular, the project will include novel functionalities such as self-correcting control grid methodologies to reduce the number and cumulative duration of long and short interruptions, nearly real-time monitoring of generation and grid conditions (including feeders' voltage, reactive and active power flows) and predictive maintenance, in more than 100 primary substations and 8,000 secondary substations within the E-Distribuzione network. Furthermore, E-Distribuzione will contribute to the deployment of a "backbone" of over 250 EV charging stations located within the distribution grid in strategic, mostly tourism-heavy areas. It will also equip 30,000 customers with smart meters, providing them with timely information on their energy consumption.

## Project outcomes

Thanks to the PAN, a smart network will cover the entire region, integrating the distributed energy generated by renewable plants and providing customers with constant access to information on their energy consumption.

Main outcomes:

- Project value of €170M, that will have a strong impact on the development of local businesses;
- Reduction of network losses;
- Increase in hosting capacity;
- Enabled integration of renewable energy sources; and,
- New added-value services.

## Lessons learned

The project has helped consumers to better manage their energy use: residents of Puglia benefit from a more reliable electricity supply and real-time information on their energy use. Primary and secondary stations use novel methods to reduce the number and duration of power cuts, enable near real-time monitoring of generation and grid conditions, and predict when maintenance should be performed.

## Next steps

Less than one year after its launch, the project has completed its first installation phase, with more than 1,200 primary and secondary substations of the planned 8,000 now in place. Work is continuing — new functionalities will be implemented and advanced network management solutions will be studied.

## Case study #10 — Ricerca di Sistema (RdS) (Research fund for the Electrical System)

| **Electricity system segment** |
| --- |
| Transmission and distribution systems innovation, microgrid and cross-cutting innovation |
| **Current status** |
| Ongoing |
| **Project duration** |
| RdS activities are carried out according to a three-year plan; the recently accomplished plan relates to R&D activities until 2018, whereas the new plan will span 2019–2021 |
| **Project lead** |
| See project partners |
| **Project partners** |
| Public R&D institutions carrying out RdS activities are Ricerca sul Sistema Energetico — RSE SpA, the National Agency for New Technologies, Energy and Sustainable Economic Development, and the National Research Council, which have made commitments under Program Agreements with MISE. Subcontractors include universities and R&D labs. The solutions and tools created during research activities are validated through collaborations and agreements with the Italian TSO (Terna), Italian DSOs and technology providers. |
| **Project cost** |
| Project cost: about €70M per year<br>Public/private € ratio: €70M public<br>Government program: RdS |
| **Project location** |
| RdS achievements relate to the entire Italian power system |
| **Project website** |
| www.ricercadisistema.it |

### Context

The RdS national R&D program was established in 2000, when the liberalization of the Italian electricity market (i.e. the progressive unbundling of generation, transmission, distribution and retail) began.

The RdS program aims to achieve scientific and technological innovation of general interest for the energy system to enhance competitiveness, security and environmental compatibility, ensuring conditions which are favourable to sustainable development. RdS activities cover topics which span the entire energy system.

## Objectives

RdS is a R&D program aimed at managing, organizing and encouraging basic research, industrial research and the experimental development of research in the national electricity sector, guaranteeing that the results of these activities are disseminated to all citizens and end users.

Regarding the smart grids sector, RdS research program aims to:

- Develop and test models and algorithms for distributed energy resource management and control;
- Study and demonstrate communication technologies for active networks;
- Develop electronic converters and protection schemes;
- Study and demonstrate DC active networks, including failure analysis;
- Analyze power quality requirements of the distribution grid;
- Support energy systems and infrastructure development and deployment; and
- Develop storage systems for different power and energy requirements.

## Project description

RdS activities address various aspects of the entire electric system. Key R&D topics related to smart grids are: the integration of distributed generation, energy storage, active distribution network control, automation and related communication needs and technologies, power electronics, user network integration and system aspects of demand response, measuring and metering, and modelling.

## Project outcomes

Examples of key RdS findings related to algorithms, innovative technologies, new architectures, and test facilities include:

- development of algorithms for voltage control;
- optimal management of flexible resources;
- load and generation forecasts, including meteorological forecasting algorithms;
    - algorithms were incorporated into a manufacturer's firmware and deployed in an actual distribution network, performing innovative functions in the field;
- development of technologies and new architectures for the development and management of regional and distribution grids.

An important accomplishment under RdS programs is the implementation of a DER test facility, a low-voltage microgrid on RSE premises in Milan which operates in grid-connected or islanded mode, and which interconnects different generators, storage systems and loads to develop studies and experiments on DERs and smart grid solutions.

## Lessons learned

RdS results belong to the public domain, thus supporting knowledge sharing about ongoing research activities and helping to identify research gaps and opportunities.

## Next steps

New themes and research areas will be identified in the 2019–2021 Plan in order to support the new challenges arising from the energy sector, following an integrated approach and taking into consideration climate and sustainability issues. Research themes will also be aligned with those identified at the European and international levels. The smart grid RD&D activities carried out within RdS will support the acceleration of the development, demonstration and deployment of smart grid technologies, services and solutions related to transmission and distribution grids as well as micro grids. Under MI, RdS will bring added value to activities carried out in MI challenges, particularly regarding IC1 through the exploration and proposal of new concepts and paradigms, sharing of experimental smart grid platforms and knowledge sharing concerning research activities.

# JAPAN

## Grid modernization – framework and overview

One of the key drivers for grid modernization in Japan is the need to reduce the costs of grid connections and renewable energy operations.

Owing to its island geography, Japan is not interconnected to any other country and interchanging power supplies with another country is not possible when its supply becomes unstable. Therefore, it is essential that power sources and grids are established and secured nationwide in a well-balanced manner so as to ensure that the power supply system can be used efficiently over a broad area.

In the future, the power source mix may change due to the reform of power systems. In such cases, large-scale capital investments may be required, not only for building new power generation facilities such as renewable energy facilities, but also for constructing power transmission and distribution networks that can adapt to different power generation time zones and power output characteristics of various energy sources. In addition, power transmission and distribution networks must take measures to enhance the stability of power grids, including the installation of load-following power sources and storage batteries.

As the introduction of renewable energy continues to expand, power grid constraints emerge. The costs of accepting renewable energy on electric power grids, including securing the load-following capacity for adjusting power output fluctuations of renewable energy, are also increasing. In order to reduce the costs of grid connections and renewable energy operations, Japan must implement new grid operation procedures in order to fully use the existing grids.

Another key driver is enhancing the resiliency of the electricity infrastructure. Japan experienced its first regional blackout in Hokkaido in September 2018, triggered by a magnitude 6.7 earthquake. The incident raised Japan's awareness of the importance of enhancing the resiliency of the electricity infrastructure. Additional measures have since been implemented.

## Modernization initiatives

Since the Feed-in Tariff program was implemented in 2012, the renewable energy market has grown steadily in Japan. It currently includes an all-time high of 40 GW of solar PVs. However, the increase has brought about challenges such as the need to reduce the cost of renewables and grid congestion, as well as the need to secure flexible resources. Japan's energy system must find solutions to these challenges in order for renewables to become reliable energy sources.

From FYs 2011–2014, the Japanese government supported the Smart Community Projects initiative. Since energy supply optimization and demand differ from one city to the next depending on how they are structured, four major cities (Yokohama, Toyota, Keihanna and Kitakyushu) with significant geographic differences were selected. Through project demonstrations, fundamental technologies to manage the power load in houses or buildings were developed in each of these cities, based on their unique supply and demand structures. The results were very useful and helped the Japanese government establish a major policy direction towards an energy system utilizing distributed energy resources. Many of the policies Japan is pursuing are based on this direction, including those explained below.

Financial support from the Japanese government has increased the popularity of DERs (including storage batteries, EVs, heat pumps and fuel cells) in Japan's energy system. In recent years, the development of digital technologies, the IoT and AI has also accelerated. Combining DERs and digital technologies creates more opportunities for modernizing the energy system. DERs are expected to become a new flexible low-carbon resource. In order for the energy system to use DERs effectively, the Japanese government has been mobilizing its efforts regarding market design related to technological developments and business models.

Regarding market design, Demand-Side Responses (DSRs) using digital technology are contributing to the electricity market by balancing electricity supply and demand in TSOs. Annual auctions by TSOs procured a capacity of approximately 1 GW DSR for 2017 and 2018. This result is remarkable in the context of electricity market reforms. The reform required TSOs to procure reserve resources which power producers or other third parties own in the auction scheme. In FY2017, DSRs were dispatched twice in the Kyushu region and 13 times in the Tokyo metropolitan area. During the summer of 2018, DSRs were dispatched twice in the Kansai region and four times in the Tokyo metropolitan area to survive difficult peak periods of high demand. Currently, new requirements concerning the capacity market and balancing market are being designed with a consideration for DSR and DER attributions. Operations should begin in the capacity and balancing markets as early as 2020.

As for technology development, the Japanese government supported demonstration projects to control DERs (including storage batteries, EVs, heat pumps, fuel cells and DSRs) as reliable energy resources in the national project regarding virtual power plants. The demonstration projects will create new energy services to provide TSOs with reserve power and retailers with electricity. In addition, as of FY2018, the Japanese government has been conducting trials to utilize EVs as an energy resource to balance electric power supply and demand. The project will verify the value of reverse power flow from EVs in the energy system. The Japanese government will continue research and development, as well as demonstration projects to enhance various uses such as virtual power plants, cost reductions and early installations.

In some areas of Japan, renewable energy cannot access the grid because of its limited capacity. Therefore, the government introduced a new grid operation concept called "Connect and Manage." This policy allows grid operators to use the existing grid more efficiently.

In the medium- and long-term, renewable energy will become the main power source in Japan. In order to respond to the challenge of upgrading the current power network to absorb renewable energy, the Japanese government launched a study group on "New Transmission & Distribution Platforms" in 2018 to consider new technologies and businesses related to the electric power network, as well as their institutional and political requirements.

## Future directions

Historically, Japan's power grids were mainly built in a way to connect large power sources to demand areas. They do not necessarily match the sites that have a potential for renewable energy power sources. Therefore, power grid constraints are becoming apparent as a result of the expansion of the introduction of renewable energy. Going forward, it is important to eliminate these power grid constraints when advancing efforts to convert renewable energy into a major power source.

In order to maximize the introduction of renewable energy and to eliminate the public burden, it is effective to firstly utilize existing power grids as much as possible. Consequently, the Japanese government refers to the European experience while proceeding with the Connect and Manage project.

Specifically, in addition to rationalizing the estimated power flow by using a method that increases the precision of estimations of the future flow of electricity based on past performance to calculate spare capacity, Japan will accelerate discussions regarding the utilization of a power transmission framework in emergencies using an instant shutdown device in the event of an accident. These measures involve a “connection to the power grid under certain constraint conditions” such as control at a time of power grid congestion.

Furthermore, if looking to 2030 and beyond, it is expected that further power grid upgrades will become necessary. In addition to structural issues such as the decline in energy demand resulting from population decline and aging, the Japanese government has decided to switch to a next-generation transmission and distribution network taking into account: the introduction of a large quantity of renewable energy, the expansion of distributed energy, and other environmental changes. They will also continue to help reduce the cost of power grid upgrades as much as possible through network cost reforms, and advance the development of an environment that secures predictability, to make the necessary investments.

Furthermore, it is forecasted that the need for load-following capacity will grow as a result of an increase in the amount of variable renewable energy being introduced. For the time being, load-following capacity will be steadily secured through the flexible operation of thermal power generation, the utilization of the adjustment functions of the renewable energy itself, and the revitalization of interchanges between areas utilizing interconnection lines, etc. Furthermore, the Japanese government will advance the decarbonization of the load-following capacity by utilizing VPPs and V2G technologies which can shift load curves or use reverse power flow by controlling distributed energy resources. In the long term, hydrogen is expected to be used as a next-generation load-following capacity.

## Case studies

### Case study #11 — Demonstration project to develop Virtual Power Plant technologies and to design business models

| **Electricity system segment** |
|---|
| Distributed energy resources, demand-side management |
| **Current status** |
| Ongoing |
| **Project duration** |
| FY2016-FY2020 |
| **Project lead** |
| Utilities (electric power companies) and telecommunication companies |
| **Project partners** |
| Manufacturers of DERs and electricity retailers: the role of participants in the demonstration project is to develop aggregation technologies to shift the power load by controlling DERs. |
| **Project cost** |
| Project cost: around ¥4 billion (USD 40M) in FY2018, ¥4 billion in FY2017, ¥3 billion in FY2016<br>Public/private ¥ ratio: Participants need to bear about 50% of the project's cost<br>Government program: The government has funded up to 50% of the cost of developing the energy management system. |
| **Project location** |
| Major project sites include the Tokyo metropolitan area, the Kansai region and the Kyushu region |
| **Project website** |
| http://www.enecho.meti.go.jp/category/saving_and_new/advanced_systems/vpp_dr/ |

### Context

Developing renewables as stable and reliable energy sources is one of the key efforts of the Japanese government in achieving its national energy policy *3E+S* "Energy Security, Economic Efficiency, Environmental Protection, and Safety." Overall, 90% of the renewables installed under this Feed-in-Tariff (FIT) scheme to date are solar PV.

Variable Renewable Energy (VRE), including solar PV, requires sufficiently flexible power to maintain supply and demand in grid lines. One way to achieve this includes stationary batteries and fuel cell stations ("Ene-farm"), the dropping costs of which increase the feasibility of their installation, while growing expectations of expanding EV markets further increase energy system storage potential. Furthermore, digital technologies, the IoT and AI technologies have been sufficiently developed to be accepted in energy markets, which will allow for a more effective integration of DERs into energy systems.

This demonstration project will develop dispatching technologies to reshape the electricity load or to provide reverse power flow to the grid by controlling DERs remotely and appropriately. In addition, project participants will share technology insights to fuel the discussion on market design, so that policy makers can consider DER attributions. The project requires participants to create aggregation business models.

## Objectives

The project has three major objectives:

1. To develop reliable dispatching technologies using DERs to meet requirements from TSOs or power retailers;
2. To provide policy makers with technical views from the perspectives of the energy service providers who aggregate energy from DERs; and
3. To create aggregation business models to provide energy services by using DERs, as third party aggregators.

## Project description

Capacity and balancing markets are currently being designed and will be operational in FY2020 and FY2021, respectively. TSOs will procure regulation and reserve resources in the balancing market. The project will verify whether power outputs that participants and expected third-party aggregators are using meet the requirements from TSOs. Forty business partners consisting of six consortiums joined the demonstration projects. The aggregators in the project will reshape the load curve, DSRs, or ensure reverse power flow by remotely controlling DERs. The balancing market will require participants to provide electrical power within 45 minutes of the dispatch order and to keep the output for three hours, in the case of Replacement Reserve for FITs. The demonstration project's specification will be based on the draft specification for the balancing market, as discussed by TSOs. It is expected that the project's results will convince TSOs to accept DERs in the market. In addition to this, aggregators need to develop new energy services, such as shifting demand load by using DERs when the trading price in the wholesale market is extremely high or low. Aggregators are expected to participate in the balancing market, capacity market or wholesale market as entrants. More active competition in the energy markets is expected to lead to a more economically efficient energy system.

## Project outcomes

The following are possible outcomes:

1. Entrants, as third party aggregators, can participate in the electricity markets (capacity market, balancing market and wholesale market) in FY2020; and
2. The capacity (kW) of DERs which aggregators can manipulate remotely will increase. The target capacity is 50 MW.

## Lessons learned

It is essential that policy makers and TSOs understand the potential of DERs and that they become a flexible source. Unnecessary investments in the energy system can be avoided if energy markets are designed appropriately. The project provided technical evidence supporting this fact. It was a key approach to incorporate TSOs into the projects at the initial stage, because TSOs have played a key role in market design. General energy consumers also understood that the DERs they own can contribute to the energy system if aggregators can integrate power from the DERs.

As technological developments can be included in discussing the markets, participants understood the importance of taking a parallel approach by simultaneously conducting technology development and designing energy markets.

## Next steps

The Japanese government plans to continue supporting projects introduced in this case study until FY2020, as aggregators need to improve their skills to provide output responding to dispatch orders from TSOs or power retailers. We will then analyze the results of these projects and identify the next step to expand the aggregation business.

# UNITED KINGDOM

## Grid modernization — framework and overview

The United Kingdom (UK) is deeply committed to combatting climate change and has ratified the Paris Agreement. The UK parliament approved a 57% reduction target for GHG emissions from 1990 to 2032 in the government's fifth carbon budget, with a target to reduce them by 80% from 1990 to 2050.[41] In 2019, the UK strengthened its commitment to combat climate change by passing a law requiring the UK to bring all GHG emissions to net zero by 2050, making it the first major economy to pass this into law.[42] Developing smart grid technology and investing in clean energy innovation is key to achieving this and securing an affordable clean energy future for the UK.

