GREEN POWERED FUTURE
MISSION

Pillar 1

Affordable and Reliable VRE

Factsheet P1-01

Renewable systems for enhancing stability and efficiency

Effective system stability assessments and feasible enhancement technologies are critical for the long-term stability and sustainable development of renewable energy (RE) in power systems. Grid-forming inverters and converters for photovoltaic (PV) and wind power plants will provide stability to power systems. Additionally, compared to alternating current (AC) systems, direct current (DC) systems are more efficient and cost-effective for integrating RE into grid and/or interconnecting them. Additionally, AI-assisted solutions also offer significant potential in RE applications. Demonstration projects of RE systems based on the above innovative solutions are showcased in this factsheet.

GPFM Innovation Priorities in scope:

- **IP 1.1.3** - Reliability evaluation of PV modules and systems
- **IP 1.3.2** - Large-scale IRE generation for improving system reliability and stability
- **IP 1.6.3** - MVDC / LVDC-based renewables systems for enhancing stability and efficiency

6 Case studies reported in the factsheet

10 Projects covering these IPs are reported in the GPFM National Pilots report

National Pilots Report

For further details on **GPFM Innovation Priorities (IPs):**

GPFM Roadmap **Action Plan 2022-2024**

GREEN POWERED FUTURE MISSION

Case studies

Case Study #1 PV MVDC power generation grid connection system

With the rapid development of renewable energy generation worldwide, photovoltaic power generation systems are evolving towards multi-scenario and high-efficiency directions. The photovoltaic medium-voltage direct current (MVDC) power generation system is a new type of system that efficiently collects power over a large area. It offers advantages such as fewer conversion stages, lower line losses, and easier integration with various energy sources or loads. This case study introduces briefly the key technologies of photovoltaic MVDC power generation systems. It also summarizes practical and industrial verification cases for photovoltaic MVDC systems.

Link to case study's detailed description

China

Case Study #4 Online stability assessment and optimization of HVREPS

The high-proportion variable renewable energy power system (HVREPS) exhibits low inertia and significant random fluctuations, leading to the degradation of system stability. To address these challenges, an online stability evaluation and flexible active support control technology for HVREPS has been developed. Firstly, a multi-timescale renewable energy probabilistic prediction method was proposed to provide essential state parameters for stability evaluation. Then, a rapid online stability evaluation model based on machine learning was proposed. Finally, the "generator-station-grid" active support control technology and related device systems were developed to enhance the stability of HVREPS.

Link to case study's detailed description

China

Case Study #2 AI-based algorithms for PV plant failure detection and diagnosis

New machine learning techniques can be adopted to develop diagnostic tools powered by Artificial Intelligence algorithms for PV Failure Detection and Diagnosis (FDD). When multiple faults or malfunctions that have similar consequences on the PV plant performances occur simultaneously, FDD algorithms have difficulties to correctly identify them. This case study focuses on studying the effect of a combination of different faults or malfunctions on the PV plant parameters to develop a model for their detection. The focus was on the overlapping effects of short circuit bypass diode and the increase of series resistance due to cell degradation, since data shows that this was the failure combination leading to the higher level of uncertainty.

Link to case study's detailed description

Italy

1066 GW/yr

Annual RE power capacity additions from 2023 to 2050 under the 1.5°C scenario

Share of RE in electricity generation by 2050 under the 1.5°C scenario

91%

Source: *IRENA*

Case Study #5 VisynC: Development of a hybrid energy storage system

This project aims to develop and validate a full-scale hybrid storage system combining lithium-ion batteries and ultracapacitors, managed by a control system to operate in synchronous grid-forming mode and provide the same services as a Synchronous Compensator. The new storage system will connect to the high voltage transmission grid in the Lanzarote-Fuerteventura electricity system, at Mácher 66 kV substation, and will operate as an integrated grid asset, offering various services to ensure the safe operation of the electricity system and increased integration of renewable energies. The system has a capacity of 16 MW, contributing to grid stability and renewable energy integration.

Link to case study's detailed description

Spain

Key metrics

To remain on a 1.5°C pathway by 2030, RE efficiency improvements must double and be driven by efficient technologies.

1. **More energy efficient technologies to reduce energy intensity, complemented by structural and behavioral changes.**
2. **A holistic approach, backed by systemic innovation to transform existing structures and systems built for the fossil fuel era**

https://www.irena.org/Digital-Report/World-Energy-Transitions-Outlook-2023

Case Study #3 800MW Offshore Wind Power Flexible HVDC Transmission Demo Project

The 800MW offshore wind power project of China Three Gorges Renewables (Group) Co., Ltd is located in the Huangsha Ocean area of Rudong County, Jiangsu Province. The total installed capacity is 800 MW, with a total of two hundred 4 MW wind turbines installed. The project has proposed a flexible high-voltage direct current (HVDC) transmission system to efficiently transmit the offshore wind power to shore. The system's overvoltage and insulation coordination design improved the safe and stable operating margin of the system under complex working conditions. The compact, lightweight equipment body design and interface coordination scheme also further reduced the size and weight of the offshore converter station.

Link to case study's detailed description

China

Case Study #6 RE empowering European and Indian communities (RE-EMPOWERED)

The "RE-EMPOWERED" project aims to develop and demonstrate novel tools for complete energy solutions for islanded/isolated communities. The tools include ecoPlanning Microgrids, Advanced Energy Management, ecoDR optimization, ecoCommunity engagement, ecoResilience for PV/wind, and ecoVehicle for e-mobility. All of these tools and solutions will be demonstrated in four demo sites with weak or non-existing grid, two in Europe (Denmark and Greece), and two in India (Ghoramara Island and Keonjhor). Additionally, hardware solutions will be upgraded and demonstrated, including dedicated converters, EVs and boats, cyclone-resistant PV and locally manufactured wind turbines, etc.

Link to case study's detailed description

India

Key findings

The case studies reported in this factsheet illustrate several novel tools for innovative energy solutions for enhancing the stability and efficiency of renewable energy systems. On the power generation side, photovoltaic medium-voltage direct current (MVDC) power generation systems offer advantages such as fewer conversion stages, reduced line losses, and greater stability. Lithium-ion battery and ultracapacitor hybrid storage systems could operate as an integrated grid asset by operating in synchronous grid-forming mode. Furthermore, several projects have highlighted the significant benefits of renewable energy in weak end-use grids. On the power system side, online assessment and optimization has been developed for stability evaluation of renewable energy systems, which shows the enormous potential of AI-assisted analysis applications. AI techniques can also be adopted to develop diagnostic tools for failure detection and diagnosis of PV plants, which is crucial for ensuring the long-term stability and reliability of the system. In terms of transmission, connecting the mainland to offshore stations using flexible high voltage direct current (HVDC) systems is a key factor in enhancing system efficiency.

