CLEAN ENERGY MINISTERIAL

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ISGAN
INTERNATIONAL SMART GRID ACTION NETWORK

## Smart Grid Case Studies

# Microgrid Value Propositions 1.0

## Casebook

Austria, Canada, Germany, Korea, and the United States

ISGAN Communication Working Group (Task 2)

**October 2022**

# About ISGAN Casebooks

ISGAN casebooks are meant as compendium documents to the global trends and discussion about smart grids. Each is factful information by the author(s) regarding a topic of international interest. They reflect works in progress in the development of smart grids in the different regions of the world. Their aim is not to communicate a final outcome or to advise decision-makers, but rather to lay the ground work for further research and analysis.

# Disclaimer

# Acknowledgments

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# Preface

Task 2 (Smart Grid Case Studies) of ISGAN Communication Working Group is one of the fundamental Working Group which initiated its activities at the establishment of ISGAN in 2011. It will ultimately enable all ISGAN Participants and other external stakeholders to have access to in-depth information on the current flow of smart grid pilot and deployment projects from many countries, including lessons learned and best practices identified.

The main objective of Task 2 of Communication Working Group is to assess outstanding examples of current case studies, develop and validate a common case study template and methodological framework, and then develop in-depth case studies using this framework. The template is currently the "casebook" to contain descriptive information.

The common frame work for case studies will allow comparison and contrast of policies and technologies adopted in different regulatory, legislative, network (grid), and natural environments. The overarching aim is to collect sufficient information from the case studies around the world to extract lessons learned and best practices as well as foster future collaboration among participating countries.

Task 2 of Communication Working Group participating coutnries have volunteered to offer information about on-going cases with an aim to share knowledge and strengthen cooperation between different stakeholders in terms of on smart grid project planning, implementation and management. Depending on the progress of the projects, some of the cases may only present outcomes or lessons learned of the projects partially. Therefore, some of the cases are anticipated to be updated on a regular basis as the projects progress to the next steps.

This casebook reflects one way that ISGAN gather experts and stakeholders globally to increase the awareness of a microgrid technology in the field of smart grid. In this stage, the casebook features five (5) cases conducted from four (4) different countries including Austria, Canada, Germany and Korea, primarily from a business model and economics standpoint.

# Abstract to Introduction

According to US DOE, a microgrid is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid[1]. Since they are able to operate while the main grid is down, microgrids can strengthen grid resilience and help mitigate grid disturbances as well as function as a grid resource for faster system response and recovery. They can also locally manage the operation of distributed energy resources, such photovoltaics (PV), wind, electric vehicles, energy-storage, demand response, and thermal energy systems while connected to larger host grid or as an independent power system.

This casebook seeks to understand the technologies, business models, scale, and vendor landscape supporting microgrids that are commercially viable. This casebook features 5 microgrid case studies from Austria, Canada, Denmark, Germany, Korea and the United States. The microgrids profiled range in size from 0.5 MW (Hawaii) to 9.5 MW (Faroe Islands), and serve commercial, municipal, education, agriculture, and utility clients. The majority of projects use solar photovoltaic and energy storage as part of the microgrid generation mix. Diesel generators and fuel cells are also prevalent.

Analysis of the case studies shows that microgrid business models are still diverse and offer numerous value propositions to hosts. Most of the projects in the casebook report value propositions of renewable energy integration, reliability & resiliency, efficiency and bill (cost) and demand charge savings. Business models appear to be moving towards performance contracting (such as Energy Savings Performance Contract) and shared savings models between the host and project developer, in which bill savings and revenue streams from grid services are split according to investment and risk tolerance.

| Category | | | Not Important | Somewhat Important | Very Important | Essential |
|---|---|---|---|---|---|---|
| **Project Level** | Efficiency | | | (G) | (C), (K) | (U) |
| | Reliability & Resiliency | | | (C) | (K) | (G), (U) |
| | Independence & Sustainability (Renewable energy integration) | | | (K) | | (C), (G), (U) |
| | Bill Savings / demand charge abatement | | | (K) | (C), (G) | (U) |
| | Sharing Economy | | (G) | (C), (K) | (U) | |
| | New business models | | | (C), (G) | (K), (U) | |
| | Provision of ancillary services | | (C) | (K) | (U) | (G) |
| **Player Level** | **Producer** | Selling electricity | | (U) | (G), (K) | |
| | **Customer** | Reducing electricity fees | | (G) | (C), (K) | (U) |
| | | Job creation | (G), (K) | | (C), (U) | |
| | | Revenue generation | (G) | (K) | | (U) |
| | **Operator** | Subscription fee | (G), (K), (U) | | | |
| | | Membership fee | (G), (K), (U) | | | |
| | | Selling electricity | | (G), (K) | | (U) |
| | | Government support | (G) | | (K) | (U) |

*** (C) Canada, (G) Germany, (K) Korea, (U) US**

[1] The U.S. Department of Energy's Microgrid Initiative

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## 1.1 AUSTRIA

### Background and Overview

While Microgrids were widely discussed in several countries around the world, they are not that much relevant for Austria's power grid development. Mainly caused by the geographical and grid topological location of Austria.

Austria is situated in the heart of Europe and the strong, well interconnected European transmission system (ENTSO-E [1]). The Transmission System Operators (TSOs) and Distribution System Operators (DSOs) can provide electric energy services with one of the lowest average annual interruption durations in Europe (SAIDI[2] in Austria is around 25 minutes per year (Haber and Urbantschitsch 2021) (Figure1)).

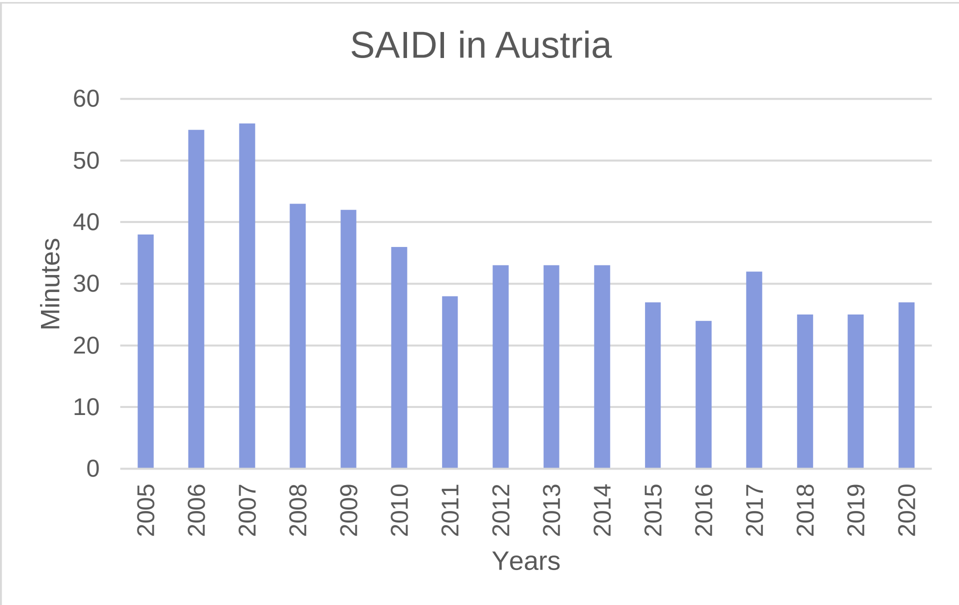


**Figure 1 : SAIDI in Austria [2]**

In addition, Austria has no geographical islands or remote communities to be supplied by microgrids. The landscape in Austria is mainly characterized by its alpine character, and grid expansion has been pushed even into the furthest valleys. Electricity is mainly provided by highly reliable run-of-river as well as hydro storage power plants (around 2/3 of the annual electricity production). Thus off-grid operation capability is required in very few niche applications and as emergency power supply for sensitive and critical infrastructure (e.g. semiconductor manufacturer, paper industry, hospitals). Niche applications are for example single remote farms or mountain huts which do not have access to the public grid at all. They usually provide their power by diesel generators and solar PV but are not connected to a Microgrid-like structure. (Kroposki und Mayr 2011)

[2] System Average Interruption Duration Index: commonly used as a reliability index by electric power utilities

A big advantage is given by the Austrian topography in the heart of the Alps and the availability of pumped hydro storage power plants, which have reasonable storage capabilities as well as functionalities to support grid recovery in case of large disturbances or even blackouts. This is not only true for the Austrian power grid, but also for supporting neighboring grids.