The drive towards a smart and flexible future energy system is a core component of the Office of Gas and Electricity Markets (Ofgem), the government regulator for energy and work, which is expected to create jobs, lower energy bills and protect the environment. This is a key part of the government's Industrial Strategy[43] and Clean Growth Strategy.[44] A 2016 study for the government estimates that the benefits of a smart and flexible energy system could be £17-40B to 2050. These benefits can come from avoided or deferred network reinforcements and generation build, avoided curtailment of low-carbon generation, and the more efficient use of the energy system.[45] The UK has already reduced GHG emissions by around 45.2% since 1990 (as of 2019),[46] while its economy has grown by 72%.[47]

Over £2.5 billion is being invested by the UK government to support low carbon innovation from 2015 to 2021.[48] The government and Ofgem, the industry regulator, are taking action alongside industry to modernize the energy grid and integrate renewable energy sources, improving efficiency through smart technology and flexibility solutions, such as smart meters and electricity storage technologies, as outlined in the Smart Systems and Flexibility Plan in July 2017.[49]

Decarbonizing heat is a major area of focus, which is fundamental to achieving UK reduction targets.[50] The UK has an extensive gas grid which heats most buildings in the country.[51] Alongside this, the UK has a varied mix of renewable technologies: wind, solar PV, hydro, biomass and shoreline wave and tidal also contribute to electricity generation and active solar, heat pumps, biomass and deep geothermal are used

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[41] The Clean Growth Strategy, HM Government, October 2017, p. 21 https://www.gov.uk/government/publications/clean-growth-strategy
[42] https://www.gov.uk/government/news/uk-becomes-first-major-economy-to-pass-net-zero-emissions-law
[43] https://www.gov.uk/government/topical-events/the-uks-industrial-strategy
[44] https://www.gov.uk/government/publications/clean-growth-strategy
[45] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/568982/An_analysis_of_electricity_flexibility_for_Great_Britain.pdf
[46] 2019 UK greenhouse gas emissions: provisional figures - statistical release, BEIS, 26 March 2020. https://www.gov.uk/government/statistics/provisional-uk-greenhouse-gas-emissions-national-statistics-2019
[47] Updated energy emissions scenarios 2018, BEIS, p. 4
[48] Clean Growth Strategy, p. 11 https://www.gov.uk/government/publications/clean-growth-strategy
[49] Upgrading our Energy System—Smart Systems and Flexibility Plan, July 2017 https://www.gov.uk/government/publications/upgrading-our-energy-system-smart-systems-and-flexibility-plan
[50] Future Energy Scenarios: bridging the gap to net zero, March 2020, National Grid, p. 7 https://www.nationalgrideso.com/news/future-energy-scenarios-bridging-gap-net-zero
[51] https://www.oftec.org.uk/consumers/heating-off-the-mains-gas-network, retrieved: 20/03/2018

in heat generation.[52] In its document *Future Energy Scenarios: bridging the gap to net zero* (published in March 2020), National Grid, the Electricity System Operator (ESO), predicts that to meet the 2050 carbon targets heating needs to move away from natural gas to low carbon sources and involve significant electrification of heat, including electric heat pumps, hydrogen heating and district heating schemes. [53]

As global markets are transformed by the shift to clean growth, the UK aims to become one of the best places in the world to develop and sell the clean energy technologies needed in a modern energy system.[54] This will be achieved by focusing on energy flexibility in a competitive market and reducing barriers to smart energy by reducing regulations and simplifying planning regimes and licence acquirement.

### Further reading:

- The Clean Growth Strategy, HM Government, October 2017
- Upgrading Our Energy System - Smart Systems and Flexibility Plan, BEIS, July 2017
- Upgrading Our Energy System - Smart Systems and Flexibility Plan: Progress Update, BEIS, October 2018
- National Grid Future Energy Scenarios, National Grid ESO, July 2019

## Modernization initiatives

### Smart Metering Implementation Programme

Smart meters are replacing traditional gas and electricity meters in Great Britain as part of an infrastructure upgrade to make the energy system more efficient and flexible, without which the costs of delivering net zero emissions by 2050 could be up to £16 billion higher each year.[55]

The Smart Metering Implementation Programme has made significant progress, with a total of 16.5 million smart and advanced meters now operating in homes and small businesses across Great Britain, as of December 2019.[56]

Smart meters are modernizing the energy system by ending manual meter reads, delivering accurate bills and enabling prepayment customers to conveniently track and top-up credit. The In-Home Display, which households are offered when they have smart meters installed, provides accurate information about energy consumption so consumers can easily understand how to use less and save money on their bills.

The half-hourly consumption and price data recorded by smart meters unlocks new approaches to managing demand. Innovative products such as smart "time of use" tariffs reward consumers for using energy away from peak times and enable technologies such as electric vehicles and smart appliances to

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[52] DUKES 2018 Chapter 6: Renewable sources of energy, p. 155 https://www.gov.uk/government/collections/digest-of-uk-energy-statistics-dukes
[53] Future Energy Scenarios: bridging the gap to net zero, March 2020, National Grid, p. 7 https://www.nationalgrideso.com/news/future-energy-scenarios-bridging-gap-net-zero
[54] Industrial Strategy, p. 43 https://www.gov.uk/government/topical-events/the-uks-industrial-strategy
[55] https://www.theccc.org.uk/wp-content/uploads/2018/06/Imperial-College-2018-Analysis-of-Alternative-UK-Heat-Decarbonisation-Pathways.pdf, retrieved: 16/04/20
[56] https://www.gov.uk/government/statistics/statistical-release-and-data-smart-meters-great-britain-quarter-4-2019, retrieved: 16/04/20

be efficiently and cost-effectively integrated with renewable energy sources.[57] Some customers have even been paid to use electricity during very windy days when there was excess clean energy in the system.

In September 2019, the UK government published a consultation on proposals for a new policy framework to continue to drive the market-wide rollout of smart meters following 2020, when the current duty on energy suppliers ends.[58]

## The Smart Systems and Flexibility Plan

In their Smart Systems and Flexibility Plan (July 2017), the UK government and Ofgem highlighted 29 actions they would undertake, working alongside industry, to deliver a smarter, more flexible energy system. These actions focused on: removing barriers to smart technologies, including storage; enabling smart homes and businesses; and making markets work for flexibility.[59] The Plan's Progress Update (October 2018) adds nine new actions, including establishing an Energy Data Taskforce.[60]

The Energy Data Taskforce, established by the UK government and Ofgem in 2018 as part of the progress update to the Smart Systems and Flexibility Plan, advised on how to unlock value from data within the energy system to deliver greater competition, drive innovation in new products, services and business models, and ultimately produce a more efficient, cost-effective energy system that works for consumers.

The Taskforce published a strategy for a modern digitalized energy system in June 2019.[61] The strategy provided recommendations on how to enable more effective sharing and use of data, including the aims to: digitalize the energy sector and evolve its culture to embed the values of "presumed open"; make data discoverable, searchable and understandable through a digital service that makes it easy to find and use; and establish an asset registration strategy and digital mapping services.

The UK government, Ofgem and Innovate UK are now delivering the Taskforce's recommendations through a new group, Modernising Energy Data, working with industry, the public sector and other stakeholders to implement the recommendations.

## Innovation funding

Between 2015 and 2021, the UK government expects to invest more than £2.5 billion in research, development and demonstration activities regarding low-carbon energy, transportation, agriculture and waste.[62] The government and UK Research and Innovation (UKRI), the UK's national research and innovation funding agency, expect to invest around £265 million between them in smart systems research, development and demonstrations up to 2021.[63] This includes £505 million from the BEIS *Energy Innovation Programme*, of which £70 million is for smart systems competitions.[64] To date, these competitions have enabled more than 70 new projects to get underway, developing innovative

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[57] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/770575/Smart_meters_Unlocking_the_future.pdf, retrieved: 16/04/20
[58] https://www.gov.uk/government/consultations/smart-meter-policy-framework-post-2020, retrieved: 16/04/20
[59] Smart Systems and Flexibility Plan, p. 4 https://www.gov.uk/government/publications/upgrading-our-energy-system-smart-systems-and-flexibility-plan
[60] https://www.gov.uk/government/groups/energy-data-taskforce
[61] https://es.catapult.org.uk/reports/energy-data-taskforce-report/
[62] The Clean Growth Strategy (page 50)
[63] Announced in the 2017 Clean Growth Strategy: https://www.gov.uk/government/publications/clean-growthstrategy
[64] The Clean Growth Strategy (Footnote, page 50)

technologies and approaches in areas such as energy storage, demand-side-response, energy management, V2G and markets for flexibility.[65]

The £102.5 million Prospering from the Energy Revolution (PfER) Challenge was also launched by the government in 2018[66] and is being delivered by UKRI. The objective of this program is to research, develop and demonstrate integrated smart local energy solutions across power, heat and transportation to provide cleaner and less expensive energy for consumers, while building more prosperous and resilient communities. The PfER Challenge is delivered through technology development, energy systems concepts, design projects and large-scale demonstration projects.[67]

As set out in the 2018 Road to Zero Strategy,[68] the government, through UKRI, has also delivered a £30M innovation competition supporting innovative V2G technologies and business models. A number of feasibility projects, RD&D projects are currently underway as a result of this competition. This has made the UK one of the first markets to explore V2G at scale, and one of the world leaders in the field.[69] The government passed the Automated and Electric Vehicles Act in 2018, providing the authority to require that all new EV charge points have smart functionalities. This means that charge points will be able to modulate their charging profile in response to external signals, allowing consumers to charge their EVs when electricity prices are low, and providing benefits to the electricity system by shifting EV charging away from the evening peak.

The government's £246m Faraday Battery Challenge is dedicated to the design, development and manufacturing of electric batteries. The Faraday Challenge, delivered by UKRI, has invested £80m in establishing a UK Battery Industrialisation Centre,[70] and the £78m provided by the Faraday Institution was used to drive research on battery technologies, including £42m invested in four "fast-start" projects[71] on extending battery life, battery system modelling, recycling and reuse, and next-generation solid state batteries. It has also invested at least £60m in feasibility studies, collaborative R&D projects, and scale up activities, including projects improving battery lifespan and range, and demonstrating how to reuse, remanufacture and recycle batteries at their end-of-life.

Ofgem also supports smart energy innovation. In the current network "Revenue = Incentives + Innovation + Outputs" (RIIO) price controls framework, innovation is a core part of the regulatory business model, including through the Network Innovation Allowance and Network Innovation Competition. Part of each licensee's price control allowance is to be spent on smaller-scale RD&D projects with up to £70M available annually specifically for electricity networks, via the Network Innovation Competition process. There are opportunities for international partnerships in these competitions.[72]

[65] See www.gov.uk/guidance/funding-for-innovative-smart-energy-systems
[66] www.gov.uk/government/news/prospering-from-the-energy-revolution-full-programme-details
[67] https://www.ukri.org/innovation/industrial-strategy-challenge-fund/prospering-from-the-energy-revolution/
[68] The Road to Zero: Next steps towards cleaner road transport and delivering our Industrial Strategy, BEIS, July 2018 www.gov.uk/government/publications/reducing-emissions-from-road-transport-road-to-zero-strategy
[69] www.gov.uk/guidance/funding-for-innovative-smart-energy-systems#funding-for-innovative-electric-vehicle-to-grid-projects
[70] https://www.ukbic.co.uk/
[71] https://faraday.ac.uk/fast-start-projects/
[72] For further details: https://www.ofgem.gov.uk/network-regulation-riio-model/network-innovation/electricity-network-innovation-competition

Ofgem is now preparing for the next set of price controls, RIIO 2, including integrating innovation findings into the business-as-usual practices of the network companies, and how best to facilitate further innovation. Ofgem's final view on price control allowances will be published by the end of 2020.

## Future directions

As detailed in the Smart Systems and Flexibility Plan, the roles of actors in the UK energy system are evolving. As the UK integrates intermittent and distributed sources of power, the need for flexible generation and consumption is increasing.

The low carbon share of UK electricity generation (renewables and nuclear generation, as a proportion of all power producers) is projected to rise from 22% in 2010 to 65% in 2020.[73]

The UK aims to phase out the use of unabated coal to produce electricity by 2025[74] and the government has committed to phasing out the installation of high-carbon forms of fossil fuels, moving heating in new and existing businesses off the gas grid during the 2020s, starting with new builds.[75]

There are upcoming projects to establish new interconnectors to France,[76] adding to the current interconnectors which accounted for 4.2% of electricity supplied in 2017:[77] England-France (2 GW capacity), England-Netherlands (1 GW), Northern Ireland-Ireland (0.6 GW), Wales-Ireland (0.5 GW) and England-Belgium (1 GW, commissioned in early 2019).

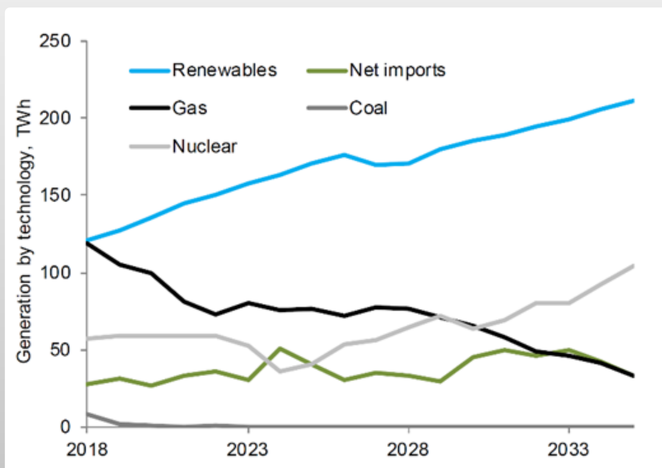


**Figure 13: Projections of UK generation + net imports (TWh) by fuel source (2017–2035)**

Building on a System Needs and Product Strategy consultation in 2017,[78] the National Grid ESO is developing balancing service markets to meet changing system needs. To do this, they are providing clear market information and product transparency, as well as ensuring routes to markets for multiple participants.

At distribution level, Distribution Network Operators (DNOs) in local electricity networks are transitioning to a DSO role which involves more active management of networks, including the procurement of market solutions to network constraints and greater coordination between the transmission and distribution systems.[79]

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[73] Updated energy and emissions projections 2018, BEIS, April 2019, p. 34-35 https://www.gov.uk/government/publications/updated-energy-and-emissions-projections-2018
[74] Industrial Strategy, p. 15
[75] Clean Growth p. 67
[76] https://www.ofgem.gov.uk/electricity/transmission-networks/electricity-interconnectors, retrieved: 26/03/2018
[77] DUKES 2018, pp. 113-114
[78] https://www.nationalgrideso.com/document/84261/download
[79] Electricity Network Innovation Strategy, p. 11

DNOs have started to open up the delivery of network requirements to market-based smart solutions (storage and DSR, for example), to reduce network costs and deliver savings for consumers.[80]

The role of consumers is also evolving with the spread of smart and renewable technologies. For instance, by 2018, close to 1 million homes (of a total of 27 million)[81] in the UK had solar panels on their roofs.[82] Increases in battery usage and these types of small-scale renewable energy generation are enabling consumers to feed excess power back into the local grid. Consumers have driven the rise in electric vehicle use, which could feed power into the grid. As of January 2019, there were over 195,000 electric vehicles in the UK, accounting for 3.8% of all registrations. Aggregators have been playing a growing role in coordinating the balancing of the resulting increasingly complex electrical demand and supply in their local areas.