- MVDC collection and grid integration technology provides a simpler, more efficient, and stable solution for large scale PV power stations
- Grid-forming hybrid energy storage system can provide various services to ensure the safe operation of electricity system and integration of renewable energies
- AI enables efficient stability analysis and control optimization of power system with high proportion renewable energy

About GPFM

The Green Powered Future Mission (GPFM), launched within the second phase of the global initiative Mission Innovation (MI2.0), is a public-private partnership with members from MI countries, private sector companies and international organisations. It aims to demonstrate that by 2030, power systems in different geographies and climates can effectively integrate up to 100% variable renewable energies, like wind and solar, in their generation mix, and maintain a cost-efficient, secure and resilient system.

https://explore.mission-innovation.net/mission/green-powered-future/

GPFM Coalition

***Case study #1** from factsheet P1-01*

PV MVDC power generation grid connection system

GPFM member
China

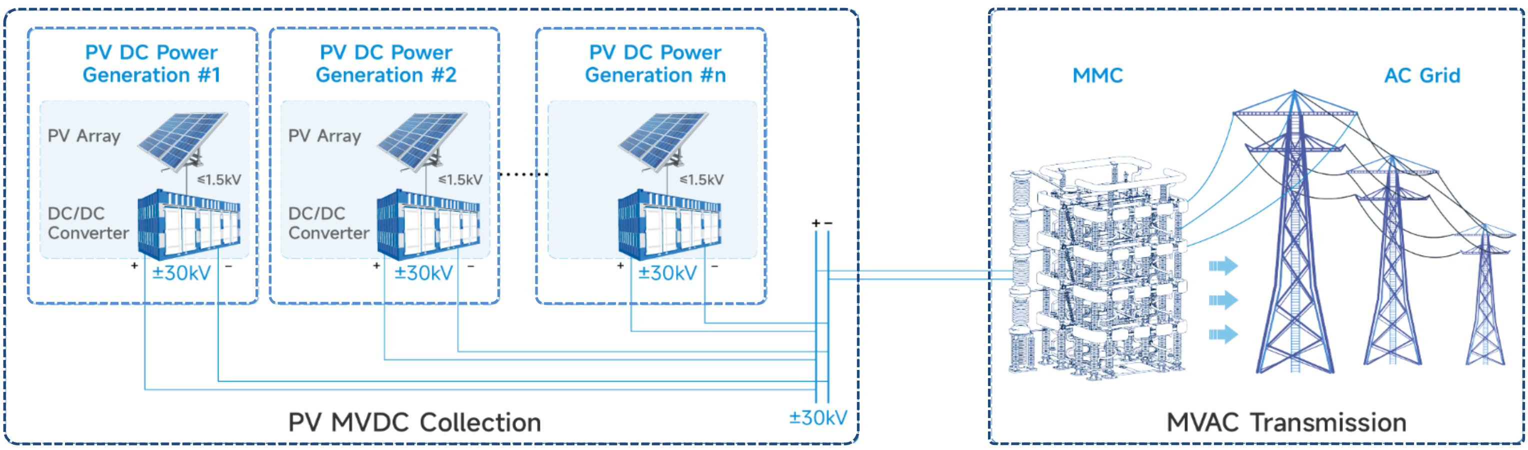
Q2 2016 → **Q2 2020**

Main involved partners

中国科学院·电工研究所 IEE CAS
Tsinghua University
中国三峡 China Three Gorges Corporation
North China Electric Power University

TRL 7

Large scale photovoltaic (PV) power generation station is an important development for renewable energy generation. In conventional alternating current (AC) systems, there are issues such as harmonic resonance, three-phase imbalance, and reactive power compensation in the marginal grid. Large scale PV power generation stations are often located at the periphery of the grid, and stability issues related to harmonic resonance and sub-synchronous oscillations frequently arise when using AC grid connection technology. Therefore, there is an urgent need for a more reliable technical solution. Some power plants use flexible direct current (DC) transmission technology, but it has complex structures, multiple conversion stages, lower efficiency, and higher costs. So, it's necessary to conduct research and development activities for a simple, efficient, and autonomously controllable new DC collection system. Medium-voltage direct current (MVDC) collection and grid integration technology in large PV power stations involves boosting the low-voltage direct current (LVDC) output from PV arrays to medium or high-voltage direct current (MVDC/HVDC) for collection and connection. MVDC collection and grid integration are the future trend, with fewer conversion stages, no harmonic resonance, and no reactive power transmission issues. It covers a wider collection range and longer transmission distances, reducing system equipment and cable requirements by over 30% and improving system efficiency by 4%-6%. This approach is more conducive to aggregating advantageous resources, leveraging economies of scale, reducing electricity generation costs, and providing a simpler, more efficient, and stable solution.



Medium-voltage Direct Current

± 30 kV DC Converter

Large Scale PV Power Plant

Innovation Priorities

MVDC / LVDC-based renewables systems for enhancing stability and efficiency | **IP 1.6.3**

The PV MVDC converter is a crucial component of PV MVDC grid integration systems. It serves functions such as maximum power point tracking, MV electrical isolation, and voltage transformation. The current mainstream research direction, both domestically and internationally, involves modular input parallelization and output series connection.

Demonstration Validation Study of the PV MVDC system

In 2019, the Institute of Electrical Engineering Chinese Academy of Sciences (IEECAS) established the world's first ±30 kV/5 MW PV DC boosting and collection grid integration demonstration system in Dali city, Yunnan province. This system includes a 2 MW centralized PV DC boosting and collection system, as well as a 3 MW series-connected PV DC boosting and collection system. IEECAS also developed a ±30 kV/1 MW centralized DC converter specifically for PV DC boosting and collection grid integration. This converter features maximum power point tracking for PV and efficient DC grid connection with high voltage ratios. Third-party testing has confirmed that the DC converter has an input voltage range of 450 V to 850 V, a maximum DC output voltage of ±33 kV, a DC voltage boosting ratio ranging from 88.5 to 143 times, soft switching over a wide power range (20% to 100%), and a maximum conversion efficiency of 97.46%. These achievements address technical requirements related to wide input voltage ranges, high power, large voltage boosting ratios, and overall efficiency. To meet the on-site operational requirements of the system, the IEECAS team elevated the DC converters from Technology Readiness Level (TRL) 3 (feasibility validation of concepts and application ideas) to TRL 6 (completion of relevant environmental verification using system or subsystem prototypes). These individual converters have a rated power of over 1 MW and a voltage boosting ratio exceeding 60 times. Furthermore, by using a power segmentation control strategy, three 20 kV/500 kW PV DC converters are connected in series to form a ±30 kV/1.5 MW series-connected system, achieving coordinated operation within the series system.