Resulting from the situation in Austria, there is no positive business case for installing and operating Microgrids. Numerous studies have repeatedly examined the option of installing microgrids, but no positive business case has yet been found. (Hacker 2017) (Einfalt, Leitinger, et al. 2009)

Nevertheless, Austria has broad know-how on the design and control of microgrids. Several researchers' groups and commercial providers are located in Austria. In the following research and demonstration sites are described, where companies demonstrate and test their products and developments:

## Siemens Campus Microgrid

The Siemens Campus Microgrid is an intelligent system for the optimization of the electricity and heating demand on the company's premises in the Viennese district of Floridsdorf. It consists of photovoltaic power generation, EV-charging infrastructure, battery storage and the microgrid controller. Next to a safe and reliable provision of electrical energy, it simultaneously reduces the $CO_2$ footprint and electricity peaks.

Siemens Campus Microgrid Key Figures:

- Photovoltaic systems: Total area of currently 1,600 $m^2$ and peak performance of 312 kWp
- Battery storage: Capacity 500 kWh, output: 500 kW
- Fire protection for battery storage: Extinguishing system Sinorix
- Charging stations for EVs
- Desigo building management system
- Microgrid Control – a SICAM application running on a SICAM A8000 platform
- Additional feature: Pre5G campus network pilot installation in cooperation with the partners A1 and Nokia

**Siemens Campus Microgrid | Topic Areas | Siemens Österreich**

## Microgrid Research Lab Wieselburg:

The major objective of the Microgrid Research Lab at Wieselburg is to integrate the existing distributed energy resources as biomass boilers, absorption and compression cooling and heat storages at the research center of the company BEST as well as the new technologies as solar PV, EV charging stations and a battery in one testbed. This concept is used for analyzing the interactions of all these technologies to increase the system efficiency. Furthermore the final Microgrid Lab will support the development of new microgrid controller strategies. For example the installed wood chip boiler has enough capacity to supply the new firefighting station completely with heat. In return, a new installed solar PV and battery system at the firefighting station can be used for the testbed.

[**Microgrid Lab 100% – R&D project for 100% decentralized energy supply with biomass and other Distributed Energy Resources (DER) (best-research.eu)**]

Both infrastructures have in common to provide rather a research, development, and demonstration environment as well as to increase self-sufficiency than to increase security of supply at the specific location.

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## 2.2 CANADA

### PROJECT OVERVIEW

| | | |
|---|---|---|
| **Title of Project** | **Lac-Mégantic Microgrid** | |
| **Location** | Lac-Mégantic, Québec | |
| **Country** | Canada | |
| **Year of Commissioning** | December, 2020 | |
| **Total Cost** | **Public** | $12,803,584 CAD (Hydro-Québec + NRCan) |
| | **Private** | n/a |
| **Lead Organization** | Hydro-Québec | |
| **Developer/ Vendor(s)** | n/a | |

| | | |
|---|---|---|
| **Grid Type** | ■ Off-grid Microgrids<br>■ Grid-connected Microgrids | ■ AC Microgrids |
| **Microgrids Classification** | ■ Commercial and Industrial Microgrids<br>■ Community, City, Utility Microgrids<br>■ Campus and Public Institutional Microgrids<br>■ Rural and Remote Microgrids<br>■ Islanding Capabilities | |
| **Renewable Energy Installation Size (MW)** | 0.8 MW solar PV + 0.6 MWh/1 MW Battery energy storage system | |
| **Microgrid Technology** | ■ Solar photovoltaic (PV)<br>■ Energy Storage<br>■ Smart Buildings | |
| **Business Model** | N/A | |
| **Total Electricity Generated per Annum** | Expected 700 MWh/year | |
| **Contact Information** | **Name** | Simone Soldati, David-Olivier Goulet, Julien Choisnard |
| | **Email** | soldati.simone@hydroquebec.com<br>goulet.david-olivier@hydroquebec.com<br>choisnard.julien@hydroquebec.com |

## Background and Overview

In 2017, the Government of Canada collaborated with provincial and territorial governments to develop the Pan-Canadian Framework on Clean Growth and Climate Change (PCF). The PCF identifies the electricity sector as a key sector in Canada's transition to a low-carbon economy.

Canada has one of the cleanest electricity systems in the world, with over 82% of electricity produced by non-emitting sources. However, in pursuit of economy-wide decarbonization, the electricity sector will have to increase grid capacity while replacing emitting generation sources with clean generation.

The Government of Canada recognized the need to support innovation in technology and business models that will support integration of renewable energy while ensuring grid flexibility, reliability, resiliency, and affordability. Smart grids are key enablers to this vision – by applying technologies pioneered in the digital information and telecommunication sectors, smart grids connect electricity generation facilities and customers through real-time communication.

However, new approaches involving digitalization will be necessary to effectively operate a modernized grid with increased renewable hosting capacity, bidirectional power flow, advanced protection and control capabilities, and tools that benefit customers. In concert with technological advancements, new market structures and business models will also have to be established to realize these solutions.

In Budget 2017, the Government of Canada announced several funding envelopes to support smart grid innovation, spanning research, development, demonstration, and deployment phases. The Green Infrastructure Phase II (GI2) fund ($812 million CAD) accelerates the deployment and market entry of next-generation clean energy infrastructure. Under the GI2 umbrella, the Smart Grid Program is one of Natural Resource Canada's targeted national programs addressing key infrastructure to advance the goals of the PCF.

The objective of the Smart Grid Program is to reduce GHG emissions and generate economic and social benefits. The Smart Grid Program funds $100 million CAD over five years to accelerate the development of smart grid technologies and integrated systems through utility-led demonstration and deployment projects.

As of 2022, the program has funded 21 highly innovative projects across the country that showcase various attributes of a smart grid system. A specific priority for Canada is the advancement of microgrid systems with local power generation sources and that can operate independently from the main grid. Such systems will enable rural, remote, and northern communities to reduce their reliance on fossil fuels and promote energy self-sufficiency. Five of the 21 projects featured microgrid technologies that amounted to a combined project value of ~132 million CAD as a direct result of NRCan's contribution of ~32 million CAD.

The Lac-Mégantic project represents the province of Quebec's first microgrid and sets the stage for further deployment across the province, and the country.

## Project Drivers and Motivations

Following a train derailment and explosion in 2013 that destroyed half of downtown Lac-Mégantic, the town is rebuilding with a focus on sustainable development as a showpiece to reinvigorate the community and the region.

In parallel, Hydro-Québec was looking to develop its first microgrid, and the rebuilding of Lac-Mégantic's core from the ground up offered a unique opportunity to create a living laboratory where smart grid technologies and supporting business models can be tested, while supporting the energy transition in Québec.

Objectives of the town of Lac Mégantic:

- Position Lac-Mégantic as an energy transition leader for rural Canada
- Make Lac-Mégantic's vision of a smart city a reality
- Help increase the town's appeal as a hub of economic and technological innovation

Objectives of Hydro-Québec:

- Master and integrate Distributed Energy Resources (DERs)
- Master two-way power flow and the concept of islanding
- Manage demand during winter peak periods
- Understand user adoption factors
- Apply the model to off-grid systems and communities to reduce fossil-fuel use and GHG emissions

The study area perimeter comprised approximately 30 buildings, including institutional, commercial and residential buildings, along with a solar PV park and battery energy storage system (BESS) connected to the 25-kV medium voltage network and located close to the study area perimeter (Figure 2). The project entailed installing 1687 modules (600 kWp) in the centralized solar PV plant as well as a 600 kW/600 kWh connected battery energy storage system, along with +/- 500 modules distributed on four customer buildings and 54 kWh of energy storage inside two of the customer buildings (Figure 3). The system also included the installation of a 240 V fast-charging EV station, and equipping buildings with smart devices, smart home systems, energy efficiency measures as well as a centralized control system for energy management.Stakeholders:

- Hydro Québec
- City of Lac-Mégantic
- Natural Resources Canada

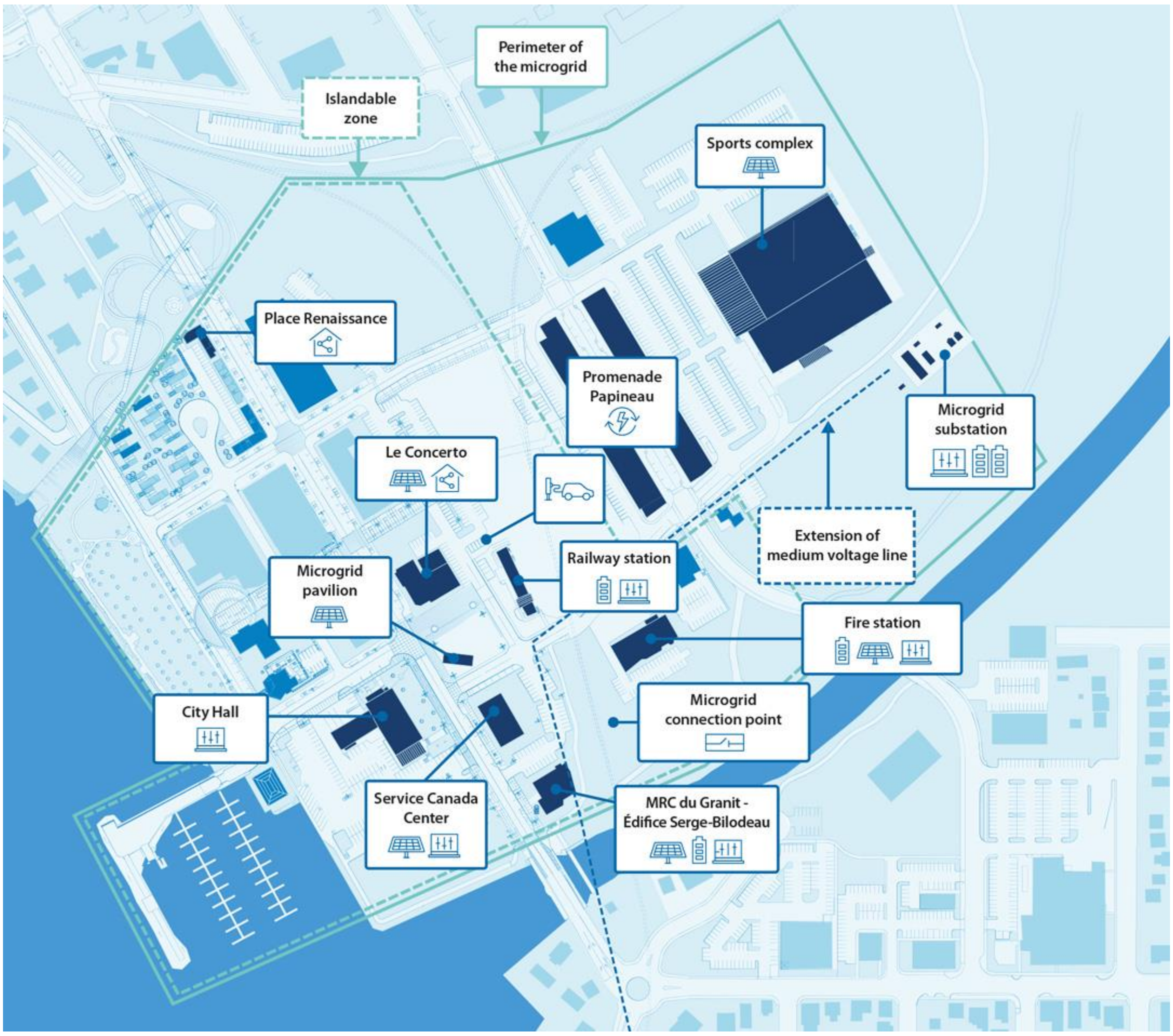


**Figure 2: Lac-Mégantic microgrid study area perimeter.**

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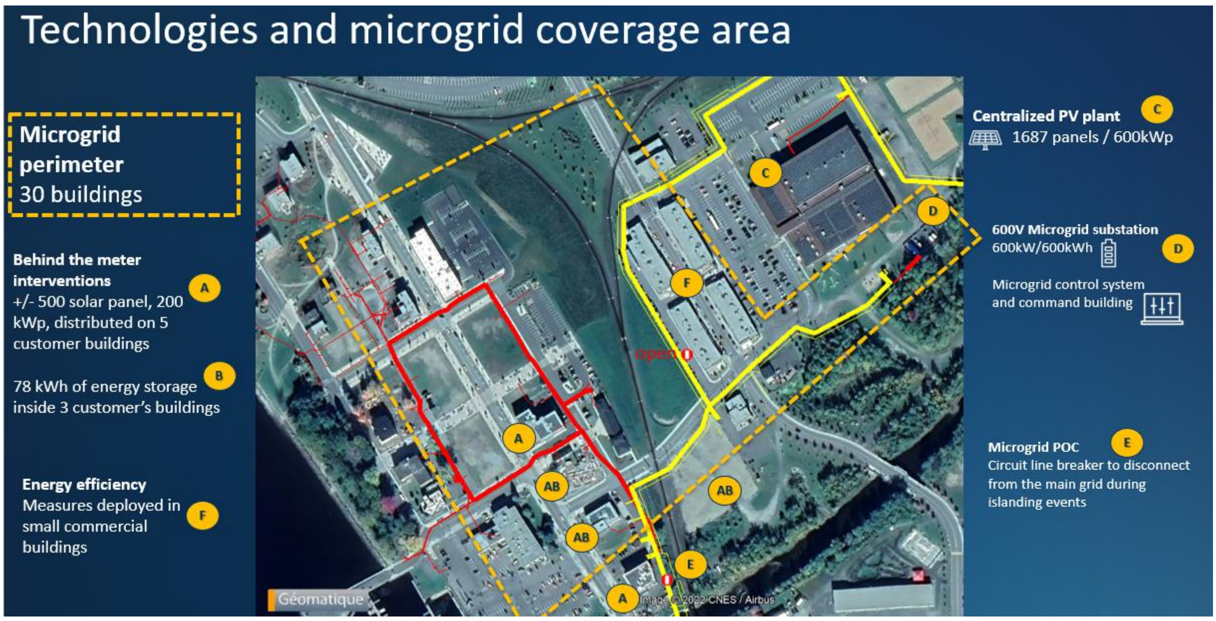


**Figure 3: Technologies and microgrid coverage area.**

**© Hydro-Quebec, 2021. Reproduced with permission.**

## Technical Characteristics and Solution (Microgrid Equipment and Technologies)

The microgrid can store the surplus energy it generates and feed it back into Hydro-Québec's main grid, allowing for two-way energy exchanges (Figure 4).

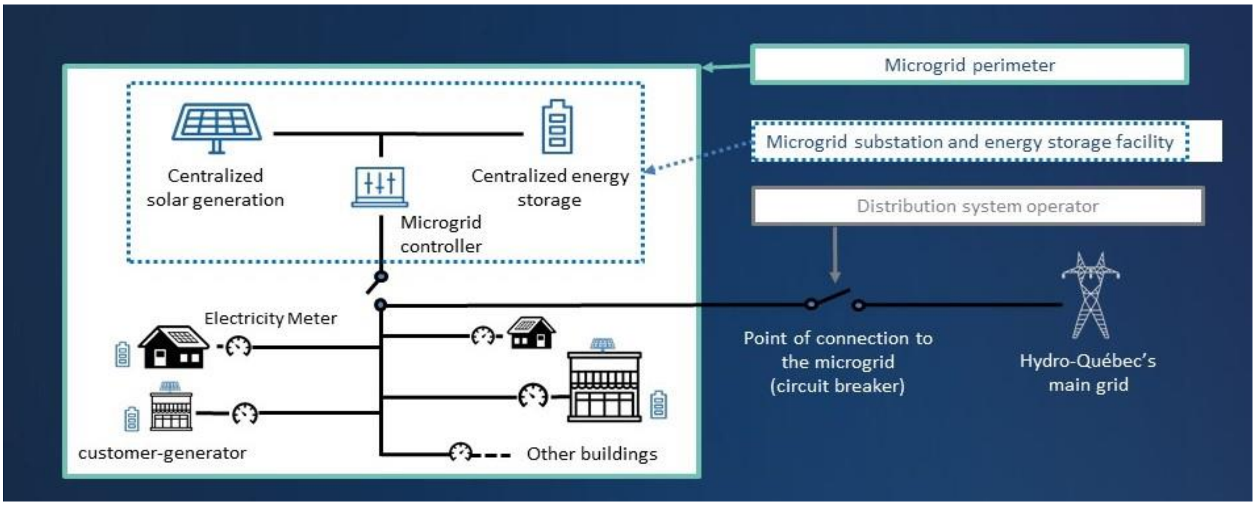


**Figure 4: System boundary areas.**

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Modelling results for the study area provide an annual average demand of ~400 kW, and a peak demand of ~800 kW. When islanded, for example in the case of an outage, the centralized battery operates in grid-forming mode to supply downtown Lac-Mégantic with electricity for several hours – modelling results indicate up to 11 hours in the summer (without a genset).