[80] Smart Systems and Flexibility Plan, p. 18

[81] https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/families/adhocs/005374totalnumberofhouseholdsbyregionandcountryoftheuk1996to2015, retrieved: 23/03/2018

[82] Upgrading Our Energy System, Smart Systems and Flexibility Plan, p. 5
https://www.gov.uk/government/publications/upgrading-our-energy-system-smart-systems-and-flexibility-plan

## Case studies

### Case study #12 – Piclo-Flex

| **Electricity system segment** |
|---|
| Distribution system |
| **Current status** |
| Completed. (This case study was provided in March 2019 and was accurate at that time.) |
| **Project duration** |
| We have funded two different projects in 2015-17 and 2017-19 related to digital energy trading. |
| **Project lead** |
| Open Utility Ltd, a small company specializing in developing digital trading in the energy sector. |
| **Project partners** |
| The following DNOs are partaking in the first auctions under the Piclo-Flex product development: UK Power Networks**,** Scottish & Southern Electricity Networks, Electricity North West**,** SP Energy Networks**,** Northern Powergrid **and** Western Power Distribution. |
| **Project cost** |
| Project cost: £1.13M<br>Public/private £ ratio: £927k public/£205k private<br>Over both projects, the UK government has provided a £927k grant leveraging £205k in private investment.<br>Government program: Energy Entrepreneurs Fund |
| **Project location** |
| The whole of the United Kingdom of England, Scotland, Wales and Northern Ireland. |
| **Project website** |
| https://piclo.energy/ |

#### Context

The UK government's policy is for network operators to use the most cost-effective way of upgrading their networks to deliver future low carbon services such as charging electric vehicles and electrifying heat. This includes using the management of peak demand where it is a less expensive option than traditional methods of network reinforcement such as installing larger cables and transformers. Opening up the delivery of network requirements to flexibility service alternatives is a key action in the UK government's Smart Systems and Flexibility Plan. This project aimed to develop an electronic market platform which network operators could use to advertise and procure flexible alternatives to network reinforcement. These flexible alternatives allow DNOs to manage peak demand in network pinch points at minimum cost.

## Objectives

The objectives of the work were to develop an electronic trading platform where consumers and electricity aggregators can sell demand-side flexibility to DNOs. This platform allows DNOs to provide visibility of network constraints and run tenders for flexibility services which can provide network constraint management services. Some of these tenders are being run as competitive auctions. DNOs will procure flexibility where the bids received are more cost-effective than traditional network reinforcement.

## Project description

This project uses the power of an online marketplace to break down the biggest barrier the energy industry faces in becoming a decentralized and decarbonized system: the ability for DNOs to access location-specific flexible resources.

DNOs will play a critical role in actively balancing local smart grids and facilitating the rollout of distributed generation, storage and smart devices. The benefits are considerable: potential savings of over £4 billion and an 18% decrease in UK electricity generation carbon emissions by 2030, but only if DNOs can quickly and easily access flexible assets on the grid. This innovation uses the latest web technologies, resource optimization algorithms and smart contracts to manage the deployment of localized flexibility in a highly efficient, easy to use and scalable way.

## Project outcomes

All six DNOs in Great Britain plan to use the platform to tender for flexibility services to provide cost-effective alternatives to expensive network building. Flexible technologies such as energy storage and demand-side response provide an alternative to traditional hard infrastructure upgrades and should reduce network costs which currently make up just over 25% of consumer bills (ref: www.ofgem.gov.uk/publications-and-updates/infographic-bills-prices-and-profits).

## Lessons learned

- It is important to keep the DNOs involved with the look and feel of any smart trading system that they will be using, especially the way that any auctions for services will run.
- Such trading systems need to bring on large amounts of demand management suppliers of all different types (batteries, load switching services, demand aggregators), which have different requirements of the platform.
- It is important to keep such new digital technology developments closely aligned with policy and regulation to ensure that there will be no barriers to utilizing the technology when it is completed.

## Next steps

For more project information, please visit: https://piclo.energy/

## Case study #13 – DESIRE (Domestic Energy Storage Integrating Renewable Energy)

| **Electricity system segment** |
|---|
| Distribution grid innovation |
| **Current status** |
| Completed. (This case study was provided in March 2019 and was accurate at that time.) |
| **Project duration** |
| June 2017–December 2019 |
| **Project lead** |
| **Upside Energy** is a Manchester-based SME offering "software as a service" to provide demand-side response services through its innovative cloud-based platform. |
| **Project partners** |
| **Upside Energy:** Through its award-winning cloud-based platform, Upside can optimize and bring thousands of enabled assets into its portfolio to provide demand-side response services. For DESIRE, Upside will integrate with Mixergy hot water tanks and Powervault batteries to analyze the consumption patterns of participants. This will support the development of the business case to determine which demand-side response services are suitable for different asset owners (individual, landlord, manufacturer).<br>**The Eden Project** is an education charity and visitor attraction featuring gardens and architecture in a worked-out china clay pit in Cornwall. The Eden Project is responsible for identifying the 500 installation sites for the Mixergy hot water cylinders, through working with local housing associations in Cornwall, West London and Somerset. Eden coordinates the project's tank installation and maintenance elements.<br>The **University of Oxford** designs trials to ensure they deliver robust results and evaluates the operation of the trials and their outputs. In parallel, advanced models and optimization frameworks are developed to determine a suitable strategy that maximizes the value extracted from the system.<br>**Mixergy** is an Oxford-based SME that is developing smart technology. Within the project, Mixergy is supplying intelligent hot water tanks.<br>**Powervault** is a London-based SME which produces domestic batteries. For this project, Powervault will be manufacturing and supplying the domestic batteries. |
| **Project cost** |
| Project cost: £2.5m \| Public/private £ ratio: £1.75M public/£0.75M private<br>Government program: Integrated Supply Chains for Energy Systems |
| **Project location** |
| The project is predominately centred in two geographical locations (Cornwall and London), although there are smaller pockets of households participating in the project across the UK. The project focuses on these two areas to understand how domestic capability and capacity in offering DSR services can support DNOs with local constraints/issues. For example, Cornwall has a constrained network capacity but an overabundance of PV generation in the summer, while London has a higher demand for urban cooling. The project's outcomes will be able to support domestic demand-side response services UK-wide. |
| **Project website** |
| www.peteproject.com |

## Context

Domestic households accounted for 27% of the UK's energy use in 2014. Most households find it difficult to access inexpensive, off-peak tariffs, thus the bulk of their energy use is at peak times, when prices and environmental impacts are highest.

At the same time, this generation creates significant issues (e.g. of over and underloads at key times) for distribution and transmission. These problems are acute in regions like Cornwall, where tariffs are 10% higher than the rest of the UK, and penetration of solar PV is high.

Domestic energy storage provides a natural solution to these problems. If people could store energy when tariffs are low or micro-generation output is high, they could use it when needed. This would reduce overall energy costs, make it easier to exploit growing amounts of renewable generation and reduce system demand at peak times, thus increasing margins and security of supply.

Multiple storage vectors are available for this purpose, but all suffer from barriers to adoption – batteries are expensive and thermal storage via hot water tanks is inflexible and often inefficient due to poor tank design.

This project brings together multiple storage vectors and explores routes to mitigate these barriers through a combination of better design of individual components and, especially, design of an integrated, multi-vector household storage system that exploits diverse component capabilities to create added system capability and flexibility. Revenue derived from this integration with systemic value streams increases the return on investment of individual storage units, thus helping to justify investment in storage and growing the storage available to the system. Finally, the project explores consumer attitudes to storage and time-shifting energy use, to support wider adoption of DSR technologies.

## Objectives

The project's objective is to understand the capabilities of domestic DSR through the installation and monitoring of 500 intelligent hot water tanks and 100 domestic batteries in 600 homes across London, Cornwall and select areas in the UK. The project has recruited households that cover both the private homeowner and social rented sectors for the trial, to ensure that a representative cross section of the domestic market participates in it.

The project aims are: 1) to develop the Upside cloud platform; and 2) to develop the supply chain of low-carbon goods.

**Figure 14: Intelligent hot water tanks**

## Project description

Dealing with a wide range of customers has led to significant further product development from partners Mixergy (intelligent hot water tanks) and Powervault (domestic home batteries), resulting in a wider market offering to future customers of their products.

Upside Energy's cloud platform has been refined to deal with a growing level of complexity and optimization from domestic assets and controls which have supported other Innovate-funded projects Upside is involved in, as well as supporting DNOs in managing network congestion.

The business case indicates that, by utilizing Upside Energy's cloud-based platform to optimize and control the assets installed in the home, a sustainable level of revenue can be generated for the asset owner while also providing an increased level of efficiency and reduced energy loss to the user.

## Project outcomes

The DESIRE project provides a solid foundation for the future expansion of DSR in the domestic sector. The project was due for completion in December 2019 and findings will be disseminated into 2020.

The project's economic, social and environmental benefits are multifold:

By opening up a large domestic energy storage resource, the project will allow the grid to access, via Upside's service, stored distributed energy that can be used to reduce the cost of balancing supply and demand and to avoid the need to reinforce networks.

Upside's service reduces the amount of "spinning reserve" (i.e. power stations operating at partial load) that the grid must hold. This in turn eliminates 600 tonnes of $CO_2e$ for every MW of demand managed. In addition, by driving the adoption of demand-side flexibility, this project will facilitate the integration of higher proportions of renewable generation in the grid, with a reduced need for curtailment.

Finally, the grid's carbon intensity fluctuates by as much as 20% over the course of a day, so intelligent demand shifting can also lead to direct environmental benefits by carefully scheduling battery recharging.

## Lessons learned

The project consortia have already learned a significant amount. From a technical perspective, partners have a better understanding of the types of DSR services that lend themselves to domestic offerings. Equally, both Mixergy and Powervault have achieved a greater understanding of the types of services and requirements the customers expect from their products, resulting in design and capability changes to the hot water tanks and batteries used in the project.

In addition, Upside is expanding its knowledge of the scope and capability of its platform. There is an understanding of how to handle a wide range of differing assets and the implications for wide-scale adoption. The project is also developing our understanding of how to balance the desire of landlords to earn revenue with the needs of their tenants to be protected from higher bills.

## Next steps

For more project information, please visit: https://gtr.ukri.org/projects?ref=103307

## Case study #14 – The Smart Islands program, Isles of Scilly

| **Electricity system segment** |
| --- |
| Smart energy, IoT, V2G, energy from waste, energy transition |
| **Current status** |
| Ongoing. (This case study was provided in March 2019 and was accurate at that time.) |
| **Project duration** |
| 2015–2025 |
| **Project lead** |
| The public-private Smart Islands Partnership: established in 2016 to provide oversight and governance for the Smart Islands program of projects. It comprises the islands' major stakeholders: Council of the Isles of Scilly; Duchy of Cornwall; Tresco Estate; Islands' Partnership; Hitachi Europe Ltd.; South West Water, and the Isles of Scilly Community Venture. These key stakeholders, who are familiar with key challenges and contribute to solution design, keep the end user at the heart of the program. |
| **Project partners** |
| **Smart Energy Islands (smart energy, IoT, energy transition) 2017–2019**<br>Hitachi Europe Ltd. (lead partner) has partnered with two leading UK smart home energy companies, Moixa and PassivSystems, to deliver the Smart Energy Islands project, together with the Council of the Isles of Scilly's Housing Department. The European Regional Development Fund is supporting the project.<br>**Go-EV (V2G, IoT, energy transition) 2018–2020**<br>The Council of the Isles of Scilly (lead partner) has partnered with the Isles of Scilly Community Venture and Hitachi Europe Ltd. to deliver the Go-EV project. The Cornwall and Isles of Scilly Local Enterprise Partnership's Local Growth Fund and the European Regional Development Fund are funding the project.<br>The Isles of Scilly are a grid-connected community and a perfect location to test multi-utility innovation. Further renewable energy generation and innovative ways to manage water and waste will commence in 2020. |
| **Project cost** |
| **Smart Energy Islands (2017–2019)**<br>Project cost: £10.8M \| Public/private ratio: £8.64M public/£2.16M private<br>Government program: European Regional Development Fund supporting the shift towards a low-carbon economy in all sectors<br>**Go-EV (2018–2020)**<br>Project cost: £3.06M \| Public/private ratio: £3.06M<br>Government program: Cornwall and Isles of Scilly Local Enterprise Partnership's Local Growth Fund and European Regional Development Fund supporting sustainable transport in Cornwall and the Isles of Scilly. |
| **Project location** |
| Isles of Scilly |
| **Project website** |
| https://smartislands.org/about |

## Context

The government is championing clean growth through its Industrial Strategy and Smart Islands is one of just a few national case studies highlighted in the strategy. This groundbreaking initiative aims to be replicable and scalable for other parts of the UK in both rural communities and cities alike. The Smart Islands program's interconnected projects provide an innovative model for the provision of local energy generation: the development of a smart electricity grid, local waste and sewage management, and the electrification of heat and transport. A multi-utility approach seeks to solve these problems in an integrated way, with the public and private sectors working together to find the right solutions for the islands.

By 2025, the Isles of Scilly's goals are to:

- Reduce electricity bills by 40%; and
- Increase energy from renewables to 40% and replace 40% of vehicles with low-carbon or electric vehicles.

With the second-highest average domestic electricity consumption per household in the UK (7,801 kWh) and imported fossil fuels being more expensive than on the mainland, the Isles of Scilly rank eighth in England for fuel poverty. Moreover, despite having 280 more hours of sunshine on average than London, local renewable energy has historically generated less than 2% of the annual demand for energy.

## Objectives

The Isles of Scilly's Smart Islands program is providing a "live laboratory" to test the technologies that will be required by the UK in the coming decades. It is an integrated approach to infrastructure, utilities and health challenges. It is demonstrating a replicable model for decarbonization and how all UK communities can benefit from a rapid transition to cleaner, low-carbon technologies.


**Figure 15: Isle of Scilly Smart Islands framework**

Part of the wider Smart Islands program, Smart Energy Islands is seeking to demonstrate that an IoT-powered Smart Grid platform, which will respond digitally to balance electricity demand and supply, will enable the more efficient use of locally produced energy.

The Isles of Scilly face testing challenges for renewable energy installation business cases. This is because the local energy network experiences excess electricity generation, due to plentiful renewable generation in Cornwall. In turn, newly installed renewable energy is turned off (curtailed) by the network operator when generation exceeds consumption. The IoT platform will control the various heating and transportation assets to turn up energy demand on the islands, mitigating curtailment by consuming energy locally. The grid operator then allows the islands' solar garden to be turned back on, making the most of the energy produced locally on the islands.

The Smart Energy Islands system also anticipates demand and supply. It predicts conditions where the islands' generation might be curtailed the next day and plans energy use by the electric vehicles, home energy storage and smart heating technologies to avoid curtailment.

The IoT platform introduces the capability to add more renewable generation to the islands in the future without it being curtailed. The Smart Energy Islands project has built the foundations needed to reach the islands' renewable energy generation targets.

Source: http://www.smartenergyislands.net

## Project description

*Smart Energy Islands and the IoT platform:*

Smart Energy Islands aim to enable a more efficient use of locally produced energy at two levels:

1. Island-wide energy optimization – maximizing revenue from electricity generated from renewables (e.g. PV gardens) by balancing excess electricity with demand response to minimize curtailment.
2. Home energy optimization – maximizing self-consumption of electricity generated from rooftop PV.

Around 400 kW of solar panels have already been installed. Homes are also piloting other energy technologies, including home batteries and air source heat pumps. Hitachi's cloud-based IoT platform will manage energy use: learning consumption patterns, optimizing power collection and use throughout the house, and linking it to the wider electricity grid. By integrating solar power, batteries and smart heating technologies, the scheme will make 100 homes more energy-efficient. The project is also providing energy efficiency support to 200 businesses on the islands and in Cornwall.

*GO-EV Vehicle to Grid electric vehicles*

Electric vehicles and the charging network infrastructure are being delivered by GO-EV, another Smart Islands Partnership project in 2018-20. V2G electric vehicles will be integrated into the islands' IoT-enabled smart grid that has been built by the Smart Energy Islands project.

*Isles of Scilly Community Venture (a community interest company)*

This not-for-profit community interest company established in 2018 will sell energy generated by the Smart Energy Islands solar panels and recycle the income to reduce electricity bills for all islanders. At the completion of the GO-EV project, it will operate a car share scheme to give islanders a new, sustainable travel option.

## Project outcomes

The Smart Energy Islands project aims to develop a replicable, innovative solution in terms of:

- Curtailment management acting on signals from the network operator, Western Power Distribution (WPD);
- Representation of flexibility in the Universal Smart Energy Framework and development of algorithms to determine the best mix of demand-side response;
- Optimization of a wide variety of controllable home assets (e.g. heat pump, storage battery, immersion heater or storage heater control) by a smart home hub;
- ICT system that supports an innovative business model delivered by a community interest company on the Isles of Scilly, called the Isles of Scilly Community Venture (IoSCV.co.uk).

Specifically, key outcomes and outputs for this phase of the program include:

- 100 social homes' energy efficiency improved;
- A pilot of 10 "smart" homes with air source heat pumps, solar PV and/or energy storage;

- 200 local businesses supported for improved energy efficiency;
- 450 tonnes of $CO_2$ saved year-over-year;
- An islands-wide energy control system built on an IoT based ICT platform with open APIs, and the intention that other companies can develop new innovative ideas and easily “plug in” their applications onto the platform. It will provide open interfaces to the connected energy assets that will allow dynamic changes in the energy system to balance generation and consumption; and,
- 463 kW of total renewable energy installed to date (January 2019).