This project was supported by the National Key R&D Program "Novel DC-DC Boost Converter Module Based on Wide Bandgap Power Device for HVDC-connected PV Unit" (2016YFB0900205).

Project coordinator: Yibo Wang

To know more about the GPFM and the factsheet series
https://explore.mission-innovation.net/mission/green-powered-future/

Case study #2 from factsheet P1-01

AI-based algorithms for PV plant failure detection and diagnosis

GPFM member Italy

Q1 2023 ▶▶ **Q4 2024**

Main involved partners

RSE Ricerca Sistema Energetico – we move research

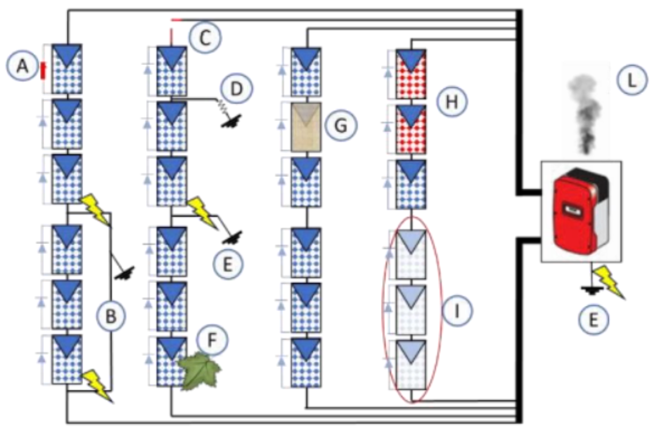
POLITECNICO MILANO 1863

TRL 3-6

Adopting advanced and innovative solutions that would increase photovoltaic (PV) plant overall efficiency while keeping a competitive levelized cost of electricity (LCOE) is paramount to meet national and international climate goals. A relevant option that can reduce Operative & Maintenance (O&M) costs for PV is to leverage the digitalization and the robotization of inspection activities. The failure monitoring systems of a PV plant already collect data with proper granularity, but there is still much room for data analysis improvement. In fact, it is relevant to recognize not only the efficiency loss but also the cause of faults, alongside the consequences to the PV plant and/or the installed assets.

New machine learning techniques can be adopted to develop diagnostic tools powered by Artificial Intelligence (AI) algorithms for Failure Detection and Diagnosis (FDD). Several factors must be considered in the development of FDD tools for utility scale PV plants such as the possibility of having PV modules from different vendors, the degradation of sensors and components as well as the weather uncertainties/peculiarities. All these factors, and potentially others, must be duly considered during the development of FDD tools, in view of guaranteeing reliable and efficient operation of photovoltaic systems over time.

In the figure the main kind of failures or malfunctions of a PV plant are presented: "**bypass diode fault**" due to thermal or electrical stresses; "**line-line fault**" due to accidental connection between two points at different voltage levels; "**low resistance insulation**" caused by silicone deterioration or by the presence of humidity; "**ground fault**" occurring when electricity is dispersed on the ground; "degradation" referring to both **cell degradation** (e.g. corrosion of the metallic contacts) or to the **potential induced degradation**; "**overheating**" occurring to the inverter due to cooling system failure or to the PV modules due to bad ventilation; "**shadowing**" and "**soiling**" as variable phenomena reducing PV modules performances and causing effects similar to faults.



A: Bypass fault
B: Line-line fault
C: Open circuit
D: Low R insulation
E: Ground fault
F: Shadowing
G: Soiling
H: Hotspot
I: Degradation
L: Overheating

Failure Detection and Diagnosis

AI-based algorithms for PV plants

PV modules faults and malfunctioning

Innovation Priorities

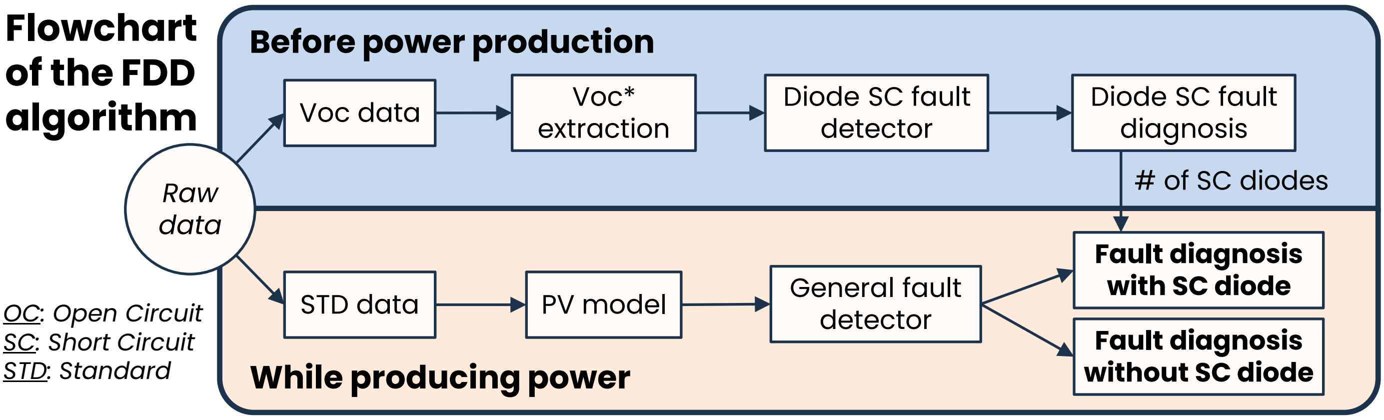
Reliability evaluation of PV modules and systems | **IP 1.1.3**

Data repository of PV failures and models for combined fault diagnosis in PV plants

When multiple faults or malfunctions that have similar consequences on the PV plant performances occur simultaneously, Failure Detection and Diagnosis (FDD) algorithms have difficulties in correctly identifying them. This case study focuses on studying the effect of a combination of different faults or malfunctions on the PV plant parameters to develop a model for their detection. In the first phase, a Test facility for PV FDD was optimized. Then, faults that can occur simultaneously were studied and methods to detect them accurately have been elaborated. Thanks to the data acquired in the test facility, a labelled data repository of PV failures was created to train the development of digital PV O&M tools; this apparatus will also be made available to the scientific community interested in this topic. Models to identify and diagnose multiple faults, as well as to recalibrate the models to take into due consideration the aging of the PV technology, have also been developed.

The approach adopted to implement the model was to study the behaviour of each failure or malfunction to assess how to clearly identify and distinguish them. The focus was on the overlapping effects of Short Circuit Bypass Diode (SCBD) and the increase of series resistance due to cell degradation since data shows that this was the failure combination leading to the higher level of uncertainty. In fact, both failures produce voltage losses, but those from SCBD are independent of the irradiance and can be evaluated before the PV plant starts up. After this classification of multiple failures, the model can act on detecting other fault possibilities (ground fault, line-line fault, low insulation resistance, increase of series resistance).