The islanding duration is optimized by the microgrid controller based on solar PV generation and demand response. In addition, smart building components were installed in several of the downtown's residential, commercial, and institutional buildings so occupants can optimize the impact of the microgrid on their comfort and, ultimately, reduce their energy consumption.

There are four main transitions to master when operating the microgrid to switch between the connected and islanded state: seamless planned islanding, seamless resynchronization to the main grid, black start, and unplanned islanding (through black start). The challenge is to perform these transitions in a closed way, similar to a transfer switch, but at the scale of a microgrid, involving several sources and several customers and at medium voltage. With those transitions mastered, the microgrid can move from grid connected to islanded without any impact on customers.

The microgrid telecom structure consisted of the following:

Inside the microgrid:

- Microgrid controller with optimization and weather forecast capabilities
- Direct or cellular links between building controls (local solar PV and ESS) and generation sources (centralized solar PV, ESS and Dgen) using private APN network
- Firewall and gateway between microgrid network and Hydro-Québec network
- Fiberoptic link between microgrid control and point of connection (POC) of the microgrid (synchronization breaker.

Communication between the POC and the microgrid:

- Specific fiber optic between microgrid POC (SEL651R) and microgrid command building (SELAXION) for voltage and frequency decrease/increase commands, open/close status of the synchronization breaker, and the general Hydro-Québec network with cellular communication using gateway (SMP4) between various grid devices up to the Distribution Control Center.

General technical challenges include maintaining good power quality in the islanded grid (medium to low voltage), coverage of short circuits up to the customer's electrical panels, and distribution of microgrid intelligence across multiple systems and equipment. There are also health and safety challenges around not interfering with Hydro-Québec's work patterns on the grid.

## Lessons Learned & Policy Recommendations

This project makes Lac-Mégantic the first smart community in Québec. The smart grid integrates a wide variety of technologies and is capable of operating on 100% renewable energy. The decentralization of power generation sources, the development of forecasting models (load and generation), and the design of an interface between control systems, automation systems, grid telecommunications and distribution operation centers enable the microgrid to optimize energy management.

The system can smooth peaks and troughs in power flow, supporting greater use of variable renewable energy sources and reducing the need for additional supply during peak demand periods, and make the grid more resilient. As Québec's grid electricity is almost entirely sourced from renewable energy (primarily hydroelectricity), the Lac-Mégantic project will only lead to small immediate decreases in greenhouse gas (GHG) emissions.

However, successful demonstration and deployment of microgrid technologies provide the groundwork in terms of expertise, technologies, and validation of microgrid standards (IEEE 2030.7 & 2030.8) to enable Hydro-Québec to replicate them across the province in 22 remote communities that are isolated from the main grid and rely on thermal power plants running on fossil fuels.

For Hydro-Québec, the experiences gained here will allow the integration of solar PV and wind turbines into these local grids and are expected to reduce fossil fuel consumption by 40%, leading to a GHG reduction of 131.1 kt $CO_{2eq}$.

For Natural Resources Canada, the successful development of microgrid technologies will provide the proof of concept and key learnings to advance innovation and inspire future projects with the goal of deploying the model at other Canadian communities to accelerate the transition to clean energy.

Lessons learned include:

Social acceptance:

- Involve the community from the start; this was what made this project so successful
- Establish a common vision and complementary objectives
- Listen, explain, and mobilize to ensure the community understands the local and global impacts of the project

Innovation across teams and organizations:

- Establish an agile structure and explore what is being done elsewhere
- Momentum: maintain mobilization and build on small successes
- Listen to users and the community, seek guidance

Testing and commissioning:

- Test plan: plan early, and in cooperation with all experts
- Stay agile when it comes to execution

## LINK TO PROJECT WEBSITE AND RELEVANT INFORMATION

- Lac-Mégantic microgrid | Hydro-Québec (hydroquebec.com)
- The Lac-Mégantic microgrid: a window on the technologies of the future | Hydro-Québec (hydroquebec.com)
- Lac Mégantic Microgrid (nrcan.gc.ca)

## < Value Proposition Ranking >

| | Category | | Not Important | Somewhat Important | Very Important | Essential |
|---|---|---|---|---|---|---|
| **Project Level** | Efficiency | | | | √ | |
| | Reliability & Resiliency | | | √ | | |
| | Independence & Sustainability (Renewable energy integration) | | | | | √ |
| | Bill Savings / demand charge abatement | | | | √ | |
| | Sharing Economy | | | √ | | |
| | New business models | | | √ | | |
| | Provision of ancillary services | | √ | | | |
| **Player Level** | **Producer** | *Selling electricity* | *N/A* | | | |
| | **Customer** | *Reducing electricity fees* | | | √ | |
| | | *Job creation* | | | √ | |
| | | *Revenue generation* | *N/A* | | | |
| | **Operator** | *Subscription fee* | *N/A* | | | |
| | | *Membership fee* | *N/A* | | | |
| | | *Selling electricity* | *N/A* | | | |
| | | *Government support* | *N/A* | | | |

## 2.3 GERMANY

### Project Overview

| | | |
|---|---|---|
| **Title of Project** | **"Inselnetz_optimal" – Integration of a high level of renewable energy in island networks** | |
| **Location** | Suðuroy | |
| **Country** | Faroe Islands | |
| **Year of Commissioning** | 2024 | |
| **Total Cost** | **Public** | 787,000€ |
| | **Private** | 15,000€ |
| **Lead Organization** | University of Bremen / Institute of Automation Technology | |
| **Developer/ Vendor(s)** | University of Bremen / Institute of Automation Technology<br>Leibniz University Hannover / Institute for Drive Systems and Power Electronics<br>Leibniz University Hannover / Institute of Electric Power Systems | |

| | | |
|---|---|---|
| **Grid Type** | ■ Off-grid Microgrids | ■ AC Microgrids |
| **Microgrids Classification** | ■ Community, City, Utility Microgrids<br>■ Rural and Remote Microgrids | |
| **Renewable Energy Installation Size (MW)** | 9.5 MW | |
| **Microgrid Technology** | ■ Solar photovoltaic (PV)<br>■ Wind<br>■ Hydro | ■ Energy Storage<br>■ Diesel |
| **Business Model** | n/a | |
| **Total Electricity Generated per Annum** | 45,000 MWh | |
| **Contact Information** | **Name** | Prof. Dr.-Ing. Kai Michels |
| | **Email** | michels@iat.uni-bremen.de |

### BACKGROUND AND OVERVIEW

The Faroe Islands are a remote group of islands located in the North Atlantic. A power line connection to the ENTSO-E grid does not exist. Therefore, the Faroese power system has always been an island grid or microgrid. Due to the high availability of hydro and wind power, roughly half of the electricity demand is already covered by renewable sources. To this day, the other half is still supplied by diesel generators for grid stability reasons. However, the publicly owned power company SEV announced the goal to achieve 100% $CO_2$ neutral electricity production by 2030.

Maintaining the reliability and resilience of the power system without relying on fossil fuels, requires advancement and innovations in the areas of energy storage systems, smart grid technologies and intelligent power and energy management systems.

## PROJECT DRIVERS AND MOTIVATIONS

The research project "Inselnetz_optimal" is settled in the described context of the Faroe Islands and aims to contribute to the planned transition with innovative solutions in the field of grid control. The main idea of the project is to develop a control system that uses the available energy resources in an economically optimal way and ensures a reliable electrical operation within the predefined grid codes, (n-1)-safety and sufficient reserves by utilizing the flexibilities provided by power electronic inverters, that are distributed in the grid. Due to the long-term foreseeable increasing diesel prices the economic optimization implicitly implies the inclusion of the technically feasible maximum possible share of renewable power generation.

While focusing on the case study of the Faroe Islands, the research results are meant to be generally applicable for off-grid microgrids worldwide. Many other inhabited islands worldwide have a good renewable primary energy supply, because they are located, for example, in the sunny trade wind area. Nevertheless, the share of conventional generation with synchronous generators has been kept relatively high on practically all islands for reasons of network stability. If alternative grid control concepts relying on renewable energy sources and batteries are developed, the $CO_2$ emissions on islands can be reduced significantly.