The Smart Energy Islands project has built the foundation needed for the islands’ sustainable energy future. The IoT platform introduces the capability to add generation to the islands in the future without it being curtailed. Without the Smart Energy Islands platform, V2G electric vehicles could not be used as part of the energy system on the islands.

The expected outcome of the GO-EV project is to introduce a network of 25 bidirectional (V2G) charge points, ten solar canopies, ten EVs available to local people on a pooled basis, and two improved multimodal connection points at St. Mary’s Airport and St. Mary’s Quay. In addition, the GO-EV project will deliver a car share ICT platform and integration with the Smart Energy Islands platform.

## Lessons learned

Projects are ongoing and only an ex-ante assessment has been completed for the Smart Energy Islands project. GO-EV was formally launched on February 13, 2019.

## Next steps

The Council of the Isles of Scilly's Energy Infrastructure Plan seeks to achieve 40% renewable energy on the islands through a range of generation technologies. In addition to the current projects described above, to meet the 40% target, it will be necessary to explore how capacity from renewable energy can be further increased:

| | Stage 1 (2015–2020) | Stage 2 (2020–2025) |
|---|---|---|
| Renewables | PV, Anaerobic Digestion, gasifier, wind and/or marine power | PV, wave, micro technologies for sewage treatment, gas storage |
| Capacity | 3.1 MWe | ~3+ MWe |
| Infrastructure | Sewage treatment, district heating, new power station, energy storage | Wave generation to connect to island grid, power to gas? New cable to islands? |
| Share of electricity | 40% | 100% |
| Share of non-electricity energy | Max. 10% | Up to 40% |
| Comment | All proven technologies, integration issues understood | New technology and deeper integration, more challenging |

Source: Council of the Isles of Scilly Smart Islands update to Full Council, December 14, 2018.

# UNITED STATES

## Grid modernization — framework and overview

The U.S. power system is a critical infrastructure that is core to national prosperity. The U.S. government's strategy for its energy systems is grounded in the 2017 National Security Strategy (NSS), which calls for maintaining America's central position in the global energy system as a leading energy producer, consumer and innovator, built on free markets and resilient, secure infrastructure. The NSS advances an approach that balances energy security, economic development and prosperity, and environmental protection, and takes advantage of America's abundant energy resources and energy efficiency to expand the economy, and provide consumers and businesses access to inexpensive electricity, while reducing emissions. Central to this strategy is to embrace and innovate on all fuels and energy technologies (i.e. "all of the above"), including coal, natural gas, petroleum, renewables, nuclear (both traditional and advanced), energy efficiency, smart grids and energy storage, recognizing that energy security is built on a diversity of sources, supplies and routes.

### Affordable electricity

Prices for electricity in many of the world's advanced economies have been rising, contributing to increases in energy poverty, which is defined as households that spend more than 10% of their income on energy. The U.S. has sought to improve economic development through affordable electricity, which has supported healthy business growth and lowered the burden on low-income consumers through some of the lowest energy prices among advanced economies. In 2019, the average U.S. energy price for all sectors stood at 10.27 cents per kilowatt-hour (kWh), while the average price paid in Europe was 24 cents per kWh. The region with the lowest energy prices in 2019 was the "West South Central" region, which consists of the states of Arkansas, Louisiana, Oklahoma and Texas, with an average of 8 cents per kWh. The highest prices in the continental U.S. were in the Pacific states of California, Oregon and Washington, at 13.24 cents per kWh.

### Current and future energy source mix

In 2019, about 4,118 billion kWh (or about 4.12 trillion kWh) of electricity were generated at utility-scale electricity generation facilities in the United States.[83] About 63% of this electricity generation was from fossil fuels—coal, natural gas, petroleum and other gases. Approximately 20% was from nuclear energy and about 18% from renewable energy sources. The U.S. Energy Information Administration estimates that an additional 35 billion kWh of electricity generation was from small-scale solar PV systems in 2019.[84]

[83] Preliminary data for 2019. Utility-scale electricity generation is electricity generation from power plants with at least one megawatt (or 1,000 kilowatts) of total electricity generating capacity. Data is for net electricity generation.
[84] Small-scale solar photovoltaic systems are electricity generators with less than one megawatt of electricity generating capacity that are usually at or near the location where the electricity is consumed. Most small-scale solar photovoltaic systems are installed on building rooftops.

# Modernization initiatives

## Background

The U.S. grid has fuelled the country's growth since the early twentieth century. Access to electricity is such a fundamental enabler for the economy that the National Academy of Engineering named "electrification" the greatest engineering achievement of the 20$^{th}$ century. However, the U.S. grid does not currently have the attributes necessary to meet the demands of the 21$^{st}$ century and beyond.

The traditional grid architecture is based on remotely located large-scale generation, hierarchical control structures with minimal feedback, limited energy storage, and passive loads. Five key trends are driving this transformation that challenges the capacity of the grid. These five trends include:

- A changing mix of types and characteristics of electric generation—in particular, distributed, and variable energy;
- Growing demand for a more resilient and reliable grid—especially due to weather impacts and cyber and physical attacks;
- Growing supply- and demand-side opportunities for customers to participate in electricity markets;
- The emergence of interconnected electricity information and control systems; and
- An aging electricity infrastructure.

To address these challenges, the DOE has created the Grid Modernization Initiative (GMI) to accelerate R&D investments in grid modernization.

## Grid Modernization Initiative

The GMI focuses on the development of new architectural concepts, tools and technologies that measure, analyze, predict, protect and control the grid of the future. The GMI also enables the institutional conditions that allow for more rapid development and widespread adoption of these tools and technologies. It lays the foundation for coordination across the DOE, linking key programs within the Office of Electricity (OE), Office of Energy Efficiency and Renewable Energy (EERE), Office of Fossil Energy (FE), Office of Nuclear Energy (NE), and Office of Cybersecurity, Energy Security, and Emergency Response (CESER). The DOE will help frame new architecture elements, develop new planning and operations tools platforms, provide metrics and analytics, and enhance state and industry capabilities in designing physical models for successfully modernizing the grid.

The DOE is supported by the National Laboratories under the Grid Modernization Lab Consortium (GMLC), a collaboration among fourteen DOE National Laboratories and regional networks that helped develop and implement the Grid Modernization Multi-Year Program Plan (Grid MYPP).

This Grid MYPP defines a vision for the modern grid and identifies key challenges and opportunities. It describes the RD&D activities the DOE will focus on over five years, including opportunities for public-private partnerships.

## Technical areas

The technical areas are areas in which research is needed to modernize the nation's grid.

- *Devices and integrated systems testing*: This technical area develops devices and integrated systems, coordinates integration standards and test procedures, and evaluates the grid characteristics of both individual devices and integrated systems to provide grid-friendly energy services.
- *Advanced sensors and data analytics*: This technical area focuses on tools and strategies to determine the type, number and placement of sensors to improve system visibility from individual devices to feeders, distribution systems and regional transmission networks.
- *System operations, power flow and control*: This technical area focuses on new control technologies to support new generation, load and storage technologies.
- *Design and planning tools*: This technical area focuses on the development of the next generation of modelling and simulation tools needed for power system planning.
- *Cyber and physical security*: This technical area aims to meet physical and cyber security challenges, analyze asset criticality, assess ways to minimize risk, address supply chain risks (specifically for transformers), and provide situational awareness and incident support during energy-related emergencies.
- *Resilience*: This technical area provides the opportunity to improve the reliability and resilience of our national electric power infrastructure in the face of a rapidly evolving threat environment and increasingly complex infrastructure systems.
- *Generation*: This technical area develops tools and technologies that accelerate emerging generation systems and/or maximize the value of existing generation assets as they provide value to the grid.
- *Institutional support*: In addition to technical assistance, this technical area develops new analytic frameworks for key grid modernization issues.

## Project portfolio

### 2016 Grid Modernization Lab Call

In 2016, the DOE announced the first Grid Modernization Lab Call—a comprehensive, $220M, three-year plan to mobilize eighty-seven projects across the country, bringing together the DOE and the National Laboratories with more than 100 companies, utilities, research organizations, state regulators and regional grid operators to pursue critical R&D in advanced storage systems, clean energy integration, standards and test procedures, and a number of other key grid modernization areas.

### Resilient Distribution Lab Call

In 2017, the DOE announced up to $32M over three years for seven projects to develop and validate innovative approaches to enhancing the resilience of electricity distribution systems, focusing on the integration of DERs, advanced controls, grid architecture and emerging grid technologies at a regional scale.

Additionally, other technology-specific research has been conducted.

## Future directions

### 2019 Grid Modernization Lab Call

In November 2019, the DOE announced approximately $80M over three years for more than twenty projects aiming to strengthen, transform and improve the resilience of energy infrastructure to ensure the nation's access to reliable and secure sources of energy now and in the future.

This portfolio is focused on developing projects in resilience modelling, energy storage and system flexibility, advanced sensors and data analytics, institutional support and analysis, cyber-physical security, and generation.

## Case studies

The following case studies are GMI projects that aim to create innovative approaches to enhancing the resilience of electricity distribution systems. These projects started in 2017 and are expected to conclude in the next twelve months.

## Case study #15 — CleanStart DERMS: Distribution System Resilience and Restoration with Distributed Energy Resources

| |
|---|
| **Electricity system segment** |
| Distribution system restoration and black start |
| **Current status** |
| In progress |
| **Project duration** |
| 2017–2021 |
| **Project lead** |
| The Lawrence Livermore National Laboratory (California, USA) is a federally funded R&D centre funded through the DOE. |
| **Project partners** |
| *Pacific Northwest National Laboratory (PNNL):* a federally funded R&D centre operated for the U.S. Department of Energy. The PNNL is the national laboratory partnered with this project to manage the simulation integration.<br>*Los Alamos National Laboratory (LANL):* a federally funded R&D centre operated for the U.S. Department of Energy. The LANL is leading the development of the optimization requirements.<br>*City of Riverside Public Utility (Riverside, CA, USA):* the primary demonstration partner for the activities in CleanStart DERMS.<br>*Pacific Gas and Electric (Northern CA, USA):* a publicly traded utility advising on the implementation of the controls in an alternate utility structure, and performing the Hardware in the Loop and functional acceptance testing of the CleanStart DERMS framework.<br>*Smarter Grid Solutions:* a distributed energy resource management system (DERMS) company, integrating control and algorithmic analytics to its STRATA platform and control nodes.<br>*XENDEE Inc:* a microgrid design and optimal component sizing company for utility and support components.<br>*OSISoft:* a software company specializing in data integration within utility operations. |
| **Project cost** |
| Project cost (in USD): $6.2M<br>Private/public $ ratio: $5M public/$1.2M private<br>Government program: DOE |
| **Project location** |
| The project is deploying and being demonstrated in the Riverside, California area at the City of Riverside Public Utility's Emergency Operations Center and Utility Operations Center, along with a mix of commercial customers served by the utility. |
| **Project website** |
| https://gmlc.doe.gov/projects/1.5.05 |

## Context

After an unexpected, accidental or even planned wide-area grid shutdown, such as a black or brown out, utilities must be able to restore electric power to customers as quickly as possible. Typically, utilities restore large generators, bulk system capabilities and stability for the customers and load in a "root to leaves" method. Outages of this scale can be driven by many types of hazards including prolonged weather patterns (clouds, low wind or drought), cyber (i.e. attacks), physical (i.e. accidental or deliberate) or natural disasters (hurricane, wildfire). The capability for utilities to safely and reliably restart, utilizing a varied suite of resources is imperative for future and long-term grid resilience and reliability.

The utilization of microgrids and DERs in the context of a resilient and assured power supply is becoming a significant area of development for many utilities and agencies. Storage, solar and hybrid systems are at the heart of these deployments. However, the utilization of distributed resources in restoration is limited by barriers in controls and communication deployment, standards and regulation, and the foundational understanding of the challenges a segmented and automated restoration could entail. The coordination of resources to support abnormal and outage conditions could be significantly boosted by utilizing and adapting resources which are not generally considered grid-forming (i.e. household inverters), along with the strategic placement of distributed and collaborative black start enabled units. The end result is that, instead of performing restoration of load after a large event solely with a root to leaves method, it will now include a leaves to root approach, thus improving the time required for full grid electrification.

Utilities typically have backup diesel generators for critical loads and specially designated generators that can supply enough support for a black start, but this power source is costly to maintain and relies on a consistent fuel supply. Therefore, supply chain disruption is a key challenge in various scenarios. In addition, it can take up to 24 hours for the process to be completed using generators, even if infrastructure is not damaged at the bulk level. Utilities need an alternative source of energy that can assist in maintaining grid stability after a shutdown, quickly achieving a black start and enabling customers to receive power supply more quickly while reducing the reliance on diesel generators.

## Objectives

The high-level, general goal of this project is to design a repeatable strategy for a resilience-based microgrid which integrates both technology and theory validation, as well as to demonstrate a process for functional acceptance testing and a full field validation. The specific goal of CleanStart DERMS is to demonstrate in a unique manner the capability to start a feeder from a complete outage, with minimal conventional generation, from the leaves (i.e. the DER and customers) to the root (i.e. feeder head). It also aims to resynchronize with the wider area network, integrating and validating distributed analytics, controls and DERMS/ADMS concepts, with enhanced communication and control for agile islanding. Components of early-stage technology which will be tested in the field include: integrated cluster control and stochastic resilient optimal power flow, advanced analytics for risk assessment and topology control, and secure layers of encryption for degraded islanded operation and hierarchical architecture. Specific project objectives to be achieved with the integration of these technologies include:

1. Minimizing the outage time for the maximum number of customers using the greatest contribution from distributed and clean energy resources.
2. Implementing methods for the coupling and validation of predictive analytics and advanced controls for resilience.
3. Providing support services from the DER back to the transmission system during critical outages.

## Project description

The CleanStart-DERMS project team will develop a black start and restoration solution leveraging 100% of DERs, with distributed energy resource management system (DERMS) integration at the utility partner, City of Riverside Public Utilities.

The project team has designed, implemented and will demonstrate a novel method for fast customer restoration during a system outage this year. In addition, the team will simulate and validate the capability to black start utility services from a high penetration of DER distribution feeders at scale, with the use case for the project demonstration utility. This demonstration, which shows the efficacy of a new DER-driven resilience concept, is multifaceted. It will include real-time analytics regarding validation and implementation, used to evaluate the stability of each line segment, and a reconnected generation cluster during segmented restoration, along with device and DER cluster control layers optimized for the black start application. The CleanStart DERMS project is implementing a repeatable design process using a transmission, distribution and communication simulation that is not generation source-specific and can utilize all available controls, making it applicable in many scenarios.

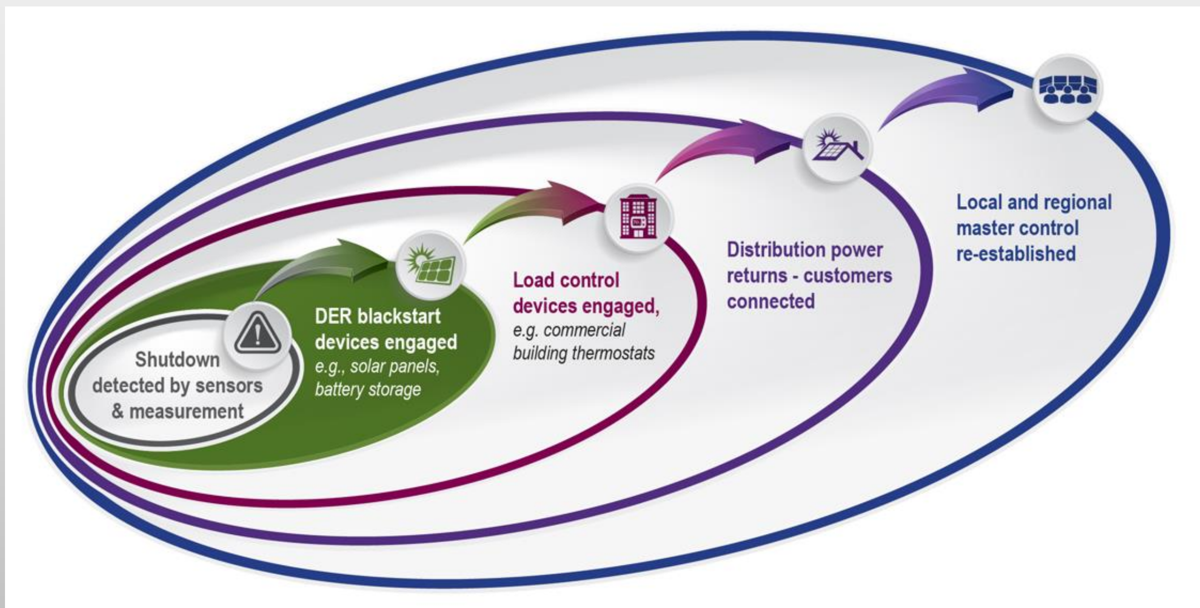


**Figure 16: DER black start restoration concept**

In addition, the project will use high-fidelity sensing and predictive analytics, modular DER control and a dynamic microgrid configuration that can be optimized in real time. The real-time optimization will provide the bulk power system with support during restoration, primarily from small distributed generators including solar PV, while simultaneously considering critical load constraints.