Flowchart of the FDD algorithm



Project website: https://www.rse-web.it/en/projects/integrated-high-efficiency-photovoltaic-project/ **Project coordinator:** RSE - Italy

To know more about the GPFM and the factsheet series
https://explore.mission-innovation.net/mission/green-powered-future/

GREEN POWERED FUTURE MISSION

Pillar 1
Affordable and Reliable VRE

***Case study #3** from factsheet P1-01*

800MW Offshore Wind Power Flexible HVDC Transmission Demo Project

GPFM member
China

Q4 2019 → **Q4 2023**

Main involved partners

TRL 9

The 800MW offshore wind power project of China Three Gorges Renewables (Group) Co., Ltd. Jiangsu Branch (Nan Tong & Ru Dong) is located in the Huangsha Ocean area of Rudong County, Jiangsu Province. The total installed capacity is 800 MW, with a total of two hundred 4 MW wind turbines installed, while two 220 KV offshore booster stations, one offshore converter station and one onshore converter station were also constructed as supporting facilities. After the wind turbine generates electricity, it is connected to the offshore converter station through two 220 kV submarine cables. The offshore converter station rectifies the electrical energy to direct current (DC) and sends it to the onshore converter station through a ±400 kV DC submarine cable. The onshore converter station then inverts the electrical energy to 500 kV alternating current (AC) and connects it to the newly built Tonghai substation through a 500 kV line.

Project Highlights

1. Offshore converter station

The building scale of the Offshore converter station is 8-10 times that of the conventional offshore booster station, which is composed of two parts: jacket foundation and upper module. Among them, the split jacket foundation type and the upper block float installation have extremely high requirements for land and offshore installation accuracy.

The offshore installation of the split jacket of the lower foundation needs to be positioned separately, and the project innovatively adopted four load-bearing positioning auxiliary piles, which controlled the relative accuracy within 10 mm after installing of the two jackets that were nearly 70 m apart.

Offshore Wind Power

Flexible DC Transmission

Offshore Converter Station

Innovation Priorities

Large-scale IRE generation for improving system reliability and stability | **IP 1.3.2**

2. High-voltage, long-DC transmission submarine cable

The project used ±400 kV DC submarine cables, including two 99 km submarine cables. It has broken through the technical bottlenecks such as the soft joint of the low cross-linking system and the world's highest cable operating overvoltage of 1235 kV. Generally, the submarine cable laying has high requirements for offshore construction technology and quality control, especially ±400 kV DC submarine cable, so the laying implementation of Rudong DC submarine cable also promotes the development of the submarine cable laying.

3. New technology of flexible high voltage direct current (HVDC)

The converter in flexible HVDC is the voltage source converter (VSC), which is characterized by the use of turn-off devices (usually IGBTs) and high-frequency modulation technology. By adjusting the amplitude of the converter outlet voltage and the power angle difference with the system voltage, the output active power and reactive power can be controlled independently.

The project researched and proposed that system's main wiring scheme was suitable for flexible HVDC transmission of offshore wind power, which has effectively solved the special engineering requirements of offshore wind power island power supply, connecting the land and offshore station. Meanwhile, the system overvoltage and insulation coordination design was proposed to improve the safe and stable operating margin of the system under complex working conditions. The compact, lightweight equipment body design and interface coordination scheme also further reduced the size and weight of the offshore converter station.

Project coordinator: Yu Liu

To know more about the GPFM and the factsheet series
https://explore.mission-innovation.net/mission/green-powered-future/

Case study #4 *from factsheet P1-01*

Online stability assessment and optimization of HVREPS

GPFM member
China

Q1 2012 ▶▶ **Q4 2021**

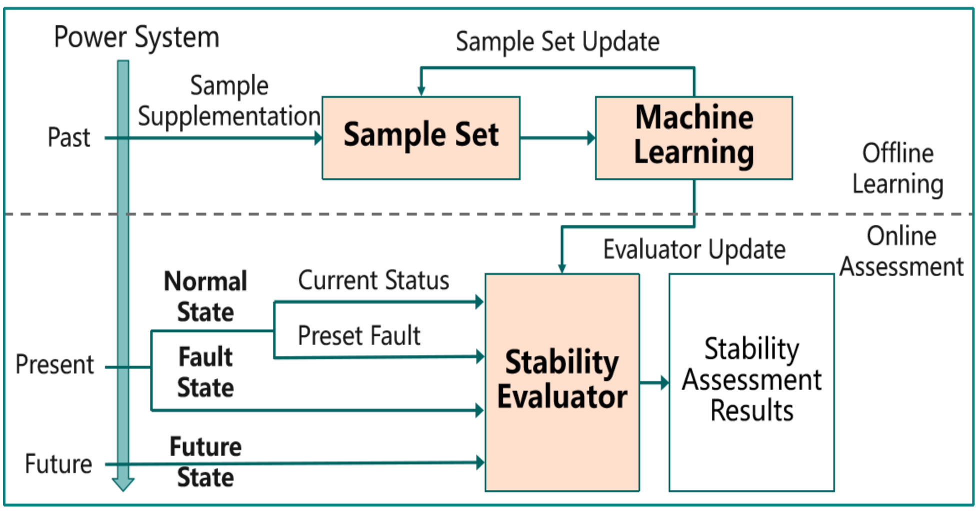
Main involved partners

国家电网 STATE GRID

中国电力科学研究院有限公司 CHINA ELECTRIC POWER RESEARCH INSTITUTE

TRL 9

Renewable energy lacks active support capabilities for continuous fault crossing, voltage regulation, frequency control, damping, etc. This leads to rapid frequency fluctuations and complex voltage transient processes of high-proportion variable renewable energy power system (HVREPS) after faults. Consequently, there is an increased risk of wide frequency oscillations and a deterioration in the stability level of HVREPS. The assessment of online stability serves as a crucial foundation for gauging the system's stability level and devising an effective control strategy. However, due to the intricate and dynamic operating conditions of HVREPS, conventional methods exhibit inadequate timeliness, thus failing to meet the operational requirements. The present study introduces a novel probabilistic prediction technology for renewable energy. Building upon this foundation, offline training and online evaluation methods are employed to achieve rapid stability assessment. Then the "generator-station-grid" flexible multi-level collaborative active support control technology was employed to optimize the stability of the HVREPS.
Multi-time scale probability prediction of renewable energy generation provides data support for system stability evaluation and control optimization. A rapid online stability assessment method based on machine learning is proposed for HVREPS to achieve swift updates in stability assessment under complex and variable operating conditions.
The proposed multi-stage collaborative flexible active support control technology for the "generator-station-grid" addresses the scenario of insufficient stability margin, with the aim of achieving transient support such as frequency, voltage, damping, continuous fault crossing control and suppression of broadband oscillation, which comprehensively improves the stability level of HVREPS.