The project is carried out by the Institute of Automation Technology at the University of Bremen, the Institute of Electric Power Systems and the Institute for Drive Systems and Power Electronics both at Leibniz University Hannover. Besides SEV, further industry partners involved in the project are ENERCON, MAN Energy Solutions and wesernetz Bremen GmbH. These companies support the research with their expertise and benefit from the developed solutions.

## TECHNICAL CHARACTERISTICS AND SOLUTION (MICROGRID EQUIPMENT AND TECHNOLOGIES)

The goals described are to be achieved by a hierarchically structured control system that is shown in Figure 1. The lowest control level 0 is decentralized. On this control level 0, the local network nodes are controlled (by inverters and synchronous generators, later summarized as DER) to hold a setpoint specified by the next higher level 1. In a grid with a high share of renewable power and battery storage systems, it is expected to have a high number of generation units that are coupled to the network via an inverter. Some of these need to actively support the grid voltage, which means they are controlled in a grid-forming mode. Within the project, two fundamentally different control concepts are compared. Classically, the inverters receive setpoints for the voltage amplitude and the active and reactive power. A new idea proposes to use voltage phasors as setpoints for distributed inverters. The angles of these phasors can be synchronized for all distributed units with a radio signal as for example GPS.

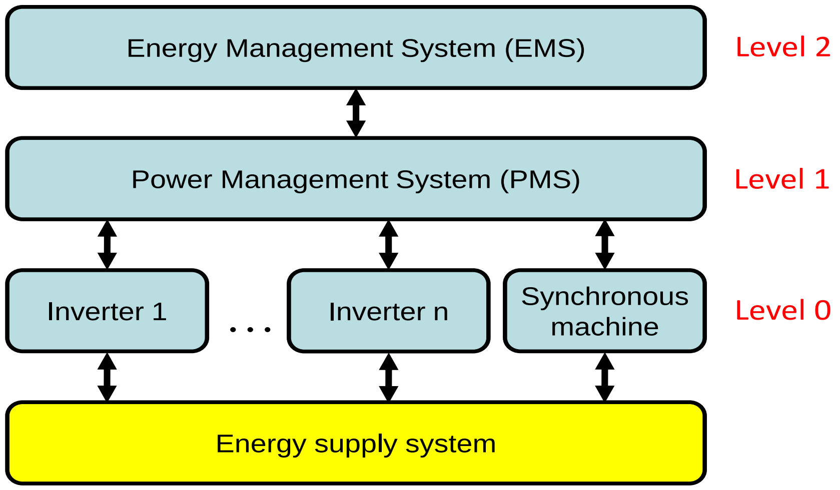


**Figure 5: Hierarchical structure of the control system**

In addition, the individual generation units must also report data on the stability reserve (with regard to the different stability criteria) back to the next higher level 1 so that the current stability reserve of the entire network can be determined in level 1 and suitable actions can be initiated. These data result largely from the physics of each individual generation unit.

At level 1, the setpoints for the units at level 0 (possibly voltage phasors) are specified in the Power Management System (PMS). The setpoint specifications have to be modified according to:

- the short-circuit current capability currently available in the network at selected network nodes (the goal is to ensure the protection functionality),
- the effective instantaneous reserve, which results from the storage content of the batteries, the inertia of the synchronous and asynchronous machines connected to the network (generating units and loads) and, if applicable, the size of the inverter capacitors,
- the primary control reserve, which results from the storage content of the batteries, the difference between the current output and nominal output of the conventional thermal generation systems and, if applicable, wind energy and photovoltaic systems that do not feed in their maximum available power, and
- the (n-1) failure safety, which essentially relates to the current network structure,

The level 0 inverters must try to hold the given setpoints while of course ensuring protective functions and local limits, such as the rated current. There will be therefore deviations between setpoints and actual values, which must be processed by the control on level 1.

In the highest level 2, the Energy Management System (EMS) specifies, based on load and generation forecasts for wind and solar PV feed-in and the state of charge of the battery storage, whether conventional generating units are to be switched on or off or a battery storage should be charged or discharged. At this level, it is no longer a matter of guaranteeing network stability, but rather the economic optimization of grid operation under the framework conditions specified in the stability assessment. Before connecting or disconnecting a generating unit, however, the same criteria must be checked that are also checked within the PMS at regular time intervals in order not to bring the grid into an unsafe state of operation.

The three control levels operate on different time scales, which is emphasized by Figure 6. Therefore, the communication between the different levels has to be carefully calibrated. Moreover, the controllers on the lower levels need to react on distortions autonomously until they receive new setpoints.

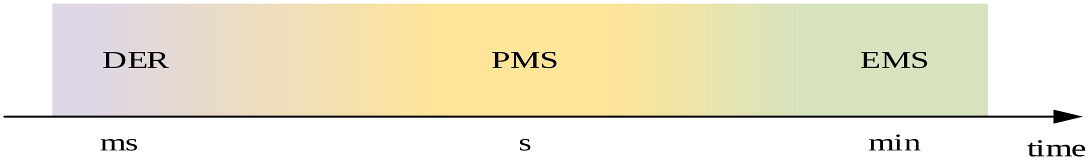


**Figure 6: Time scales of the different control levels**

The developed control concepts will be analyzed and evaluated in simulations with models of the Faroese grid. Afterwards bench tests will be conducted before lastly field tests on the Faroe Islands are performed for further assessments as shown in Figure 7.

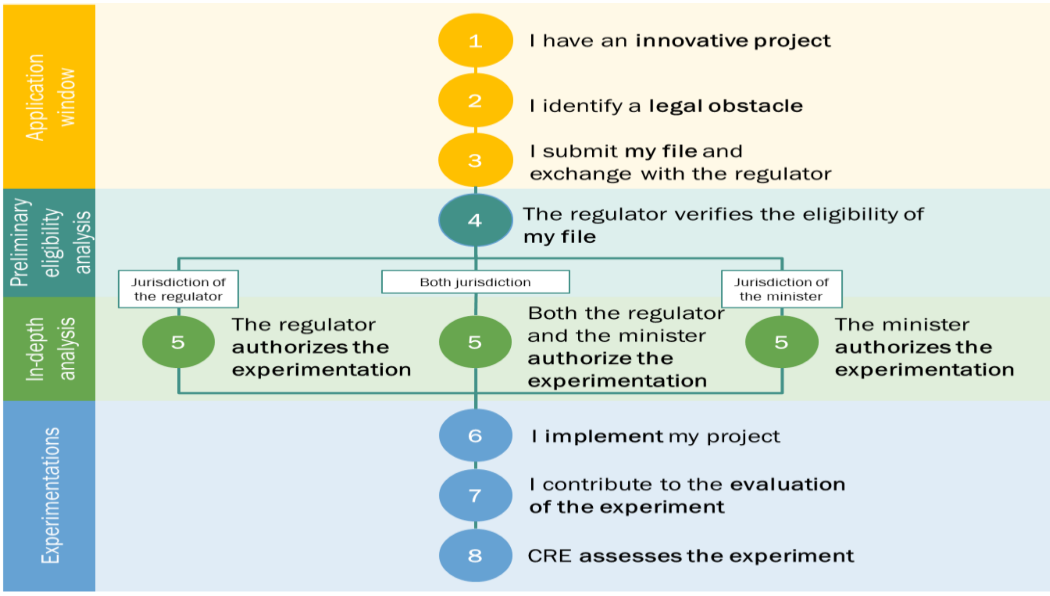


**Figure 7: Process of the French regulatory sandbox implemented by the Energy regulator from the point of view of the project holder**

## OWNERSHIP STRUCTURE, FINANCING AND BUSINESS MODEL

This research project is funded by the German Federal Ministry for Economic Affairs and Climate Action. The fundamental results are going to be published and discussed in the academia. Due to the need for island grids to become independent from fossil fuels, the developed solutions are expected to be commercializable. Therefore, associated industry partners are deeply involved in the ongoing research.

## LESSONS LEARNED & POLICY RECOMMENDATIONS

The main goal of this project is to develop a holistic control approach for island grids with a high share of renewable power. If successful, this could be implemented on the Faroe Islands in order to support the planned energy transition. In the future, further microgrid projects worldwide can benefit from the solutions as well. More specifically, it will be investigated if the usage of voltage phasors as setpoints for distributed grid-forming inverters can lead to a more stable grid voltage.