Smarter Grid Solutions, as a vendor of DERMS platforms, integrated novel restoration algorithms and collaborative control algorithms to its product for future implementation and deployment. The utilization of a commercial vendor for integration enabled the rapid transition from foundational research to implementation and demonstration.

The control and real-time analytics framework integrates real-time analytics from high-fidelity sensor data including distribution synchrophasors and point-on-wave line current measurement. These capabilities enable users to evaluate the ongoing risk of an outage to the feeder, allowing proactive segmentation and the stability of each node during the Cleanstart DERMS restoration process. The control strategy is leaves to root, or customer to bulk system—a fundamentally opposite approach to the normal condition in restoration where bulk system is the first consideration.

The analytics, enabled by applying knowledge about reinforcement to advanced sensors, will determine the best available controllable device configuration before the outage. The resources from that configuration—in conjunction with inverter-based black start devices—will be used to create a robust islanded network. In turn, the islanded network can be optimized to black start the remaining feeder and non-controllable DER devices.

The self-healing microgrid and distribution grid configuration will be robust with regard to both cyber and physical events. A secure SCADA protocol wrapper will be applied to the DERMS platform and emergency communications protocols will be tested for applicability in emergency scenarios, as opposed to following the commonly utilized version. It will also provide critical restoration support to the primary substation from renewables, other small distributed resources, loads and buildings. The CleanStart DERMS methodology can enable parallel restoration, accounting for uncertainty in topology and resource availability.

## Project outcomes

The primary technology outcome of this project is a strategy for resilience-based microgrids, DER-driven black start, and segmented restoration that can be adapted anywhere in the country. This approach integrates new technologies, system control theories and advanced analytics, and demonstrates their application through field validation. CleanStart-DERMS will demonstrate the capability to start a feeder from a complete outage, from the leaves (e.g. the DER and customers) to the root (e.g. feeder head), and to resynchronize with the wider area network, all with a minimal amount of conventional electricity generation. It will achieve this by integrating and validating distributed analytics, controls and DERMS/ADMS concepts with enhanced communication and control for agile islanding.

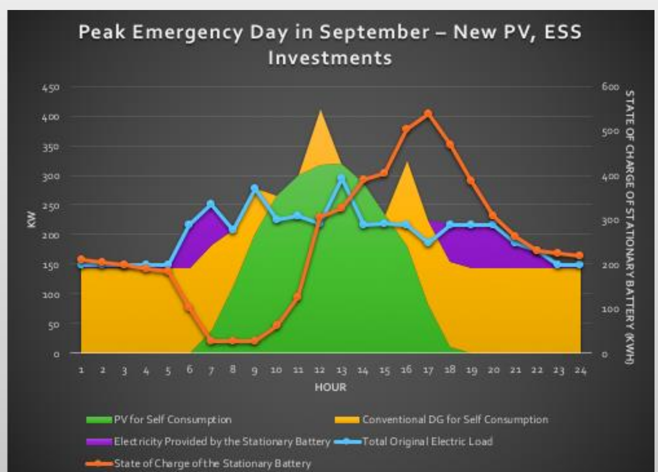


**Figure 17: Analysis of the load and generation capacity needs at the project test site**

## Lessons learned

While the project is still in progress, there have been several lessons learned. These include, but are not limited to:

1. Standard, secure interfaces between the DERMS, inverters and protection can benefit research and development as well as vendor participation.
2. During outages, the communications system is likely to be one of the key interconnected resources requiring support and resilient power in itself. Many sensors are not designed to collect data during the first few stages of restoration and have minimum current levels. Cloud-based data collection infrastructures are not useful during large events due to issues with reliable communication.
3. Customer and multiparty utility engagement is key to a successful demonstration and must be done early in the process for a project to move rapidly from foundational research to implementation.
4. Engaging a commercial vendor in the technology transition early in the project enables the development of research products which can be implemented in a repeatable and useful manner, which increases the value of the research from the national labs significantly. Engaging other parties in industrial advisory activities also enables the transition of the research to other architectures and vendors, meaning it is not a one-off deployment.
5. Utility partners' priorities will change throughout the project, and you must build flexibility in this regard into every schedule. For example, the project started with a focus on black start and emergency operations support, which in time and to the benefit of this project, became the most important challenge for our partners rather than just an interesting project for the future.

## Next steps

In November 2020, the CleanStart DERMS project will be demonstrated for the utility and U.S. Department of Energy sponsors, as well as a number of industry partners. Concurrently, some of the project's most successful aspects in collaborative control algorithms and simulation have been transitioned to follow-on activities, such as the Grid Modernization Lab Consortium Project — Citadels and U.S. Department of Defense funded activities for microgrid controls. The R&D will be presented at many industry conferences over the next year, and commercialization will be performed by both the laboratory Industry Partnerships Office and the vendors who participated in the work.

## Case study #16 — Increasing Distribution System Resiliency using Flexible DER and Microgrid Assets Enabled by OpenFMB

| **Electricity system segment** |
|---|
| Distribution system resiliency |
| **Current status** |
| In progress |
| **Project duration** |
| 2017–2021 |
| **Project lead** |
| The Pacific Northwest National Laboratory (PNNL) is a federally funded research and development centre (FFRDC) funded through the DOE. |
| **Project partners** |
| *Duke Energy*: an investor-owned utility providing electric power to 7.7 million retail customers in six states.<br>*Oakridge National Laboratory (ORNL)*: a federally funded R&D centre operated for the United States Department of Energy.<br>*National Renewable Energy Laboratory (NREL)*: a federally funded R&D centre operated for the United States Department of Energy.<br>*University of Tennessee Knoxville (UTK)*: a publicly funded university which is part of the University of Tennessee System.<br>*University of North Carolina Charlotte (UNCC)*: a publicly funded university which is part of the University of North Carolina System.<br>*General Electric Grid Solutions (GE)*: a GE renewable energy business serving customers in approximately 80 countries.<br>*Smart Electric Power Board Alliance (SEPA):* a non-profit organization that envisions a carbon-free energy system by 2050. |
| **Project cost** |
| Project cost: $7.2 million<br>Public/private $ cost: $6.0M public/$1.2M private<br>Government program: Department of Energy |
| **Project location** |
| The primary location for the field evaluation will be in the service territory of Duke Energy, in the city of Anderson, SC. |
| **Project website** |
| https://gmlc.doe.gov/projects/1.5.03 |

## Context

This project addresses near-term operational challenges faced by Duke Energy—an American electric power holding company with over 7.7 million customers—which cannot be addressed with current technologies. Specifically, Duke Energy is faced with two operational challenges, with non-complementary solutions. First, an increase in extreme weather events is impacting system reliability and resiliency. Second, an increasing level of non-utility DER, typically in the form of large commercial solar PV, is being deployed. To address the issues of reliability and resiliency, Duke is looking to deploy traditional self-healing systems. However, due to the increasing number of non-utility solar PV facilities, there is an increasing number of situations in which the deployment of self-healing systems must be halted. The core issue is the lack of effective coordination between the centralized self-healing systems and the distributed non-utility solar PV. This project will develop "flexibility" operating concepts to support the deployment of centralized self-healing systems with distributed non-utility solar PV. Additionally, the concepts developed for this project will be applicable to a wide range of utilities because the operational challenges faced by Duke Energy are just one example of a large class of issues which require the coordination of centralized and distributed systems. This project optimizes the use of commercial off-the-shelf (COTS) equipment and open-source software to ensure that the work is made accessible to the largest possible segment of the industry.

## Objectives

The primary objective of this project is to increase the resiliency of distribution systems at utilities around the United States of America by deploying flexible operating strategies. These strategies will be validated by being deployed in the field within the Duke service territory. The increase in resiliency will be achieved by increasing operational flexibility in three ways:

1. First, by operating with active reconfigurable segments, with each segment on a distribution system having the ability to support a level of autonomous operation, coordinated with the utility's Distribution Management System (DMS). This will allow the system to reconfigure itself to support critical end-use load during extreme events.
2. Second, through the coordinated engagement of utility and non-utility DERs as assets rather than barriers, to be engaged as active elements to support the segment-based operation of the system. These DER assets will be engaged through a transactive-based incentive signal.
3. Third, through the coordination of centralized and decentralized assets: DERs will be able to rapidly make local decisions that will support the centralized systems which have access to a wider range of information.

## Project description

This project will accelerate the deployment of resilient and secure distribution concepts through the flexible operation of traditional assets, DERs and microgrids. Centralized DMS functions are being coordinated with decentralized DERs and microgrids using Open Field Message Bus (OpenFMB), a reference architecture for security and interoperability. This represents a change in the operational paradigm from treating DERs and microgrids as boundary conditions to active system assets with distributed controls, enabling system flexibility to address all hazards. Interoperability will also be supported by using open standards. Interoperability and scaleability will be achieved using OpenFMB, through the development of an OpenFMB harness as shown in Figure 18.

OpenFMB is an industry-developed framework and reference architecture which enables the coordination of grid edge devices through interoperability and distributed controls. The framework reduces the need for centralized intelligence or control and allows the management of distribution systems at the circuit level. OpenFMB adapters enable communication between such varied protocols as: distributed network protocol 3 (DNP-3), Modbus, American National Standards Institute (ANSI) C12, Message Queuing Telemetry Transport (MQTT), Data Distributed Service (DDS), IEC 61850 Generic Object Oriented Substation Event (GOOSE) messages, Advanced Message Queuing Protocol (AMQP) and NATS. The OpenFMB adapters have been developed, tested and placed in the open source.

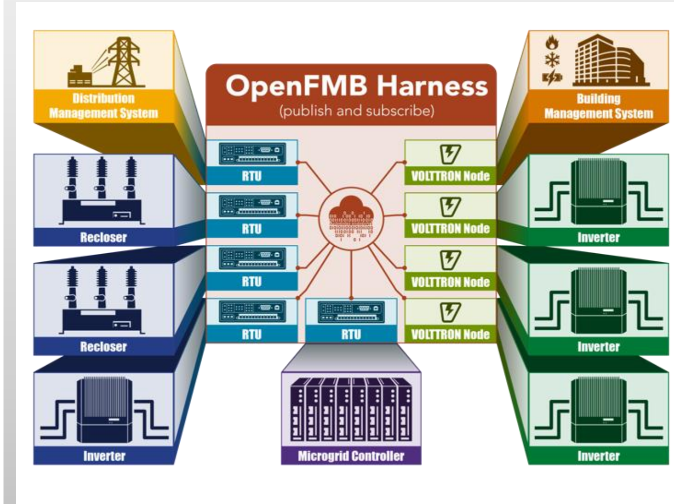


Figure 18: Structural view of the OpenFMB Harness being deployed on the system shown in Figure 19

The concepts developed in this project to accelerate the deployment of resilient systems will be validated with an operational field test on four operational distribution circuits of Duke Energy. The four circuits are part of a centralized self-healing scheme that can control four circuit breakers and twelve reclosers; overhead switches are also present but require manual operation by line crews. In addition to the switching devices, there is an inverter-based utility microgrid and non-utility rooftop solar at two locations. The utility microgrid is designed to supply a local civic centre during major storm disruptions, while the non-utility rooftop solar is designed to support their commercial owners. The civic centre is considered a critical load because it acts as an emergency staging area for the region during extreme events. A reduced order one-line diagram of the electric distribution system is shown in Figure 19.

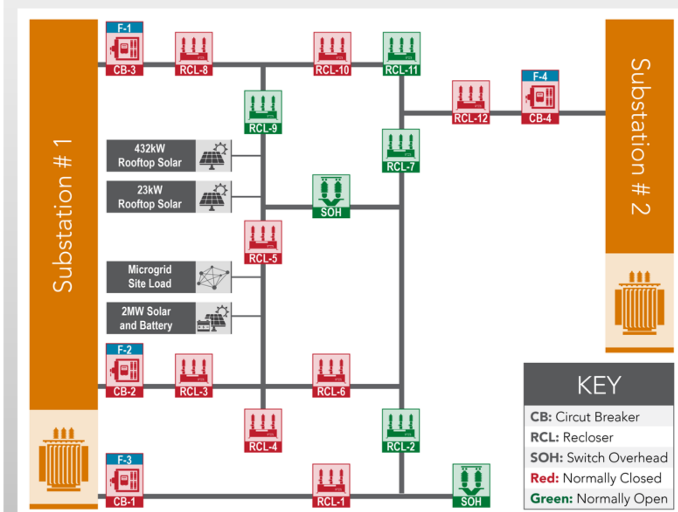


Figure 19: Reduced order one-line diagram of Duke Energy circuits

Additional project work will examine the use of transactive-based incentive signals to coordinate the operation of non-utility assets, but those functions will not be tested in the field validation. Due to regulatory considerations, they will be tested in simulation and in hardware in the laboratory only.

## Project outcomes

The final goal of the project will be to deploy a "segment" based self-healing distribution system that actively engages DERs through a transactive control system. The segment-based self-healing system will be designed to operate four distribution circuits as a collection of individual segments that have the ability to operate as a connected unit in a wide range of topologies. During a resiliency event, the system will have the ability to reconfigure itself based on local control and centralized controls to increase "optimality." To increase the flexibly of the system, the deployed DERs will be connected to a transactive control signal which will incentivize the DERs to operate in a manner that increases the amount of available reconfiguration options. Specifically, a tailored incentive signal will be sent to each DER to incentivize it to adjust its active and/or reactive power output to change power flows and voltage so that additional switching operations are available for the system to respond to the resiliency event. In addition to engaging the DERs as active elements in the segmented based operations, loads could be leveraged as a resource. While this project will not integrate end-use loads as part of the field demonstration, an "adapter" will be made so that VOLTTRON enabled nodes can connect to the decentralized OpenFMB harness. This enables this project, and allows sibling GMLC projects to leverage one another. The project will also provide the foundational research necessary to enable an individual segment to seamlessly transition as a microgrid if there are no other sources available.

The developed flexibility methodology will be applicable to a wide range of technology combinations, but the field demonstration will focus on a specific example of fault location, isolation, and service restoration (FLISR), solar PV and microgrids. The developed capabilities will be applicable to technologies deployed across all of Duke's service territory, in six states, as well as utilities across the nation. Specifically, the generalized framework for coordinating the operation of centralized and decentralized systems, enabled by OpenFMB, will be applicable to the various combinations of technologies deployed across the nation.

## Lessons learned

While the project is still in progress, there have been several lessons learned. These include, but are not limited to, the following.

This project contains work that ranges from the development of foundational architecture and control concepts, to the development of an operational system. This requires detailed simulations in software, control testing with hardware-in-the-loop, system level emulation and interoperability testing with subsystems. In order to maximize the benefit of these parallel activities, it is necessary to coordinate the source models, data and output results. This ensures that the information obtained from one activity directly supports the other activities, and that there are no "orphaned" activities.

To maximize the impact of the project work, COTS hardware and open-source software should be used to the greatest extent possible. This helps to support the interoperability of systems with mixed vendors and ensures the largest number of participants can benefit from developed work.

When developing flexible operating strategies that can be effectively operated by a utility, it is necessary to use an open standards-based approach. This ensures interoperability across a wide range of vendor products and supportability of the deployed equipment over its entire life. An open standards-based approach prevents the abandonment of assets after the initial demonstration phase.

When developing operational concepts that are focused on increasing operational flexibility, it is essential to obtain multiple stakeholder perspectives. This ensures the work is not directed towards a solution that is overly optimized for a single scenario, at the expense of others. This project has established an industry advisory board comprised of multiple utilities to ensure a broader perspective, and to increase broader applicability to the industry.

## Next steps

This project represents one effort in a larger industry trend towards the integration of distributed and edge assets. In addition to the numerous industry-led efforts, this project has resulted in a direct follow-on project as part of the DOE GMLC. The project, which is named Citadels, leverages the architectures, controls and OpenFMB harness of this project and applies them to the operation of networked microgrids.