High-proportion VRE power system

Online stability assessment

Active support optimization control

Innovation Priorities

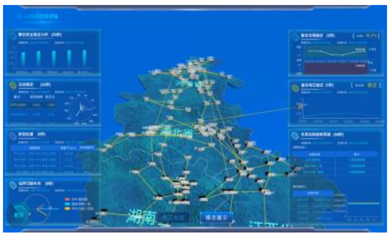
Large-scale IRE generation for improving system reliability and stability | **IP 1.3.2**

AI enables efficient stability analysis and control optimization of HVREPS

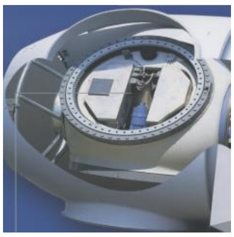
A medium and long-term wind power prediction method based on a regular non-complete beta function and a distributed photovoltaic power prediction method based on data enhancement were proposed. The changing trend of the load side and power generation side was simulated by constructing two neural networks, namely the load strategy network and the power generation strategy network, in order to achieve online stability evaluation. Improving the active support capability of wind farms by integrating frequency full trajectory optimization, multi-mode dynamic voltage support and subsynchronous oscillation suppression. The control of wind turbines was realized by applying over-speed/variable pitch energy storage, continuous fault ride-through and equivalent inertia control algorithms. Considering the safety margin and reactive power coordinated output and based on the DC voltage deviation characteristics of the converter station, the multi-objective master-slave hierarchical voltage optimization was realized.

Significant accomplishments through the implementation of data-driven analysis and control for stability

The error of the proposed multi-temporal scale wind power supply capacity prediction method is less than 4%, which is 31% lower than that of the traditional method. The evaluation accuracy of the stable evaluation method is more than 98%, and the evaluation speed is increased by 97%. The inertia response speed of the wind turbines/wind farm is increased by 60% and 50%, and the reactive power response time is shortened by 61.7% and 60%, respectively. The reactive power margin and voltage safety margin are increased by 87.5% and 15%, respectively, which reduces the system network loss, stabilizes the voltage fluctuation, and reduces the maximum frequency drop of 42.8% when wind power participates in frequency regulation.



On-line monitoring system



Wind turbine pitch system

Converters and control cabinets

Wind farm VSG6.0

Wind farm EMS

Project coordinator: Zongxiang Lu

To know more about the GPFM and the factsheet series
https://explore.mission-innovation.net/mission/green-powered-future/

***Case study #5** from factsheet P1-01*

VisynC: Development of a hybrid energy storage system

GPFM member
Spain

Q4 2024 → **Q4 2028**

Main involved partners

censolutions, cere by UL Solutions, redeia, S2 GRUPO

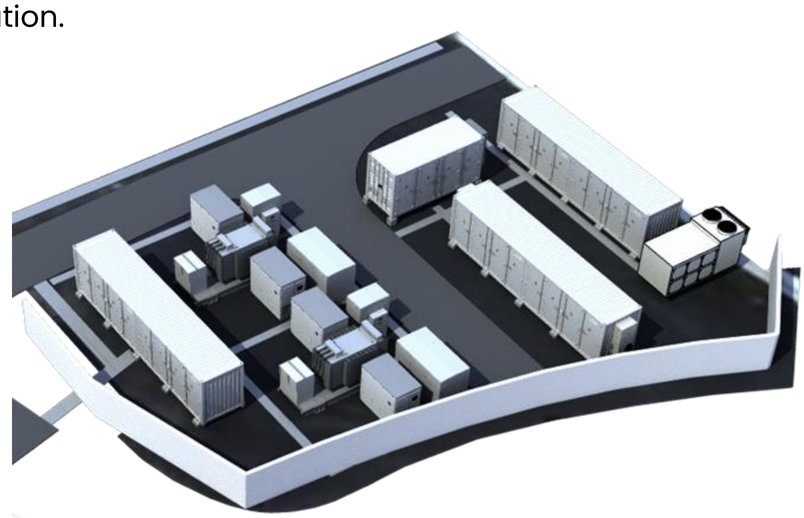
TRL 6

Spain's Energy Storage Strategy aims to meet the targets in the National Integrated Energy and Climate Plan (PNIEC) and the Long-Term Decarbonization Strategy by increasing energy storage capacity from 8.3 GW in 2021 to around 20 GW by 2030. This significant boost is essential for achieving renewable integration goals. The island systems (Balearic and Canary Islands) are particularly crucial for energy storage installations due to their isolated nature and limited grid interconnection, which hampers renewable energy penetration.

Energy storage solutions play a vital role in integrating renewable energies by offering various services to the electricity system. These services range from rapid, high-power responses lasting seconds or minutes to longer-duration, energy-intensive responses lasting 30 minutes to hours. This versatility improves the economic viability of storage systems. However, relying on a single technology like lithium-ion often leads to either oversizing or premature degradation. Hybrid storage, which combines different technologies, can address these issues by optimizing the response to diverse electricity system needs. For example, hybridizing lithium-ion batteries with ultracapacitors, known for their fast power response, is a promising approach.

This project aims to develop and validate a full-scale hybrid storage system combining lithium-ion batteries and ultracapacitors, managed by a specific control system for synchronous grid-forming mode. The system will connect to the high voltage transmission grid in the Lanzarote-Fuerteventura electricity system at the Mácher 66 kV substation.

Operating in synchronous grid-forming mode, it will serve as an integrated grid asset, providing numerous services to ensure the electricity system's safe operation and support increased renewable energy integration. This project tackles the dual challenge of enhancing grid stability and facilitating renewable energy integration, significantly contributing to Spain's energy storage and decarbonization goals.



Energy community

Storage

Flexibility

Innovation Priorities

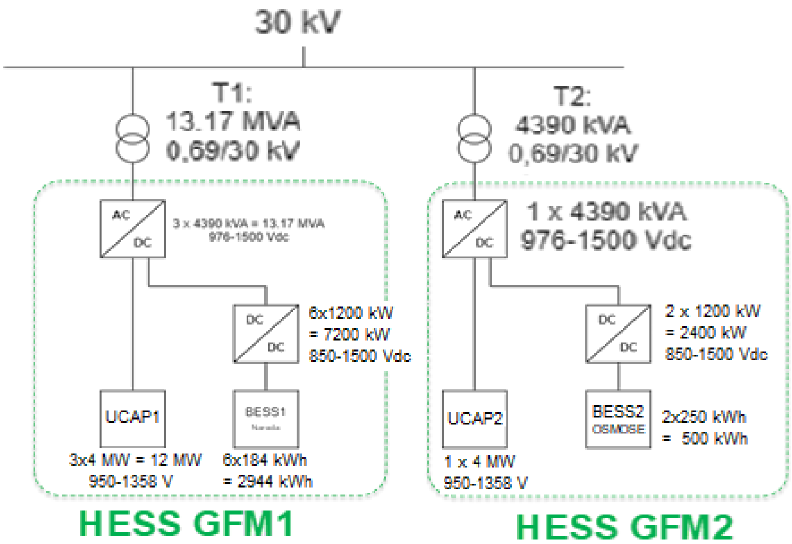
MVDC / LVDC-based renewables systems for enhancing stability and efficiency | IP 1.6.3