## LINK TO PROJECT/PROGRAMME WEBISTE AND RELEVANT INFORMATION

**https://www.uni-bremen.de/en/iat/ag-prof-dr-ing-michels/projects/projects-control-of-process-plants/island-grids**

## < Value Proposition Ranking >

| Level | Category | | Not Important | Somewhat Important | Very Important | Essential |
|---|---|---|---|---|---|---|
| **Project Level** | Efficiency | | | √ | | |
| **Project Level** | Reliability & Resiliency | | | | | √ |
| **Project Level** | Independence & Sustainability (Renewable energy integration) | | | | | √ |
| **Project Level** | Bill Savings / demand charge abatement | | | | √ | |
| **Project Level** | Sharing Economy | | √ | | | |
| **Project Level** | New business models | | | √ | | |
| **Project Level** | Provision of ancillary services | | | | | √ |
| **Player Level** | **Producer** | *Selling electricity* | | | √ | |
| **Player Level** | **Customer** | *Reducing electricity fees* | | √ | | |
| **Player Level** | **Customer** | *Job creation* | √ | | | |
| **Player Level** | **Customer** | *Revenue generation* | √ | | | |
| **Player Level** | **Operator** | *Subscription fee* | √ | | | |
| **Player Level** | **Operator** | *Membership fee* | √ | | | |
| **Player Level** | **Operator** | *Selling electricity* | | √ | | |
| **Player Level** | **Operator** | *Government support* | √ | | | |

# 2.4 KOREA

## Project Overview

| | | |
|---|---|---|
| **Title of Project** | **Practical Demonstration of Power to Gas (P2G) based Multi-Microgrid (MG) for Grid connected Operations** | |
| **Location** | Ulsan Techno General Industrial Complex, Ulsan | |
| **Country** | South Korea | |
| **Year of Commissioning** | July, 2022 | |
| **Total Cost** | **Public** | |
| | **Private** | $15 million |
| **Lead Organization** | KEPCO | |
| **Developer/ Vendor(s)** | Ulsan TP, Elchemtech, E&M solution | |

| | | |
|---|---|---|
| **Grid Type** | ■ Grid-connected Microgrids | ■ AC Microgrids |
| **Microgrids Classification** | ■ Commercial and Industrial Microgrids<br>■ Community, City, Utility Microgrids | |
| **Renewable Energy Installation Size (MW)** | 1MW solar PV, 0.25MW ESS, 0.2MW fuel cell | |
| **Microgrid Technology** | ■ Solar photovoltaic (PV)<br>■ Fuel Cells | ■ Energy Storage<br>■ Others: Hydrogen |
| **Business Model** | P2P energy trading between MGs, Selling Hydrogen | |
| **Total Electricity Generated per Annum** | 1,300MWh | |
| **Contact Information** | **Name** | Wook Won Kim |
| | **Email** | Wookwon.kim@kepco.co.kr |

### BACKGROUND AND OVERVIEW

On July 14, 2020, the South Korean government announced that it is accelerating the transition to a green economy through the announcement of Green New Deal, aiming for a carbon-neutral (Net-Zero) and speeding up the transition to a low-carbon and eco-friendly economy. Therefore, the future energy policy will focus on energy conservation, environmental improvement, and the transition to green energy including hydrogen and renewable energy.

The transition to green energy is still largely uncertain in terms of economic feasibility, and in order to invigorate it, it is necessary to preemptively establish a technology base and business ecosystem to drive private demand and serve as a pick-up point. For this, the development of technologies for system efficiency and energy optimization that can improve the economics of P2G and the development of a biz-model that can diversify the use of hydrogen must be preceded.

## PROJECT DRIVERS AND MOTIVATIONS

In 2019, KEPCO started the "Practical Demonstration of P2G based Multi-Microgrid for Grid connected Operations" project to apply P2G technology to the power system. It is a project to demonstrate a new type of green energy community that can be used to produce green hydrogen with water electrolysis facilities using unused power, and the remaining power to be traded to nearby microgrids.

This research project was launched in May 2019. The project is developing technology for demonstration and building infrastructure in Ulsan Techno General Industrial Complex. On the demonstration site, the MW class hybrid water electrolysis (Proton Exchange Membrane (PEM) + Alkaline) for P2G, as well as power generation sources such as 1 MW solar PV power, 250 kWh ESS, and 200 kW hydrogen fuel cell, is being built with the goal of completion by July 2022.

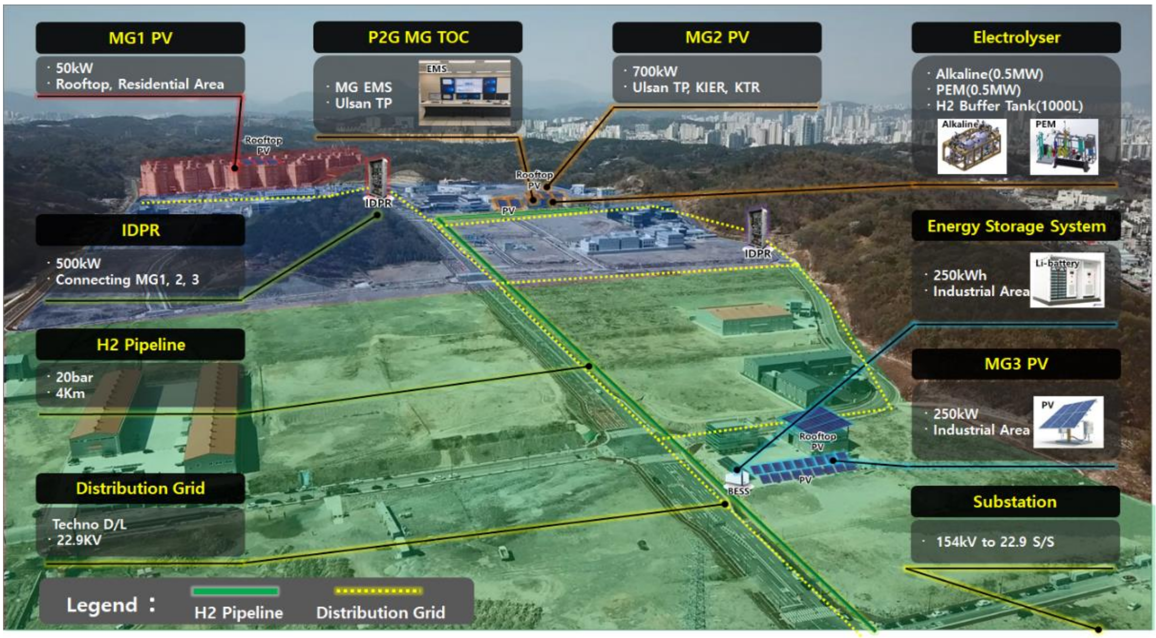


**Figure 8: Demonstration Site Overview**

## TECHNICAL CHARACTERISTICS

Since the mid-2000s, KEPCO has been conducting research on various microgrids, such as stand-alone microgrid, grid-connected microgrid, and campus microgrid. This study focused on research on how to improve the utilization of resources and make a smooth connection with the system when there are multiple microgrids and various energy sources by exploiting existing research.

In this project, some technologies that are different from the existing MG project will be introduced. The first is DGPR (Digital Grid Power Router), which is a core facility for operating multi-MGs. DGPR is the electric device in which multiple inverters are connected to a common DC bus. Using DGPR, power can be sent to specific MGs or distribution line because this device can control active power flow. DPGR makes it possible to achieve balancing demand-supply in mutually connected MGs through the DGPR. In addition, by applying blockchain technology, it is possible to demonstrate a business model through electricity trading with nearby microgrids.

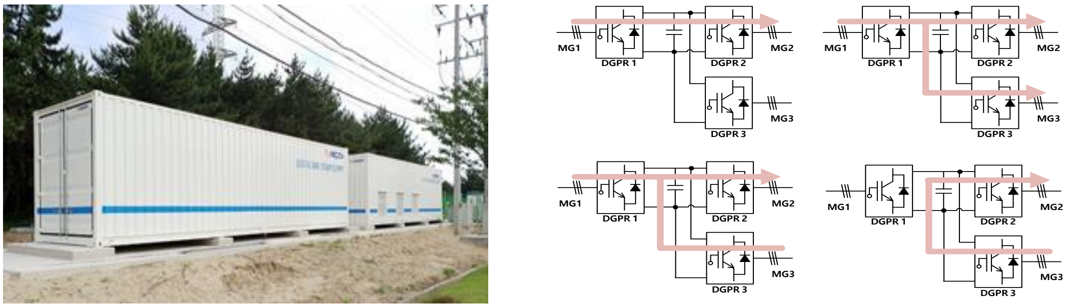


**Figure 9: DGPR & Control Scheme**

Another technology is a hybrid water electrolysis operation technology. A 1 MW PEM + alkaline water electrolysis facility is installed at this demonstration site. Although PEM water electrolysis has a fast response, it is expensive. On the other hand, alkaline water electrolysis can increase the capacity at a low cost. If the two types of water electrolysis are operated in a hybrid form, the advantages of the two systems can be utilized. As a result, the overall system efficiency increases, and it is possible to easily increase the capacity while responding to the intermittent of renewable energy sources.