# EUROPEAN UNION

## European grid modernization — framework and overview

The European Union is one of the few regions in the world in which energy grids span across borders, and the only region that has a dedicated legal cross-border regime for the efficient organization of energy flows on its grid. This regime concerns the question of "hardware," i.e. efficient network planning and development.

The Regulation (714/2009) on conditions for access to cross–border exchanges in electricity establishes a methodology for the development of a ten-year network development plan (TYNDP) for Europe. Every two years, the European Network of Transmission System Operators (ENTSO-E) incorporates the infrastructure needs described in the TYNDP and undertakes an assessment of relevant pan-European infrastructure projects.

The Trans-European Networks — Energy (TEN-E) Regulation (347/2013) establishes a biennial procedure for developing European Projects of Common Interest (PCI) in energy infrastructure, both in electricity and gas. Energy infrastructure was historically developed with a national focus, which was often suboptimal from a European perspective. Market integration requires the development of an adapted infrastructure. The PCI model has been a pioneer in fostering cross-border and regional cooperation.

There are four regional groups established for electricity and gas respectively, which focus on the varying regional needs and ambitions across Europe. The established high-level groups set the political priorities for the various regional cooperation efforts, which include the reinforcement of electricity transmission grids, the digitalization and smartening of the grids, and the deployment of new infrastructure solutions, particularly in the electricity storage area. In addition, the TEN-E Regulation established the thematic areas for smart grids and carbon dioxide transport PCIs, in order to move the development forward and achieve a more sustainable energy system.

The efficient use of energy grids is also about "software," i.e. the rules that guarantee that networks are optimally used, such as rules to guarantee fair competition in the network monopoly. What is unique in the EU context is that national grids are not only physically interconnected but regulated by a common set of EU-wide rules on grid operation and trade (e.g. tariff, third party access and unbundling rules). This creates true cross-border electricity and gas markets, in which electricity can be exchanged not only within one country, but across the borders of the 27 member states and some neighbouring countries. The EU is also the only region which has created a multilateral market coupling system (EU-wide), which combines bids and offers from the whole EU and sends electricity where it is most needed.

The experience from the EU shows that sharing resources by connecting networks across borders not only substantially increases consumer welfare and security of supply, but also allows a much more effective integration of renewable energy sources by aggregating the more volatile production from renewable generation over larger areas. This aggregation can mitigate production peaks and lows and significantly reduces the need for national backup generation, thereby saving significant amounts of $CO_2$.

In addition to PCIs in the electricity sector contributing to the digitalization and smartening of the grids, Smart grid PCIs will contribute significantly to the integration and involvement of network users with new technical requirements regarding their electricity supply and demand. Smart grid PCIs will benefit from political support through the PCI label as well as the possibility for financial support through funding from the Connecting Europe Facility (CEF). There are strict requirements in the selection process, including TSO-DSO involvement and a cross-border dimension.

The smart grid projects that apply for a PCI label are evaluated and proposed for inclusion in the Union list of PCIs[85] by the Smart Grid Regional Group[86] established under the TEN-E Regulation. The latest PCI list from 2019 includes 6 smart grid projects[87] as shown below.

| 4th Union list - Priority Thematic Area Smart Grids Deployment |
| --- |
| **SINCRO.GRID**[88] (Slovenia, Croatia) - An innovative integration of synergetic, mature technology-based solutions in order to increase the security of operations of the Slovenian and Croatian electricity systems simultaneously |
| **ACON**[89] (Czechia, Slovakia) - The main goal of ACON (Again COnnected Networks) is to foster the integration of the Czech and Slovak electricity markets. |
| **Smart Border Initiative**[90] (France, Germany) - The Smart Border Initiative will connect policies designed by France and Germany in order to support their cities and territories in their energy transition strategies and European market integration. |
| **Danube InGrid**[91] (Hungary, Slovakia) - The project enhances the cross-border coordination of electricity network management, with a focus on smartening data collection and exchange. |
| **Data Bridge** (Estonia, Latvia, Lithuania, Denmark, Finland, France) - Aims to build a common European Data bridge Platform, to enable the integration of different data types (smart metering data, network operational data, market data), with a view to develop scalable and replicable solutions for the EU. |
| **Cross-border flexibility project** (Estonia, Finland) – This project aims to support RES integration and increase security of supply through the cross-border provision of flexibility services to Estonia, Finland and Åland provided by distributed generation. |

Among other things, PCIs benefit from improved regulatory conditions and are eligible to apply for financial support from the CEF.[92] So far, three smart grid PCIs have been selected to receive financial assistance following the 2016 and 2018 calls, for a total of €135 million.[93]

Integrating more renewable energy in the electricity system requires increased flexibility. New challenges include such issues as inertia, ramping, curtailment of production and keeping a stable frequency at all times, all with the potential to affect security of supply.

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85 Key cross-border energy infrastructure projects — PCI lists https://ec.europa.eu/energy/topics/infrastructure/projects-common-interest/key-cross-border-infrastructure-projects_en?redir=1#the-pci-lists

86 Smart Grid Regional Group: https://ec.europa.eu/energy/topics/infrastructure/projects-common-interest/regional-groups-and-their-role/smart-grid-regional-group_en?redir=1

87 https://ec.europa.eu/energy/sites/ener/files/c_2019_7772_1_annex.pdf;
Brief summaries of the activities covered under these projects were made publicly available during the consultation phase before the establishment of the Union list at:
https://ec.europa.eu/info/sites/info/files/detailed_information_about_smart_grids_candidate_project_for_consultation.pdf

88 https://www.sincrogrid.eu/en

89 https://www.acon-smartgrids.eu/

90 https://www.sbi-energy.eu/

91 https://danubeingrid.eu/

92 https://ec.europa.eu/inea/en/connecting-europe-facility

93 Smart Grid PCIs that have received CEF funding to date: "SINCRO.GRID", "ACON" and "Smart Border Initiative" under the 2016 and 2018 CEF calls - https://ec.europa.eu/energy/topics/infrastructure/projects-common-interest/funding-for-PCIs_en

The percentage of solar and wind is expected to double in 2030 and reach 29% of total generation, up from around 15% today, with a large amount of this variable renewable generation being connected to distribution grids, a trend which is expected to continue in the future.

According to the EU framework (Electricity Directive [EU] 2019/944), DSOs are responsible for the operation, maintenance, and development of distribution networks. In this context, DSOs in member states are responsible for undertaking investments, including for the modernization of their grids. National regulatory authorities for energy are responsible for overseeing those investments and incentivizing DSOs through a suitable regulatory framework and remuneration scheme in order to increase efficiencies, foster market integration and security of supply, and support the related research activities.

In this framework, member states and DSOs can take advantage of the European funding and financing opportunities described in detail in the next section.

Furthermore, based on the requirements of the Electricity Directive, EU member states have proceeded with the rollout of smart metering systems in order to optimize electricity use and improve network operation. Electricity smart metering was rolled out to approximately 37% of EU households, as of December 2017. Seven member states have completed their rollouts (reached or surpassed installing to 80% of households), i.e. Denmark, Estonia, Finland, Italy (currently installing second generation smart meters), Malta, Spain and Sweden. Ten other member states have committed to a large-scale rollout.

A recent report on the deployment of smart metering in the EU found that:[94]

- Close to 225 million smart meters for electricity and 51 million smart meters for gas will be rolled out in the EU by 2024. This represents a potential investment of €47 billion.
- By 2024, it is expected that almost 77% of European consumers will have a smart meter for electricity and about 44% will have one for gas.
- The cost of installing a smart meter in the EU is on average between €180 and €200.
- On average, smart meters provide savings of €230 for gas and €270 for electricity per metering point (distributed among consumers, suppliers, distribution system operators, etc.) as well as energy savings between 2% and 10% based on data from pilot projects.

The clean energy transition provides considerable business opportunities and is a major contributor to economic growth. More flexibility, storage facilities and smart solutions help grid operators manage the grids more efficiently and have the potential to generate new sources of income, for instance for consumers by selling flexibility through smart appliances or electric vehicle batteries, or by becoming "prosumers" (where the end user also contributes to the grid through generation).

The Clean Energy for All Europeans Package (which includes the recast Electricity Directive) sets the right framework for rolling out interoperable, fit-for-purpose smart metering systems, and gives every consumer the right to request a smart meter and to participate in demand response programs. Moreover, it provides a comprehensive framework for demand response and for the availability of dynamic price contracts in the market. Currently in Europe, 21 GW of demand response is available for activation, from

[94] Study "Benchmarking smart metering deployment in the EU-28"; https://op.europa.eu/en/publication-detail/-/publication/b397ef73-698f-11ea-b735-01aa75ed71a1/language-en; and "Supporting Country Fiches"; https://op.europa.eu/en/publication-detail/-/publication/09ca8b61-698f-11ea-b735-01aa75ed71a1/language-en

a theoretical potential of over 100 GW. It is estimated that by 2030 over 50 GW will be available through demand response programs, providing multiple benefits to consumers and the power system.

More investments in innovation and smart grids may reduce the pressure on the cost of electricity for households due to various support schemes for renewables and reduce the need for investments in regular grid capacity.

In December 2019, the European Commission put forward the European Green Deal, a roadmap for making the EU's economy sustainable by turning climate and environmental challenges into opportunities across all policy areas and making the transition just and inclusive for all. The Communication on the European Green Deal recognizes the enabling role of energy infrastructure, namely:

> "The transition to climate neutrality also requires smart infrastructure. Increased cross-border and regional cooperation will help achieve the benefits of the clean energy transition at affordable prices. The regulatory framework for energy infrastructure, including the TEN-E Regulation, will need to be reviewed to ensure consistency with the climate neutrality objective. This framework should foster the deployment of innovative technologies and infrastructure, such as smart grids, hydrogen networks or carbon capture, storage and utilization, energy storage, also enabling sector integration. Some existing infrastructure and assets will require upgrading to remain fit for purpose and climate resilient."

These provisions will guide European grid modernization initiatives as well as energy system innovation in the coming years.

Some countries choose nuclear as a low-carbon energy source to meet their climate targets. In this context, the European Commission will continue to contribute to strengthening nuclear safety.

The Nuclear Decommissioning Assistance Programme (NDAP) budget also invested in measures aimed at reinforcing the energy sector in Bulgaria, Slovakia and Lithuania after the early shutdown of eight nuclear reactors. A substantial share of these investments was earmarked for upgrades to power transmission lines and cross-border integration (e.g. LIT-POL connection).

## Modernization initiatives

The main European program supporting research as well as innovation in smart grids and energy systems is the Horizon 2020 Programme (H2020). H2020 is the biggest EU R&I program to date, with nearly €80B of funding available over seven years (2014 to 2020) in a number of thematic areas. Its successor, the new Horizon Europe Programme, will run from 2021 to 2027.

Under Horizon 2020, nearly €6B has been allocated to R&I in the area of energy, with approximately €700M allocated to projects on smart grids, storage and energy systems between 2014 and 2020 (WP2014-2015: €239M, WP2016-2017: €166M, WP2018-2019: €174M).

The priorities funded under these calls focus on the following areas.

Distribution:

- Distribution grid and retail market
- Demonstration of smart grid, storage and system integration technologies with an increasing share of renewables: distribution system
- Flexibility and retail market options for the distribution grid

Transmission:

- Innovation and technologies for the deployment of meshed offshore grids
- Transmission grid and wholesale market
- Demonstration of system integration with smart transmission grid and storage technologies with an increasing share of renewables
- Solutions for increased regional cross-border cooperation in the transmission grid

Storage:

- Local/small-scale storage
- Large-scale energy storage
- Next generation technologies for energy storage

RES heating and cooling:

- Development of next-generation technologies in renewable electricity and heating/cooling

Cross-cutting:

- Research on advanced tools and technological development
- TSO–DSO–Consumer: large-scale demonstrations of innovative grid services through demand response, storage and small-scale RES generation
- Pan-European Forum for R&I on Smart Grids, Flexibility and Local Energy Networks
- Customer engagement in demand response

Geographical and energy islands:

- Integrated local energy systems (energy islands)
- Decarbonizing the energy systems of geographical islands
- European Islands Facility—unlock financing for energy transitions and supporting islands to develop investment concepts

As a complement to H2020, there are a number of other European programs providing funds to R&I relevant to smart grids and energy systems:

- The ERA-Net Smart Energy System (SES): a transnational research, development and innovation (RDI) program funded by several European member states, regions and the European Commission. The ERA-NET SES is the result of the merge of two ERA-NETs: ERA-Net Smart Grids Plus (SG+) and ERA-Net Regional and local energy systems and networks (RegSys). Since 2015, ERA-Net SG+ has provided a total of over €53 million in funding to 34 transnational projects. The 2018 REGSYS call is expected to provide an additional €33 million in funding.

- The Connecting Europe Facility (CEF) Energy program: the main EU funding program aiming to upgrade the EU's energy infrastructure to match future demand for energy, to ensure security of supply and to support the large-scale deployment of energy from renewable sources. A total budget of around €5 billion was available for 2014–2020, mostly in the form of grants. During the implementation of the program, 139 actions contributing to the implementation of PCIs were funded. A total of more than €2 billion of CEF Energy funds have been allocated to projects in the electricity and smart grids sectors.

- Other EU programs: the European Structural and Investment Fund (ESIF) provides funding at a national or regional level, one of its focus areas being R&I. The Programme for Environment and Climate Action, known as the LIFE program, provides funding for implementing and testing solutions with a positive impact on the environment and climate. The European Fund for Strategic Investments (EFSI) helps to overcome the current investment gap in the EU. It is also one of the three pillars of the Investment Plan for Europe that aims to revive investment in strategic projects throughout the continent to ensure that money reaches the real economy.

## Future directions

The Clean Energy for All Europeans package provides the legal framework for the grid operation in a system with more decentralized renewable energy production, demand response and electricity balancing. The Clean Energy Package puts a lot of emphasis on enabling investments in grids, in particular in smart solutions for grids, as well as on innovative network management by TSOs and DSOs and on digitalization. Establishing markets and platforms to procure flexibility services is also part of the picture.

Since flexibility is key to connect renewables to the grid and avoid curtailments, markets need to reward it at all levels and in different forms. For example, if a network operator can take advantage of the flexibility of local producers or consumers (households with PV panels, electric cars, smart heating systems, etc.), it is better than curtailing production. Network operators should still invest in expanding the grid capacity if the congestion is structural. However, rewarding flexibility can reduce the need for investments to the benefit of grid users.

In this context, the new market design rules provide a framework for network operators to procure flexibility services, and whenever it is most cost-beneficial to use flexibility solutions rather than investing in the grid.

A related pathway towards the decarbonization of the grid is the creation of new connections between energy carriers, such electricity and gas. This can help avoid curtailment by evacuating some of the excess renewable electricity via power-to-gas facilities, into the gas grid in the form of hydrogen, where it can be used or stored (hydrogen also offers one of the few options for the long-term storage of carbon-free energy). The advanced integration of the energy system across carriers can also contribute to decarbonizing additional demand sectors, in a cost-efficient way and partly thanks to the use of the existing gas network, with some adaptations. One of the challenges facing this promising development is a change of paradigm in infrastructure planning, from the sector-based planning of parallel networks to cross-sector holistic planning with increasing interconnections between networks.

The EU is pursuing the goal of making Europe the first climate-neutral continent by 2050. By 2030, more than half of the EU's electricity should come from renewables and the EU Green Deal ambitions aim to transform and fully decarbonize the EU energy system. The EU Green Deal provides a clear roadmap with actions aiming at making the EU's economy sustainable by transforming environmental challenges into opportunities across all sectors, including energy infrastructures. The Green Deal gives new impetus to the deployment of innovative technologies and infrastructure, such as smart grids, hydrogen networks, carbon capture, storage and utilization, and energy storage. It also aims to enable sector integration and fully explore its potential to boost the penetration of renewables and help the decarbonization of other sectors.

This is why the European Commission is working on a strategic approach to the transformation of the energy system, linking together sectors, energy vectors and uses and exploiting the synergies enabled by an integrated energy system. This will include increasing the use of renewable power through the electrification of sectors that currently still rely on fossil fuels, such as transportation and heating. Hydrogen produced from renewable electricity will play a key role in replacing fossil fuels and gases in sectors that are hard to decarbonize. The energy sector should also become more circular, based on the "energy efficiency first" principle, for instance through the use of waste heat.

The objective of this initiative is to strengthen the necessary links across different sectors in our energy system, and to use every opportunity to reduce emissions. This integration of our energy system is necessary if we want to achieve a deep but also cost-effective decarbonization of our economies. It will build a more decentralized and digital energy system, in which consumers are empowered to make their energy choices.