Renewable systems for enhancing stability and efficiency

Renewable Energy Sources (RES), like photovoltaic and wind, lack mechanical inertia to stabilize the grid during frequency disturbances, requiring new services to mimic this inertia. As RES increase, new technologies must enhance grid flexibility. Investigating RES solutions, like coupling VRE with storage systems, deploying flexible RES, and utilizing novel RES, is crucial. Integrating RES with Power to X (P2X) technologies can optimize energy use but faces challenges. Increased RES shares introduce mismatches in production and demand, necessitating long-term storage solutions like synthetic fuels or hydrogen.

This use case outlines the information exchanges between Transmission System Operators (TSOs), Distribution System Operators (DSOs), Flexibility Operators, and Market Operators for procuring flexibility from distributed energy resources. Flexibility Operators must coordinate with both TSOs and DSOs to prevent double service activation. Collaboration between TSOs and DSOs is vital to avoid negative impacts from Distributed Flexibility Resource (DFR) activation on their networks. DFR providers should be able to offer services to both TSOs and DSOs, with TSOs procuring flexibility from large industrial consumers or aggregators and DSOs from aggregators and various Distributed Energy Resources (DERs), such as distributed generation, demand response, decentralized storage, and electric vehicles, to maintain service quality and supply security.

Flexibility delivery is verified by comparing requested and actually delivered flexibility, calculated as the difference between baseline and metered consumption / generation of the Flexibility Service Provider. Penalties are imposed for under-delivery, and the imbalance settlement process follows, although it is beyond the scope of this use case.



Project coordinator: Red Electrica Infraestructuras

To know more about the GPFM and the factsheet series
https://explore.mission-innovation.net/mission/green-powered-future/

GREEN POWERED FUTURE MISSION

Pillar 1
Affordable and Reliable VRE

Case study #6 *from factsheet P1-01*

RE empowering European and Indian communities (RE-EMPOWERED)

GPFM member India

Q3 2021 ▶▶ **Q4 2024**

Main involved partners

Department of Science & Technology, Government of India

सत्यमेव जयते

TRL 6

Ghoramara Island (India)

- Not connected to main grid, few rooftop PVs, severe cyclonic storms every 2-3 years
- A power plant of 160 kW capacity (150kW PV, 10kW Wind, 720 kWh BESS) is built to electrify 1100 houses of the island.
- A solar powered EV charging station is installed.

Keonjhar (India)

- Isolated rural Villages
- Existing renewable facilities will be upgraded to improve the living standards of the community.
- 30 kW PV, 180 kWh Battery, 10 kW Biomass and 10kW biogas are added to the existing system.

Bornholm Island (Denmark)

- Received the 2019 RESponsible Island Prize by the EC
- Synergies of integrating energy vectors (power/heat) will be explored.
- Focus on unlocking the demand flexibility for higher RES utilization in grid-connected islands.

Kythnos Island (Greece)

- It has Kythnos power system and Gaidouromantra microgrid (first microgrid in Europe).
- Focus on optimal operation and higher penetration of RES.

Installations at Ghoramara Island

Installations at Keonjhor

Islanded Microgrid

A locally made Wind Turbine

Wind Resilient Structure

Large-scale IRE generation for improving system reliability and stability | **IP 1.3.2**

Innovation Priorities

Technology Developed under this Project

1. A 20 kW plug-and-play type inverter
2. A 20 kW microgrid with RE-EMPOWERED developed technologies - A complete solution for Islanded Local Energy Systems (ILES)
3. STATCOM- A power conditioner to mitigate power quality issues of an islanded local energy system
4. Temperature Controlled EV Charger (1.5 kW)
5. An advanced forecasting algorithm for accurate prediction of renewable generation
6. Dual Active Bridge (DAB) converter for the integration of multiple energy vectors (e.g. PV, biomass, biogas, and BESS)
7. Advanced smart meters with load limiting functionality
8. A low cost ecoMonitor tool to measure key air quality parameters
9. Wind resilient structures for PV and Wind Turbines
10. A locally manufactured small wind turbine (2.5 kW)
11. An FPGA based real time digital control platform
12. A business model for sustainability of the local energy system

Digital control platform

DAB based DC-DC converter

Installations at Bornholm Island

Installations at Kythnos

Project website: https://reempowered-h2020.com/ **Project coordinator:** IIT KGP, NTUA

To know more about the GPFM and the factsheet series
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GREEN POWERED FUTURE
MISSION

Pillar 2

System Flexibility and Market Design

Factsheet P2-01

Tools and solutions for flexible power systems

Power systems flexibility is crucial to allow integration of high shares of Variable Renewable Energy (VRE) sources. Exploiting and managing flexibility requires a broad set of technologies and solutions, as well as innovative components able to measure not only electrical but also environmental variables, allowing optimal use of the grid infrastructure. Markets for ancillary services, local flexibility and Demand Response (DR) also need to be implemented, considering VRE characteristics, storage and electric vehicle capabilities in providing flexibility.

This factsheet highlights relevant case studies from GPFM members addressing Innovation Priorities aimed at developing tools and solutions to enhance power systems flexibility.

GPFM Innovation Priorities in scope:

- **IP 2.3.2** - Enhanced TSO-DSO coordination platform for flexibility markets optimisation
- **IP 2.3.4** - Tools and solutions for DSO flexibility management
- **IP 2.7.1** - Flexibility markets for innovative ancillary services by VRE and storage

6 Case studies reported in this factsheet

31 Projects covering these IPs are included in the GPFM National Pilots report

For further details on **GPFM Innovation Priorities (IPs):**

GPFM Roadmap

Action Plan 2022-2024

National Pilots Report

October 2024, Brazil – CEM15/MI-9

GREEN POWERED FUTURE MISSION

Case studies

Case Study #1 Massive deployment of DR for grid operation optimization, with focus on energy communities

Energy communities are revolutionizing local energy management by enabling residential, commercial, and industrial users to collaborate on efficient energy generation and consumption.
By integrating advanced technologies, innovative market mechanisms, and active community participation, Areti Pilot #1 aspires to set a benchmark for sustainable urban energy management. The project not only tackles immediate grid management challenges but also lays the groundwork for a resilient and inclusive energy future for Rome. Moreover, it could serve as a model for other cities facing similar energy transition challenges.