<P2G Operating System> <0.5MW PEM > <0.5MW Alkaline >

**Figure 10: P2G Operating System**

In addition, in this project, various technologies are necessary for microgrid operation such as multi-energy (power, hydrogen, heat) optimization and distributed resource fleet control.

These technologies and P2G technology will be demonstrated throughout the entire cycle from hydrogen production to sales and utilization.

## OWNERSHIP STRUCTURE AND FINANCING

This project cost a total of $15 million, and KEPCO support research expense, $10.5 million, and public institutions such as Ulsan City and Ulsan Technopark and hydrogen-related companies jointly invested. All of deliverables including intellectual property rights generated by this project are jointly owned by the participating organizations and will be used for R&D purposes for 5 years (~ 2027) after the project is completed. The operating cost for use for 5 years is covered by the revenue generated from the demonstration site.

## BUSINESS MODEL

Microgrid operators can produce hydrogen as a surplus renewable energy source and sell it directly to hydrogen sellers or regenerate electricity using hydrogen fuel cell after storage. It also generates revenue by buying and selling electricity from nearby microgrids. In this process, owners of renewable energy sources can create value through the sale of surplus resources, and consumers can use high-quality, eco-friendly resources at low prices. By reducing the intermittency of renewable energy sources by P2G, the grid operator (utilities) can operate the system reliably.

## LESSONS LEARNED & POLICY RECOMMENDATIONS

The P2G operation technology under study in this project has the effect of increasing the renewable integration of the connected grid because it is possible to compensate for the intermittent output of renewable energy. The produced hydrogen can be sold directly or it can supply electricity and heat to various demanding places by using fuel cells, which has the effect of diversifying the use of hydrogen. In addition, hybrid P2G technology and energy optimal operation technology are expected to increase power-hydrogen conversion efficiency, thereby enhancing the economic feasibility of green hydrogen production. Advancement of development technology through long-term demonstration for the next five years and securing of operation know-how connected to the green hydrogen distribution system will contribute to improving the capacity of new and renewable energy sources connected to the distribution system and stable system operation.

**< Value Proposition Ranking >**

| Category | | | Not Important | Somewhat Important | Very Important | Essential |
|---|---|---|---|---|---|---|
| **Project Level** | Efficiency | | | | √ | |
| | Reliability & Resiliency | | | | √ | |
| | Independence & Sustainability (Renewable energy integration) | | | √ | | |
| | Bill Savings / demand charge abatement | | | √ | | |
| | Sharing Economy | | | √ | | |
| | New business models | | | | √ | |
| | Provision of ancillary services | | | √ | | |
| **Player Level** | **Producer** | Selling electricity | | | √ | |
| | **Customer** | Reducing electricity fees | | | √ | |
| | | Job creation | √ | | | |
| | | Revenue generation | | √ | | |
| | **Operator** | Subscription fee | √ | | | |
| | | Membership fee | √ | | | |
| | | Selling electricity | | √ | | |
| | | Government support | | | √ | |

## 2.5 UNITED STATES

### Project Overview

| | | |
|---|---|---|
| **Title of Project** | **Microgrid System for 55" Pump Station at the Natural Energy Laboratory of Hawaii Authority in Kona, Hawaii** | |
| **Location** | Kailua-Kona, Hawaii | |
| **Country** | US | |
| **Year of Commissioning** | January, 2023 (to be) | |
| **Total Cost** | **Public** | $2,200,000 |
| | **Private** | N/A |
| **Lead Organization** | Encored, Inc | |
| **Developer/ Vendor(s)** | Encored, Inc / Encored, Inc | |

| | | |
|---|---|---|
| **Grid Type** | ■ Off-grid Microgrids<br>■ Grid-connected Microgrids<br>■ AC Microgrids | |
| **Microgrids Classification** | ■ Commercial and Industrial Microgrids<br>■ Rural and Remote Microgrids<br>■ Islanding Capabilities | |
| **Renewable Energy Installation Size (MW)** | Solar PV 0.5MW | |
| **Microgrid Technology** | ■ Solar photovoltaic (PV)<br>■ Energy Storage<br>■ Diesel | |
| **Business Model** | ■ Optimal economic operation in grid-connected mode<br>■ Resiliency increase in islanded mode<br>■ Automatic mode change<br>■ Advanced Energy Management System | |
| **Total Electricity Generated per Annum** | 898,477 kWh / year | |
| **Contact Information** | **Name** | RAEKYUN KIM |
| | **Email** | rkkim@encoredtech.com |

** Simulation results provided below were obtained based on RTDS (Real-Time Digital Simulator) simulations using real data.*

## BACKGROUND AND OVERVIEW

In 2015, the Hawaii legislature adopted Act 97 featuring a renewable portfolio standard of 100% by 2045, making Hawaii the first U.S. state to make a legally binding commitment to produce all of its electricity from indigenous renewable sources.

The Hawaii legislature subsequently adopted Act 200 into law, concluding that microgrids can provide valuable services to the public utility electric grid, including many ancillary services, such as frequency and voltage control, and thereby can increase public safety and security. Also, Hawaii policy makers are seeking a consensus of various energy players to create a electricity rate plan for microgrid, and it will be launched soon.

Act 200 notes potential opportunities for microgrid demonstration projects at the Natural Energy Laboratory of Hawaii Authority (NELHA) that test advanced technologies and market concepts that can facilitate microgrid development consistent with the purpose of Act 200. Accordingly, NELHA is planning a microgrid that consists of solar PV generation, ESS, and an energy management system (EMS) to enhance energy resiliency, self-sufficiency, and reliability through the capability of operating in an islanded mode during outages of the Hawaii Island electrical grid.

BESS as the principal means of managing power variation of RESs has long been a focus of optimal scheduling problems, typically with equations that feature optimization techniques

## PROJECT DRIVERS AND MOTIVATIONS

General scope of the project are as follows:

- To install microgrid system that includes solar PV, ESS and EMS
- Cloud-based web monitoring service
- High-efficient solar PV system using bi-facial panel
- AI-based advanced energy forecasting system
- Optimal DERs scheduling that make the microgrid cost-efficient in grid-connected mode (solar PV, ESS, Load)
- Optimal DERs scheduling that make the microgrid operate longer in islanded mode (solar PV, ESS, Diesel, Load), and
- Black-out/recovery scenario to minimize microgrid’s down time and enhance microgrid’s resiliency

## TECHNICAL CHARACTERISTICS

In the project, three key technical solutions were applied as follows:

■ **Optimization of energy production**

- Improve the solar PV power generation efficiency by utilizing bi-facial solar PV modules and optimized reflection of the installation area
- Reduction of energy costs through AI-based solar PV prediction, load forecasting and ESS optimization in grid-connected mode

- **Increased resiliency**

- Configure the microgrid systems for uninterrupted automatic transition from grid-connected mode to islanded-mode through analysis of load characteristics and specific scenarios
- Coordinated control between renewable resources to maximize operating time with limited diesel fuel usage during islanded-mode operation
- Secure grid stability by controlling the frequency and voltage in the microgrid system by an MPC (Model Predictive Control) in islanded-mode operation

- **Advanced microgrid EMS**

- Proactively detect abnormalities of ESS operation and solar PV generation through AI functional data analysis
- Provide AI-based guidance on reducing energy costs by providing monitoring and analysis of existing and future expandable resources at NELHA including the research campus (Not directly control distributed energy resources)
- Advanced EMS flow chart, as seen in Figure 11.