The EU will continue to invest in R&I supporting the shift towards a carbon-neutral energy system and contributing to ensuring the overall security, reliability, resilience and quality of energy supply. With regard to the modernization of energy systems, possible areas for research could focus on integration solutions for energy systems and coupling different energy carriers, networks and infrastructure; solutions for a digitalized and cyber-secure energy system; as well as new approaches to empower market players, consumers and communities.

## Case studies

### Case study #17 — Generalized Operational Flexibility (GOFLEX) for Integrating Renewables in the Distribution Grid

| **Electricity system segment** | |
|---|---|
| • Distribution system<br>• Flexibility options<br>• Network management, monitoring and control tools | • Demand response<br>• Storage integration<br>• Ancillary services |
| **Current status** | |
| Ongoing | |
| **Project duration** | |
| 2016–2019 | |
| **Project lead** | |
| IBM IRELAND LIMITED (IRELAND) | |
| **Project partners** | |
| • University of Cyprus (Cyprus)<br>• Archi Ilektrismou Kyprou (Cyprus)<br>• Aalborg Universitet (Denmark)<br>• B.A.U.M. Consult Gmbh (Germany)<br>• Sww Wunsiedel Gmbh (Germany)<br>• Technische Universitaet Dresden (Germany)<br>• Avtomatizacija Doo (Slovenia) | • Etrel Svetovanje In Druge Storitve Doo (Slovenia)<br>• Inea Informatizacija Energetika (Slovenia)<br>• Robotina D.O.O., Podjetje Za Inz Eniring, Marketing, Trgovino In Proizvodnjo (Slovenia)<br>• Haute école spécialisée de Suisse occidentale (Switzerland)<br>• L'energie De Sion-Region Sa, Esr (Switzerland) |
| **Project cost** | |
| Project cost: €11.2M<br>Public/private € ratio: €6.8M public/€4.4M private<br>Government program: Horizon 2020 Call, LCE-02-2016 (Demonstration of smart grid, storage and system integration technologies with increasing share of renewables: distribution system) | |
| **Project location** | |
| Physical demonstration sites:<br>• University of Cyprus campus and dispersed prosumers within Cyprus (Nicosia, Cyprus)<br>• German flexibility demo (Wunsiedel, Germany)<br>• Swiss flexibility demo (Sion, Switzerland) | |
| **Project website** | |
| http://www.goflex-project.eu/ | |

## Context

GOFLEX focuses on the active use of distributed sources of flexibility to provide services for grid operators, balance electricity demand and supply, and optimize energy consumption and production at the local level. Sources of load flexibility include thermal (heating/cooling) and electric storage (electric vehicles charging/discharging). A backbone data services platform offers localized estimations and short-term predictions to support data-driven decisions for stakeholders. Demonstration sites for GOFLEX are in Cyprus, Switzerland and Germany, and cover a diverse range of structural and operational distribution grid conditions.

## Objectives

- Focus on the active use of distributed sources of flexibility to provide services for grid operators, balance electricity demand and supply, and optimize energy consumption and production at the local level.
- Support data-driven decisions for stakeholders thanks to a backbone data services platform offering localized estimations and short-term predictions.
- Test solutions at three European demonstration sites in Germany, Switzerland and Cyprus involving over 400 prosumers from industry, buildings and transportation.

## Project description

GOFLEX involves the creation of a system where energy flexibility is offered to a market and used to balance electricity supply and demand at a local level. The project aims to enable DSOs, balancing responsible parties or other players, to bid for flexibility offered by prosumers. In addition, the project intends to foster energy trading for a variety of "flexible" prosumer types (industrial, tertiary and residential). GOFLEX is developing a cloud platform to integrate data from sources that traditionally were considered in isolation such as network telemetry data and customer profiles. These innovations have the potential to spur new businesses to enter the market.

The project delivers demonstrations of flexibility trading at three European sites and their results will be publicly available.

## Project outcomes

The project builds upon existing technology (TRL5-7) from several areas:

- Demand-response schemas and infrastructure
- Energy storage systems
- Energy management systems
- Electrification of transportation
- Distribution grid monitoring and management
- Energy data management infrastructures

An expected outcome of the project is an increase in technology readiness in these areas to level seven or eight.

The project takes a phased approach over its three-year implementation period. An initial requirements analysis by month 6 led to the completion of the first prototypes. The second year prototypes were integrated and tested under simulated and real-world conditions. In the third year, fully integrated systems will be demonstrated and evaluated.

## Lessons learned

*Replicability:* By adopting the harmonized market model and deploying each technological solution in at least two cases, replicable solutions are achieved.

*Socio-economics:* GOFLEX delivers technology to enable final consumers to play an active part in the energy market. The final user's consumption and generation patterns thus become better aligned with wholesale energy prices and are therefore more cost-effective.

*Environment:* By delivering technologies that allow the injection of a higher share of renewable energies into the grid and the electrification of transportation, GOFLEX supports the reduction of GHG emissions.

*Market Transformation:* The services and solutions targeted by GOFLEX are designed for distribution system operators (real-time trading of load flexibility and improved observability of energy demand, generation and flexibility at a localized level), aggregators (load flexibility to compose the desired portfolio of grid-service offerings), and the empowerment of prosumers in the energy market.

*Policy:* Demonstration activities can feed into policy recommendations. GOFLEX aims to provide evidence that flexibility solutions based on demand response are able to compete with other means to extend the capacity of grids, avoid grid congestion and balance supply and demand.

## Case study #18 — FLEXITRANSTORE, An Integrated Platform for Increased FLEXIbility in Smart TRANSmission grids with STORage Entities and Large Penetration of Renewable Energy Sources

| **Electricity system segment** | |
|---|---|
| Transmission system, flexibility options, demand response, storage integration, network management, monitoring and control tools, electricity market, ancillary services | |
| **Current status** | |
| Ongoing | |
| **Project duration** | |
| 2017–2021 | |
| **Project lead** | |
| European Dynamics Belgium S.A. (Belgium) | |
| **Project partners** | |
| • Operatori Sistemit Transmetimit OST (Albania)<br>• EMAX (Belgium)<br>• CEZ Distribution Bulgaria AD (Bulgaria)<br>• Elektroenergien Sistemen Operator EAD (Bulgaria)<br>• Independent Bulgarian Energy Exchange EAD (Bulgaria)<br>• Software Company Ltd. (Bulgaria)<br>• Technical University of Sofia (Bulgaria)<br>• Studio elektronike Rijeka d.o.o. (Croatia)<br>• Cyprus Energy Regulator Authority (Cyprus)<br>• Electricity Authority of Cyprus (Cyprus)<br>• Transmission System Operator — Cyprus (Cyprus)<br>• University of Cyprus (Cyprus)<br>• GE Energy Products France SNC (France)<br>• Independent Power transmission Operator (Greece) | • Institute of Communication and Computer Systems/National Technical University of Athens (Greece)<br>• Budapest University of Technology and Economics (Hungary)<br>• VPP Energy Zrt (Hungary)<br>• Smart Wires Europe (Ireland)<br>• Centro de Investigação em Energia REN - State Grid, S. A. (R&D NESTER) (Portugal)<br>• C&G d.o.o. Ljubljana (Slovenia)<br>• Elektro Ljubljana, d.d. (Slovenia)<br>• JEMA Energy S.A. (Spain)<br>• Loyola University Andalusia (Spain)<br>• Schneider Electric España SA (Spain)<br>• WING Computer Group SRL Abengoa Innovación S.A. (Spain) |
| **Project cost** | |
| Project cost: €21.7M \| Public/private € ratio: €17M public/€4.7M public<br>Government program: Horizon 2020 call, LCE-04-2017 (Demonstration of system integration with smart transmission grid and storage technologies with increasing share of renewables) | |
| **Project location** | |
| Physical demonstration site: active substation controller with storage integration at the TSO/DSO interface (Athienou, Cyprus) | |
| **Project website** | |
| www.flexitranstore.eu | |

## Context

Renewable energy is gaining a continuously increasing share in the production mix throughout the world. System decarbonization, long-term energy security and the expansion of energy access in developing countries, due to the distributed nature of renewable sources, are only a few of the benefits it introduces. However, further integration of renewables remains a challenge. Barriers include their intermittent and unpredictable production, the need for large-scale storage integration, and the energy market's undervaluing of their services.

The FLEXITRANSTORE project identifies flexibility integration in the European power system as the main solution to overcome the aforementioned barriers and achieve higher renewable energy source (RES) penetration. At a technical level, novel smart grid technologies, control and storage methods will be introduced into the existing power system. At a market level, new business plans, players and market rules will facilitate the valorization of flexibility services offered by renewables and enable increased cross-border flows.

## Objectives

- To assist the evolution towards a pan-European transmission network with high flexibility and interconnection levels
- To demonstrate flexible resource applications that mitigate the effects of RES network variability.

## Project description

The FLEXITRANSTORE project will assist the evolution towards a pan-European transmission network with high flexibility and interconnection levels. The flexible energy grid proposed includes the adaptation and integration of technologies to ensure that their management demonstrates flexible resource applications that mitigate the effects of RES variability on the network. The project supports the advancement of the internal European market, focusing on technologies that facilitate the networking of cross-border players and further enable energy trading. Within this context, the strategic objectives of the project have been defined as follows:

- To enhance and accelerate the integration of renewables into the European energy systems.
- To increase cross-border electricity flows across Europe.

A range of state-of-the-art ICT technologies and control improvements are used to enhance the flexibility of the energy grid by integrating storage and demand response management.

## Project outcomes

- RES storage integration: mitigate RES volatility, aiming for a “near dispatchable” nature.
- Devices for congestion relief: relieve congestion and exploit remaining grid capacity.
- Market platform: demonstrate a market platform that remunerates flexibility services through the wholesale market.
- Flexible and stable conventional generation: solutions tailored for gas turbine plants to improve stability from low frequency oscillations and provide several services, including frequency response and black start capacity.

- Demand side flexibility at the TSO-DSO border: controllers and battery storage located at the TSO-DSO border.

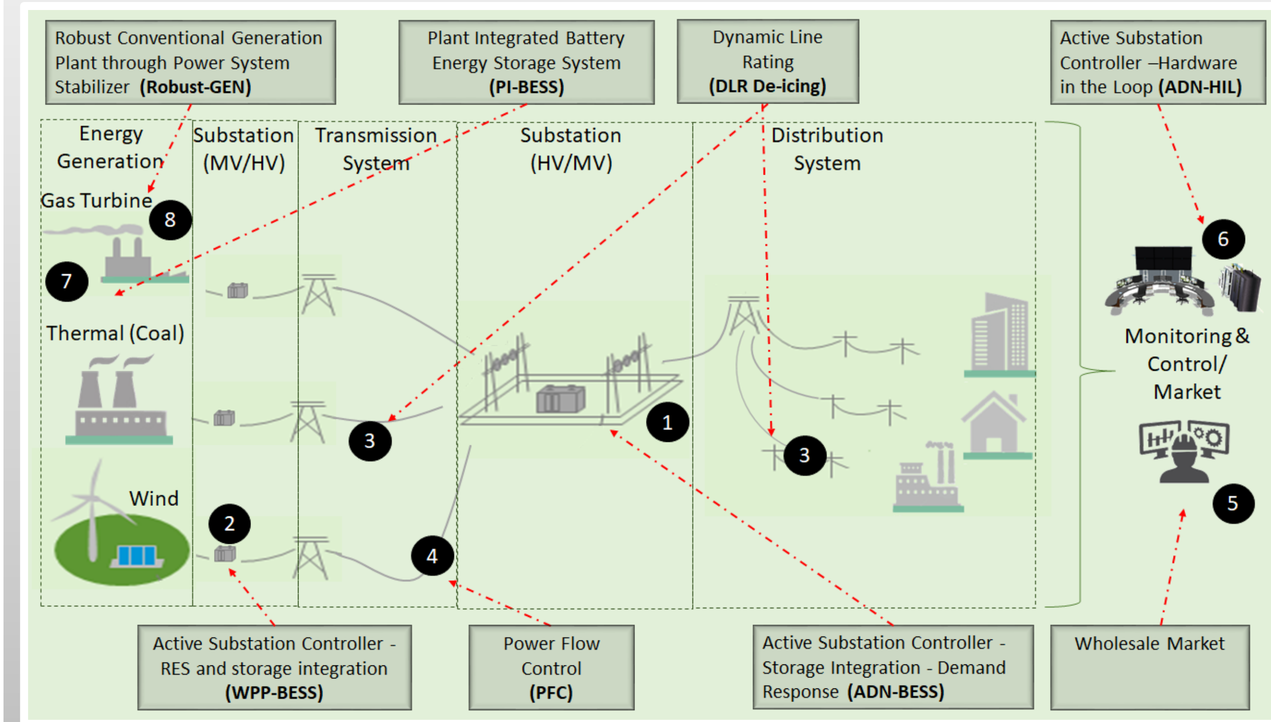


**Figure 20: FLEXITRANSTORE network diagram**

## Lessons learned

*Replicability:* Work is underway to develop a liberalized energy market in Cyprus. FLEXITRANSTORE can feed into this project. Once the approach succeeds in the Cypriot system, it can be seen as a starting point for scaling on a regional and eventually pan-European level to develop a single European internal energy market.

*Socio-economics:* The new market approach will include consumer participation in the market. The novel technologies will facilitate the improved utilization of the available energy, thus reducing operational and capacity costs. The project will ensure that the EU electricity network operates within a wholesale market, providing consumers with competitive prices and integrating renewable sources.

*Environment:* By enabling higher RES penetration, FLEXITRANSTORE will contribute to the reduction of $CO_2$ and other greenhouse gases emissions.

*Market transformation:* FLEXITRANSTORE is in line with the ETIP SNET 10 Year R&I Roadmap and the ENTSO-E R&I Roadmap 2017–2026 and will be relevant to both new and existing market participants.

*Policy:* FLEXITRANSTORE will provide policy recommendations to TSOs, DSOs, market regulators, power plant owners and other players of the energy value chain.

# 3. CHALLENGES AND OPPORTUNITIES

This section aims to discuss the main opportunities and challenges related to the modernization of a power system. These findings have been synthesized from the conclusions and lessons learned presented in the previous section.

## EVOLVING TECHNOLOGY

Upgrades to physical grid infrastructure are among the most obvious challenges and opportunities facing power system modernization. Most of the power system infrastructure for all reporting G7 members was installed many decades ago and designed for unidirectional power systems. This architecture poses two challenges: (1) the physical infrastructure itself is decades-old and in need of refurbishing, and (2) its original design no longer serves the needs of modern power systems (e.g. new loads, or bidirectional power flow to effectively integrate increasing amounts of DER). Therefore, it would be prudent in the long term to not limit infrastructure upgrades to merely refurbishing existing technology, but to also make additions at the system design level that would help facilitate countries' transitions to the power systems of tomorrow. Innovative applications of DERs, also known as "non-wires alternatives," and the flexibility they offer can help defer costly infrastructure upgrades to the grid and improve existing asset utilization.

To maximize the integration of DERs, additional control and coordination mechanisms such as VPPs will be needed. Microgrids can also be used to improve resiliency. Both the VPPs and microgrids require visibility and control of connected resources to effectively manage the power between DERs and non-flexible loads. Resources like smart inverter-connected solar panels, energy storage, EVs and flexible loads can support this and provide grid services. Technology can be used to tap into the potential of existing resources on the grid and create tools to maximize their potential in a cost-effective manner.

The electrification of various sectors also presents several challenges and opportunities for the power grid. For example, transport electrification can create huge demand draws if multiple EVs are charging simultaneously. Without proper control capabilities, this can strain grid assets and overload the system without warning. Tools should be considered to properly integrate EVs and optimize the potential they offer. Concepts pertaining to vehicle-to-building (V2B) and V2G are being explored to complement the business operations of the respective building, grid or any other entity to which EVs are being integrated (V2X). Trials of V2G technologies and business models are demonstrating how traditionally separate energy sectors (power and transport) can be linked to maximize the economic use of the assets and support aims like emissions reduction. Beyond EVs and the transportation sector, the electrification of other sectors also serves as an opportunity for a smart grid. In terms of Power to X, hydrogen is expected to grow significantly in use as a next-generation load-following capacity, with long-term energy storage potential to enable seasonal shifting of supply to meet demand.

Standardizing ICT allows for an easier integration of additional energy resources and their communication with other smart grids as networks continue to expand. As elements within the grid interoperate with one another, standardizing these devices and sharing interfaces between them will streamline integration. Likewise, an important challenge is to ensure information technology services are sufficiently advanced to maintain these vast interconnected networks. Concurrently, there is a need to continue to ensure the physical and cyber security of the grid as it becomes more dependent on DER and digital technologies, recognizing the central importance of reliable power systems for sustaining economic growth and national security.