Link to case study's detailed description

Areti

Case Study #4 Edge

The pilot project Edge has the aim to the test of 'local ancillary services'- i.e. flexibility related to distribution grid criticalities management. It was required by the National Regulatory Agency to Italian DSOs to assess planning methods, products definition, procurement and operational procedures. The project is set by e-distribuzione in 2024 within 4 areas. Services can be offered by any connected user or aggregate set of users that complies with the technical requirements and will be compensated according to the contract conditions coming from 'pay-as-bid' competitions performed in third party market platform (Piclo). The software in use is the Enel DERMS, in charge to foresee criticalities and allocate flexibility to resolve them.

Link to case study's detailed description

Enel Grids

Case Study #2 Smarter homes for South Australia

South Australians are enthusiastic adopters of distributed energy resources (DER). Over 40% of homes in South Australia have rooftop solar installed and around 10% also have batteries. Rooftop solar has at times fully met the entire electricity demand of the state. Achieving secure operation of this GW scale region with extensive distributed energy has required a range of measures – including inverter disturbance ride through; remote connection capability; dynamic export limits, upgraded smart metering & tariff reform. Measures such as enhanced voltage management have allowed the transition to progress while coordinated DER control schemes are developed and implemented.

Link to case study's detailed description

Australia

Installed solar PV capacity by 2050 according to 1.5°C scenario

14000 GW

Installed wind capacity by 2050 according to 1.5°C scenario

8100 GW

Source: *IRENA*

Case Study #5 Blockchain for local energy communities

The progressive engagement of final users, thanks to the wide spreading of distributed resources, calls for the deployment of technologies to support local energy management systems and energy markets. Blockchain can be exploited in this context and particularly within energy communities as a distributed ledger to enable reliable management of energy transactions. RSE implemented a blockchain market architecture, integrating it with a final users' emulator, to enable study of market mechanisms applicable for energy and flexibility services trading. The architecture is based on a "trading agent" for each end user that automatically generate buy or sell orders and match them with the ones submitted by other users.

Link to case study's detailed description

Italy

Key metrics

To manage large-scale VRE, flexibility must be exploited in all sectors of the energy system, from production to stronger electrical systems, storage and more flexible demand.

Well-developed grid infrastructure allows the system to access existing flexibility

Improving system operations make possible to reduce requirements for grid flexibility

https://www.irena.org/publications/2018/Nov/Power-system-flexibility-for-the-energy-transition

Case Study #3 Market-based approaches to securing local services from DERs

The project demonstrated the first distribution-level Non-Wires Alternative market for DER providers in North America based on a full DSO model, interoperable with participation in the wholesale market. The project held two auction periods securing 10 and 15 MW of DERs to provide grid services (capacity, energy, reserve) over 6-month summer periods. The amount of DERs registered exceeded procurement targets, with clearing prices lower than the ceiling price. Resource categories consisted of demand response and distributed generation. Participating DERs were activated on 15 occasions, providing a total of 366 MWh in energy services. The project found that DER availability, reliability, and cost-effectiveness were sufficient to consider scaling the concept.

Link to case study's detailed description

Canada

Case Study #6 Data-driven operation of distribution networks to unlock flexibility services / FlexOnGrid

The FlexOnGrid project aims to enhance the operation of distribution networks using flexibility services from third parties. Despite proven benefits, technical challenges persist, such as the vast data from smart meters, low real-time monitoring, lack of detailed network models, poor communication between stakeholders, and the unbalanced nature of grids. FlexOnGrid addresses these by demonstrating that data-driven techniques can provide the needed flexibility, working on distributed and autonomous local control with partial network information, and testing model-free solutions to integrate renewable sources effectively.

Link to case study's detailed description

Spain

Key findings

The case studies reported in this factsheet highlight the opportunities for system operators to procure flexibility services from distributed energy sources, through aggregators in the case of small units, to solve congestion and maintain high levels of security and quality of supply. To optimally manage this new sources of flexibility, coordination among TSOs and DSOs as well as with other system level actors like aggregators and market operators is crucial.
Another significant outcome from the case studies is that to enable the trading of innovative flexibility services, the implementation of suitable platforms for local flexibility markets aimed at optimizing the exploitation of distributed resources potential is key.
Two case studies also highlight the opportunities opened by energy communities that allow local energy management by enabling residential, commercial, and industrial users to collaborate on efficient energy generation and consumption. In this view, blockchain has been proposed to implement a reliable system to manage local energy transactions.

- DERs demonstrated the ability to provide grid services to DSOs without safety incidents, meeting activations signals and fulfilling grid distribution needs
- TSO-DSO coordination is needed to ensure that services from DERs are activated without affecting grid security
- Off-grid microgrids can support local renewable energy use and self-consumption thanks to storage and dedicated energy management systems

About GPFM

The Green Powered Future Mission (GPFM), launched within the second phase of the global initiative Mission Innovation (MI2.0), is a public-private partnership with members from MI countries, private sector companies and international organisations. It aims to demonstrate that by 2030, power systems in different geographies and climates can effectively integrate up to 100% variable renewable energies, like wind and solar, in their generation mix, and maintain a cost-efficient, secure and resilient system.

https://explore.mission-innovation.net/mission/green-powered-future/

GPFM Coalition

***Case study #1** from factsheet P2-01*

Massive Deployment of Demand Response for Grid Operation Optimization, with focus on Energy Communities

GPFM member
Areti

Q3 2024 ▶▶ **Q3 2027**

Main Involved partners

areti

TRL 7

Energy communities are revolutionizing local energy management by enabling residential, commercial, and industrial users to collaborate on efficient energy generation and consumption. This collaborative approach enhances energy security, reduces costs, and supports broader decarbonization goals.

In cities like Rome, where rapid electrification of transportation and heating is increasing energy demand, the Areti Pilot #1 project addresses the challenges posed by this surge. It employs Demand Response (DR) strategies to shift or reduce energy use during peak periods, helping to balance the grid amidst growing renewable energy sources like solar and wind.

A significant aspect of the project is the creation of a local flexibility market, which integrates with the Transmission System Operator's system via Traffic Light mechanisms. This market enables trading of energy flexibility between consumers and grid operators, optimizing the use of distributed energy resources. Energy communities play a crucial role here by aggregating and managing distributed generation and flexible consumption, thus stabilizing the grid.

Additionally, Areti Pilot #1 aims to manage the distribution grid effectively while promoting social equity. It redistributes surplus electricity to vulnerable consumers at risk of energy poverty, supporting both grid stability and social welfare.

By integrating advanced technologies, innovative market mechanisms, and active community participation, Areti Pilot #1 aspires to set a benchmark for sustainable urban energy management. The project not only tackles immediate grid management challenges but also lays the groundwork for a resilient and inclusive energy future for Rome. Moreover, it could serve as a model for other cities facing similar energy transition challenges.