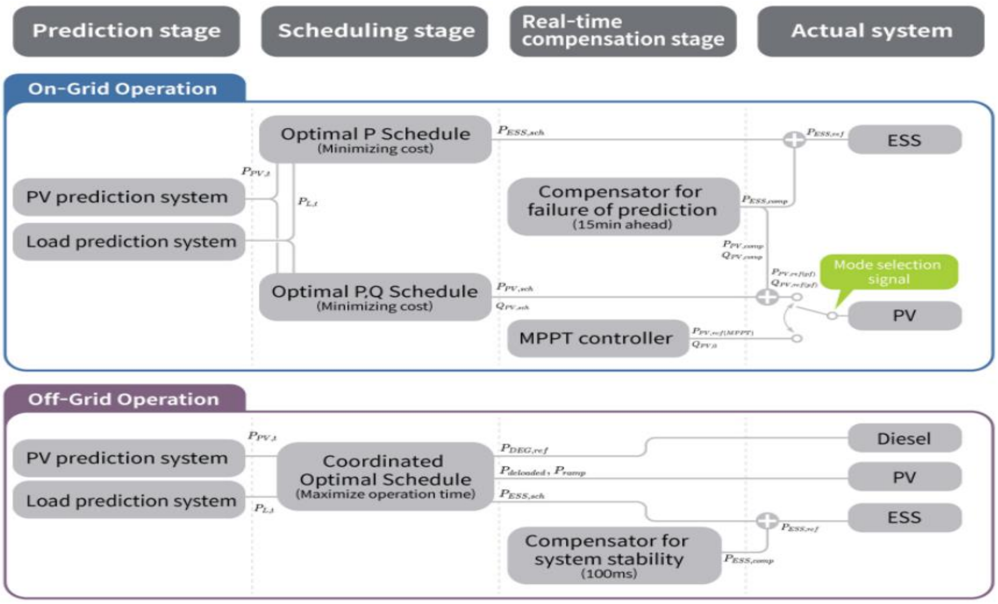


**Figure 11: Advanced EMS flow Chart**

- Provide cloud-based web monitoring application that can monitor and manage multiple site's load and energy resources

## OWNERSHIP STRUCTURE AND FINANCING

This project utilized two governmental tax incentive programs, one is ITC (Investment Tax Credit) provided by Federal government and the other is STC (State Tax Credit) provided by State government.

## BUSINESS MODEL

In terms of the business model, it was successful to improve the economics of the project by up to 20% by adopting advanced solar PV module (bi-facial) and AI-based energy management techniques. According to the simulation result from 2021.1 to 2021.6 in Figure 12, 28.65% saving from solar PV generation and additional 7.45% saving from ESS operation and a total of 36.11% saving is expected.

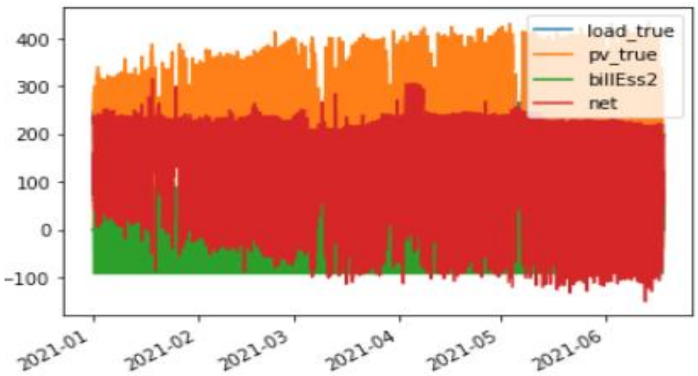


**Figure 12: Simulation result of savings from PV generation**

In addition, a state-of-the-art DERs optimal management technology shown in Figure 13 allows the microgrid system to utilize the solar PV system in standalone mode was applied, and after applying the proposed technology, a 27% increase in total operating time with limited diesel fuel usage was found.

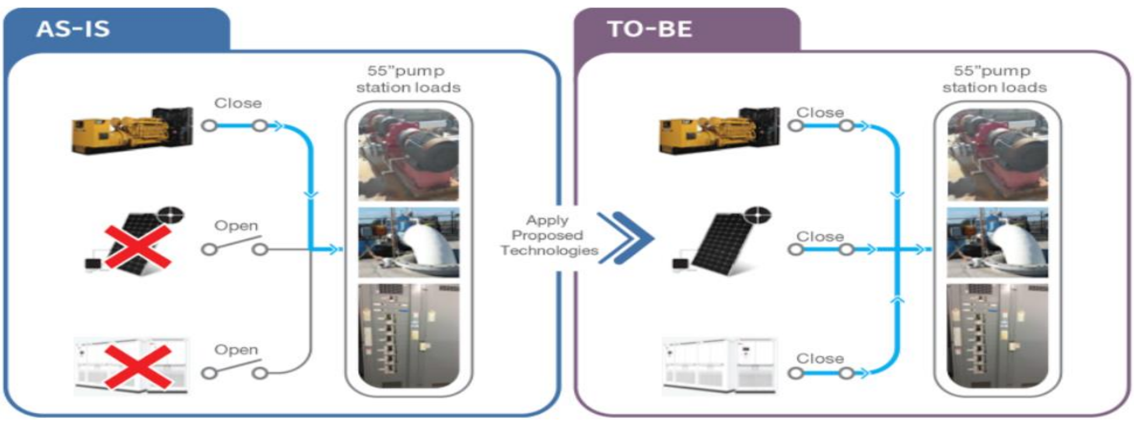


**Figure 13: DERs optimal management technology**

Black-out/recovery scenarios and automatic transition techniques were developed so that critical load can be Immediately re-powered when outage happens, and losses and costs due to power outage is minimized

Produce/Consumer/Operator benefits are as follows:

- **Producer**

- Sells produced energy, and
- Upgrades products based on actual site operation

- **Consumer**

- Bill saving
- Operation cost reduction by automating grid operation
- Higher resiliency
- Outage loss saving, and
- Longer operating time in islanded-mode operation

## LESSONS LEARNED & POLICY RECOMMENDATIONS

- **Main outcomes of the project**

- PPA contract

- **What went well and what were unexpected barriers (challenges)?**

- Optimal operation concept was verified with real-time simulator (RTDS) and the result was more than we expected
- Varying electricity tariff makes us continuously monitor the tariff and upgrade bill saving algorithm
- Various costs have been incurred due to Covid-19
- The cost of labor for construction workers was high, so the economic feasibility of the project did not come out as much as expected
- Hawaii State emphasizes eco-friendly policy. Although the project is related to renewable energy, there were many permits and licenses issue due to the PV construction
- The site is near the airport. So, a permit was needed to ensure that the light reflections from the solar panels did not interfere with the operation of the airport

- **How might it be replicated or what would be needed to change?**

- The most difficult thing was permit issue. We will make a guideline that treats permits and licenses and we expect that it will help us easily replicate this kind of project

- **What is the public reception on your project?**

- Act 200 notes potential opportunities for microgrid demonstration projects at the Natural Energy Laboratory of Hawaii Authority (NELHA) that test advanced technologies and market concepts that can facilitate microgrid development consistent with the purpose of Act 200

## LINK TO PROJECT/PROGRAMME WEBISTE AND RELEVANT INFORMATION

https://nelha.hawaii.gov/main/nelha-announces-advanced-microgrid-project/

**< Value Proposition Ranking >**

| Category | | | Not Important | Somewhat Important | Very Important | Essential |
|---|---|---|---|---|---|---|
| **Project Level** | Efficiency | | | | | √ |
| **Project Level** | Reliability & Resiliency | | | | | √ |
| **Project Level** | Independence & Sustainability (Renewable energy integration) | | | | | √ |
| **Project Level** | Bill Savings / demand charge abatement | | | | | √ |
| **Project Level** | Sharing Economy | | | | √ | |
| **Project Level** | New business models | | | | √ | |
| **Project Level** | Provision of ancillary services | | | | √ | |
| **Player Level** | **Producer** | *Selling electricity* | | √ | | |
| **Player Level** | **Customer** | *Reducing electricity fees* | | | | √ |
| **Player Level** | **Customer** | *Job creation* | | | √ | |
| **Player Level** | **Customer** | *Revenue generation* | | | | √ |
| **Player Level** | **Operator** | *Subscription fee* | √ | | | |
| **Player Level** | **Operator** | *Membership fee* | √ | | | |
| **Player Level** | **Operator** | *Selling electricity* | | | | √ |
| **Player Level** | **Operator** | *Government support* | | | | √ |

# 2. CONCLUSION

With aim of addressing key acheivements and challenges of microgrid deplolyment or demonstration projects around the world, this casebook provides impressive characteristics of 5 microgrid case studies implemted from Austria, Canada, Denmark, Germany, Korea and the United States. It is shown that the most of the introduced projects in the report use solar photovoltaic and energy storage as part of the microgrid generation mix with value propositions of renewable energy integration, reliability & resiliency, efficiency and bill (cost) and demand charge savings

This casebook is the first edition of the microgrid published by ISGAN Communication Working Group and will be updated each year with additional examples from other countries.