## CUSTOMER BEHAVIOUR

Customers are driving the adoption of low-cost, commercial power system modernization solutions. In particular, customers are playing a more active role in the electricity grid, and utilities are responding by developing customer-centric service models. Prosumers are investing in various DERs (e.g. rooftop solar, electric vehicles) to offset high energy costs and play a role in adopting low-GHG emission solutions. Utilities can leverage prosumer investment in DERs with a potential for flexibility by creating customer tools and providing customer incentives to leverage these behind-the-meter resources. Deploying these customer tools is an essential step to facilitating prosumer behaviours and power system modernization.

For example, in Canada and the U.S., the Green Button data standard facilitates this type of interaction enabling customers to choose various software solutions that easily and securely access their energy data in a user-friendly format. Additionally, ensuring a seamless customer experience increases customer engagement in new energy efficiency programs. Further demonstrations of the Green Button standard in Europe and Korea show how it can be deployed internationally. This allows for tools to be designed and shared to create added value for all customers with access to universally structured data across utility boundaries. Energy solutions that are utility-enabled, easily accessible and user-friendly benefit the customer and the environment, and provide new opportunities for increasing the reliability of the grid for the future. It is also important that utilities gain a better understanding of various types of utility-driven demand side response services (e.g. through projects like UK DESIRE). A greater understanding of the types of services and requirements customers expect from their products will result in design and capability changes to smart assets like hot water tanks and batteries.

As flexibility will be a crucial element of the design of successful future power systems, policymakers should consider how it could be rewarded at various levels. Ideally, network operators would be able to take advantage of the flexibility of local producers or consumers (households with PV panels, electric cars, smart heating systems, etc.) and allow them to become an active part of the energy grid. This better aligns the consumption and generation patterns of the final user with wholesale energy prices, improving efficiencies and therefore costs. For example, the UK's Piclo-Flex project uses online marketplaces to provide DNOs with access to location-specific flexible resources, boosting grid flexibility and decentralization. It is important that DNOs are agile and flexible as they will play a critical role in actively balancing local smart grids and facilitating the rollout of distributed generation, storage and smart devices. At the same time, for such trading systems to succeed, numerous and diverse demand management suppliers are necessary (batteries, load switching services, aggregators), all of which will have different requirements of the platform. Likewise, policy and regulatory updates may be needed to reduce barriers, ensure open, transparent markets, and enable a cost-effective deployment.

Smart and advanced metering infrastructure can enable additional ways for utilities to engage with customers for better consumption management. For example, smart meters can be a key enabling technology to deploy demand management tactics like ToU or other dynamic rate structures. Net metering also serves as a way for customers to leverage smart meter deployment to become prosumers by consuming and generating their own power. This evolving customer-utility relationship will require further tools, supported by well-designed policy-regulatory frameworks and market designs, to tap into mutually beneficial scenarios.

Transactive peer-to-peer solutions are increasingly being explored as a means of democratizing the energy system. Customers are looking for increasingly interactive and digital solutions that present more service options. To deploy these solutions, various aspects need to be carefully considered, including managing customer profiles, exchanging data to address security concerns and implementing economic frameworks. These types of solutions challenge the current model of monopolistic electric utility company operations by providing customers with more control.

## DATA

Data is necessary to improve our understanding of how energy resources can be better managed. Structured and clean datasets can help to improve or create tools for utilities and customers, helping utilities optimize the use of their assets and modernize their customer relations at the same time. With concepts like big data and data mining being explored across various sectors, the energy sector can also leverage these concepts in grid modernization efforts. Utilities in particular have massive datasets from outage management systems, distribution automation systems, SCADA, asset management and billing systems that can benefit from an integrated platform where various data is used to improve operations, planning and customer relations. Advanced transmission and distribution system infrastructure can collect relevant data for an integrated platform which can include functions like automated demand response event negotiations with customers' flexible loads. This serves as a cost-effective solution for utilities since flexible load investments have already been made by customers.

With the proper communication channels in place to gain access to relevant data, intelligence strategies can be used to optimize system operation and planning. Techniques including model predictive control and AI-based learning can be used to optimize grid operation, planning and maintenance while considering various parameters dependent on the environment, economy, resource health or human factors.

These techniques can also be useful for security measures — cyber and physical alike. Cyber security in particular must address both intentional (e.g. viruses and data theft) and unintentional (e.g. human error and environmental hazards) threats where vulnerabilities are exposed regarding the confidentiality, integrity, availability and accountability of digital information. The increasing interconnectedness being pursued to integrate variable and distributed energy systems creates added vulnerabilities for our energy security, which could be leveraged by malign actors. Collaborating with other sectors on cyber security can be explored to ensure the smart grid is well equipped to be protected from cyber threats. Furthermore, the modernization of regulations regarding the use, sharing and vulnerability of sensitive data must be considered to ensure that the public is protected while enabling the new opportunities that data exchange provides.

Within the power system alone, there remain key integration and interoperability challenges — for example, collecting and managing data in a secure and sustainable way. In all these areas, multilateral sharing of results, knowledge transfer or even collaborative R&I will be important ways to help us find solutions for our future power systems.

## MULTILATERAL COLLABORATIONS

Collaborations and joint work developed in the framework of international initiatives have been fruitful in identifying common issues and potential synergies. This is discussed in greater depth in the first section of this report.

Examples include: the pan-North American approach to efforts aiming to integrate renewable energy, which led to the North American Renewable Integration Study, a three-year study to assess how the three countries can decrease the emission intensity of their electricity supply mix, improve interconnection operations, and apply common datasets and methods across all three countries; as well as the Clean Energy for All Europeans package, which provides the legal framework for a power system with more decentralized renewable energy production, demand response and electricity balancing. The Clean Energy Package puts a lot of emphasis on enabling investments in grids, in particular in smart solutions for grids; innovative network management by TSOs and DSO; and better markets and platforms to procure flexibility services.

# 4. FINAL REMARKS

Under Canada's 2018 G7 presidency, G7 members agreed to concrete actions to advance the modernization of power systems that support economic growth, ensure energy security and improve environmental protection. One critical way they are doing so is by investing in cleaner, more reliable and more affordable energy sources and technologies. Power systems that are efficient, secure, sustainable, resilient, and which afford opportunities to a diverse array of workers and industries are critical to country-driven energy transitions. To modernize the energy systems of tomorrow, it is essential to promote innovations in power system technologies.

This report brought together 18 case studies from across the G7 members representing over USD 1.2B in total project value made up of private and public investment. Some cases represented R&D, and others were later stage demonstrations or deployments illustrating the mix of emerging and mature technologies and business models spanning the spectrum of power system modernization. Cases also spanned the system topography, from transmission to distribution, in front of the meter and behind the meter, with many noting how the distinct operational lines between those infrastructures are becoming blurred. Both challenges and opportunities facing further power system modernization were recognized with respect to evolving technologies, customer behaviour, data-enabled value creation and multilateral collaborations. A summary table of the cases is included in the Annex to this report.

As a final note, this report and the included case studies were written before the onset of the COVID-19 pandemic. While the immediate and medium-term outlook for G7 members will most certainly be affected by the economic recovery required, the challenges and opportunities discussed in Section 3 will likely remain relevant, especially in the medium to long term. Furthermore, continued smart grid project development can play a strategic role in supporting economic recovery.

# GLOSSARY

| Term | Full title |
| --- | --- |
| **A** | Ampere |
| **AC** | alternating current |
| **AI** | artificial intelligence |
| **AMI** | Advanced Metering Infrastructure |
| **ANR** | National Research Agency |
| **API(s)** | application program interface(s) |
| **AREA** | Arctic Renewable Energy Atlas |
| **ARENA** | Arctic Remote Energy Networks Academy Project |
| **ARERA** | Italian Regulatory Authority for Energy, Networks and Environment |
| **B2B** | business-to-business |
| **BC** | British Columbia |
| **BCUC** | British Columbia Utilities Commission |
| **BEIS** | Department for Business, Energy and Industrial Strategy |
| **BEV** | battery electric vehicles |
| **Bundesnetzagentur** | Federal Network Agency |
| **CEF** | Connecting Europe Facility |
| **CEM** | Clean Energy Ministerial |
| **CEV** | Clean Energy Vehicle |
| **CIS** | Customer Information Systems |
| **COP21** | 21$^{st}$ Conference of Parties to the UNFCCC |
| **COTS** | Commercial off-the-shelf |
| **DC** | direct current |
| **DCFCs** | direct current fast chargers |
| **DC-GIL** | direct current gas-insulated line |
| **DER(s)** | Distributed Energy Resource(s) |
| **DERMS** | Distributed Energy Resource Management System |
| **DMS** | distribution management system |
| **DNO(s)** | distribution network operator(s) |
| **DOE** | Department of Energy |
| **DSM** | demand side management |
| **DSO(s)** | distribution system operator(s) |
| **DSR** | demand side response |
| **EEG** | Renewable Energy Sources Act |
| **EERA** | European Energy Research Alliance |
| **ENTSO-E** | European Network of Transmission System Operators |

| | |
|---|---|
| **ESO** | Electricity System Operator |
| **ETIPS** | European Technology and Innovation Platforms |
| **EV(s)** | electric vehicle(s) |
| **FIT(s)** | Feed-in-Tariff(s) |
| **FLISR** | Fault location, isolation, and service restoration |
| **GHG** | greenhouse gas |
| **GIL** | gas-insulated line |
| **GMI** | Grid Modernization Initiative |
| **GMLC** | Grid Modernization Lab Consortium |
| **GOFLEX** | Generalized Operational Flexibility |
| **Grid MYPP** | Grid Modernization Multi-Year Program Plan |
| **GW** | Gigawatt |
| **GWh** | Gigawatt hour |
| **H2020** | Horizon 2020 Programme |
| **HEV** | hybrid electric vehicles |
| **HVDC** | High-voltage direct current |
| **IC1** | MI - Innovation Challenge #1 on Smart Grids |
| **IEA** | International Energy Agency |
| **IEC** | International Electrotechnical Commission |
| **IESO** | Independent Electricity System Operator |
| **ILM** | Intelligent Load Management |
| **IoT** | Internet of Things |
| **IRENA** | International Renewable Energy Agency |
| **ISGAN** | International Smart Grid Action Network |
| **kV** | Kilovolt |
| **kWh** | Kilowatt hour |
| **LDC** | local distribution company |
| **MI** | Mission Innovation |
| **ML** | Megalitre |
| **MiSE** | Ministry of Economic Development |
| **Mt** | Megatonne |
| **MV** | medium voltage |
| **MW** | Megawatt |
| **NABEG** | Grid Expansion Acceleration Act |
| **NARIS** | North American Renewable Integration Study |
| **NB Power** | New Brunswick Power Corporation |
| **NECP** | National Energy and Climate Plan |
| **NES** | National Energy Strategy |
| **NRCan** | Natural Resources Canada |
| **NREL** | National Renewable Energy Laboratory |
| **Ofgem** | Office of Gas and Electricity Markets |

| | |
|---|---|
| **OpenFMB** | Open Field Message Bus |
| **PAN** | Puglia Active Network |
| **Pan-Canadian Framework** | Pan-Canadian Framework on Clean Growth and Climate Change |
| **PCI** | European Projects of Common Interest |
| **PHEV** | plug-in hybrid electric vehicles |
| **PIA** | National Innovation Fund |
| **PPE** | Multi-annual Energy Programming |
| **PV** | Photovoltaic |
| **R&D** | research and development |
| **R&I** | research and innovation |
| **RD&D** | research, development, and demonstration |
| **RdS** | Research fund for the Electrical System |
| **RECSI** | Regional Electricity Cooperation and Strategic Infrastructure |
| **RES** | renewable energy sources |
| **RIIO** | Revenue = Incentives + Innovation + Outputs price controls framework |
| **RTE** | Réseau de transport d'électricité |
| **SET Plan** | European Strategic Energy Technology Plan |
| **SETIS** | SET Plan Information System |
| **SINTEG** | Smart Energy Showcases — Digital Agenda for the Energy Transition |
| **SNET** | Smart Networks for Energy Transition |
| **TCP(s)** | Technology Collaboration Programme(s) |
| **TEN-E** | Trans-European Networks—Energy regulation |
| **time-of-use** | ToU |
| **TSO(s)** | transmission system operator(s) |
| **TWh** | Terawatt hour |
| **TYNDP** | Ten-year network development plan |
| **UKRI** | UK Research and Innovation |
| **V2G** | Vehicle-to-Grid |
| **VPP(s)** | Virtual Power Plant(s) |
| **VRE** | variable renewable energy |

# ANNEX 1 — SUMMARY TABLE OF CASES

| Case # | Case study title | Country | Project type | Electricity system segment | Project value (millions USD) | | | Page |
|---|---|---|---|---|---|---|---|---|
| | | | | | Public | Private | Total | |
| 1 | PowerShift Atlantic: The Maritime Provinces Customer Load Control Demonstration for Wind Integration | Canada | Demonstration/ Pilot | Generation to distribution | 11.1 | 12.7 | 23.8 | 19 |
| 2 | British Columbia Electric Vehicle Smart Infrastructure Project | Canada | Deployment | Distribution system | 4.8 | 1.1 | 5.9 | 23 |
| 3 | Empowering the Digital Utility Customer via an Open Data Platform using Smart Meter Data | Canada | Demonstration/ Pilot | Distribution system | N/A | N/A | N/A | 27 |
| 4 | Smart Grid Vendée | France | Demonstration/ Pilot | Distribution system | 10.4 | 19.8 | 30.2 | 35 |
| 5 | Postes intelligents (Smart substations) | France | Demonstration/ Pilot | Transmission system / substations | 10.6 | 24.3 | 34.9 | 38 |
| 6 | "compactLine" space-optimized overhead lines | Germany | Demonstration/ Pilot | Transmission system | 2.0 | 1.4 | 3.4 | 45 |
| 7 | DC gas-insulated lines (DC-GIL) | Germany | R&D and testing | Transmission system | 12.6 | 13.1 | 25.7 | 50 |
| 8 | Smart Energy Showcase: Digital Agenda for the Energy Transition (SINTEG) | Germany | R&D and testing | Transmission, distribution systems and remote microgrids | 217.8 | 326.8 | 544.6 | 55 |
| 9 | Puglia Active Network (PAN) | Italy | Deployment | Distribution system | 92.6 | 92.6 | 185.2 | 62 |
| 10 | Ricerca di Sistema (RdS) (Research fund for the Electrical System) | Italy | R&D and testing | Transmission, distribution systems, microgrids | 228.7 | 0 | 228.7 | 64 |

| Case # | Case study title | Country | Project type | Electricity system segment | Project value (millions USD) | | | Page |
|---|---|---|---|---|---|---|---|---|
| | | | | | Public | Private | Total | |
| 11 | Demonstration project to develop Virtual Power Plant technologies and to design business models | Japan | Demonstration/ Pilot | Distributed energy resources, demand side management | 51.1 | 51.2 | 102.3 | 70 |
| 12 | Piclo-Flex | United Kingdom | Demonstration/ Pilot | Distribution system | 1.2 | 0.3 | 1.5 | 79 |
| 13 | DESIRE (Domestic Energy Storage Integrating Renewable Energy) | United Kingdom | R&D and testing | Distribution system | 2.2 | 0.9 | 3.1 | 81 |
| 14 | The Smart Islands Programme, Isles of Scilly | United Kingdom | Demonstration/ Pilot | Distribution system | 14.7 | 2.7 | 17.4 | 84 |
| 15 | CleanStart DERMS: Distribution System Resilience and Restoration with Distributed Energy Resources | United States | Demonstration / Pilot | Distribution system | 5.0 | 1.2 | 6.2 | 93 |
| 16 | Increasing Distribution System Resiliency using Flexible DER and Microgrid Assets Enabled by OpenFMB | United States | Deployment | Distribution system | 6.0 | 1.2 | 7.2 | 98 |
| 17 | Generalized Operational FLEXibility (GOFLEX) for Integrating Renewables in the Distribution Grid | European Union | Demonstration / Pilot | Transmission, distribution, grid operation | 7.4 | 4.8 | 12.2 | 110 |
| 18 | FLEXITRANSTORE, An Integrated Platform for Increased FLEXIbility in Smart TRANSmission grids with STORage Entities and Large Penetration of Renewable Energy Sources | European Union | Demonstration / Pilot | Transmission, distribution, grid operation | 18.5 | 5.1 | 23.6 | 113 |