Energy communities

IoT Device

Electrical grid

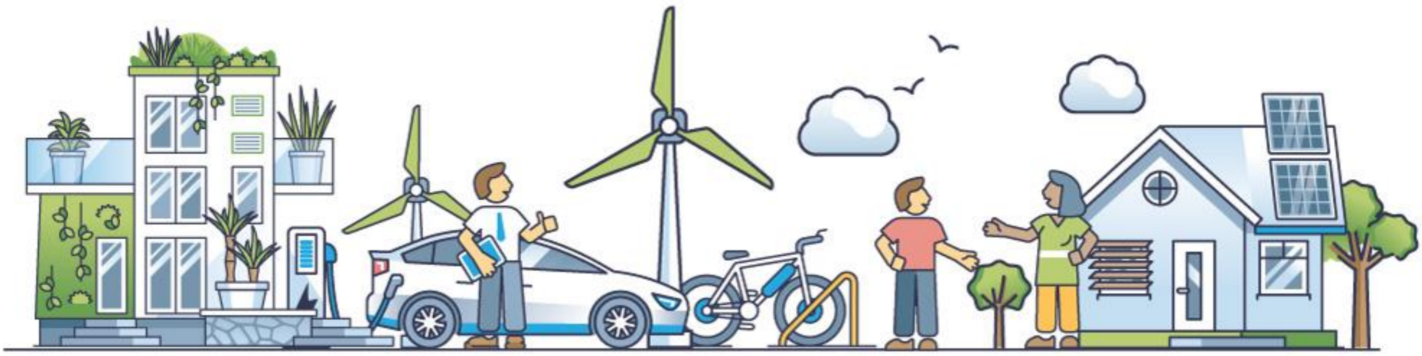
Innovation Priorities

Tools and solutions for DSO flexibility management | **IP 2.3.4**

Flexibility markets for innovative ancillary services by VRE and storage | **IP 2.7.1**

Massive Deployment of Demand Response for Grid Operation Optimization, with focus on Energy Communities

- The Areti Pilot #1 project aims to deploy an advanced Demand Response (DR) system in Rome's electrical grid. It involves collecting and analyzing data to manage peak demand using smart meters, sensors, and advanced analytics. The project uses Traffic Light mechanisms to signal demand response events, prompting customers to adjust energy usage via automated control systems.
- A key component is the creation of a local flexibility market, allowing the trading of energy flexibility between consumers and the grid operator. This market maximizes resource utilization by aggregating flexible loads and distributed generation from Energy Communities, which manage their consumption and generation through integrated platforms.
- The project includes deploying smart meters and IoT devices communicating over a secure network, supported by software platforms providing analytics and user-friendly interfaces for community members. A central control center operated by areti collects and analyzes data in real-time, aiding effective decision-making.
- Initial results show significant potential for reducing peak demand and improving grid stability, addressing congestion and voltage issues, and contributing to a more reliable and resilient electrical grid in Rome. This approach sets the stage for a sustainable and inclusive energy future.



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GREEN POWERED FUTURE MISSION

Pillar 2
System Flexibility and Market Design

***Case study #2** from factsheet P2-01*

Smarter homes for South Australia

GPFM member Australia

Q1 2020 ▶ Q4 2027

Main Involved partners

SA Power Networks

Government of South Australia

TRL 7-9

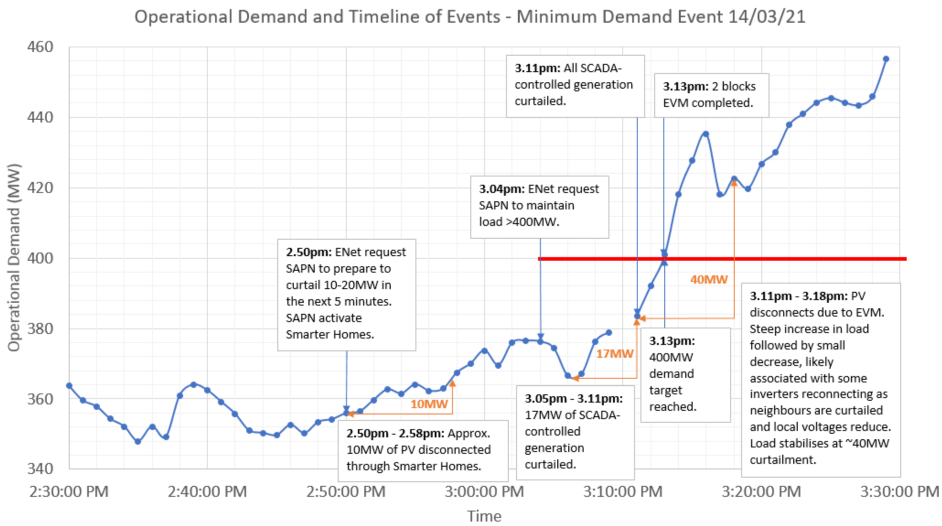
South Australians are enthusiastic adopters of distributed energy resources (DER). Over 40% of homes in South Australia have rooftop solar installed and around 10% also have batteries. Rooftop solar has at times fully met the entire electricity demand of the state.

Achieving secure operation of this GW scale region with extensive distributed energy has required a range of measures – including inverter disturbance ride through; remote connection capability; dynamic export limits, upgraded smart metering & tariff reform. Measures such as enhanced voltage management have allowed the transition to progress while coordinated DER control schemes are developed and implemented.

In 2020, the South Australian government working with the Australian Energy Market Operator (AEMO) identified a set of challenges and prioritised actions arising from the increasing and (at the time) unmanaged supply of electricity to the grid from rooftop solar. Essential foundational measures identified were:

- Improving DER performance standards, particularly inverter ride-through capability to ensure sustained operation during power system disturbances;
- Develop compliance monitoring and management processes to ensure DER devices operate according to existing standards – at the time, 30-40% of inverters were exhibiting behaviours that suggested non-compliance;
- Introduce flexible export mechanisms to allow active management of distributed PV - such as during periods of low demand or when SA is operating islanded from the main Australian electricity system;
- Strengthening transmission connections between the SA region and the main Australian electricity system.

With foundational measures in place, focus is now on the coordination of consumer energy resources and smart appliances to better match energy use to supply and respond to market signals, shifting households' energy use away from peak demand periods.



https://www.energymining.sa.gov.au/industry/hydrogen-and-renewable-energy/solar-batteries-and-smarter-homes
https://arena.gov.au/news/south-australia-leading-the-way-with-energy-smart-homes/

Rooftop PV

Voltage control

Smart home

Innovation Priorities

Tools and solutions for DSO flexibility management | **IP 2.3.4**

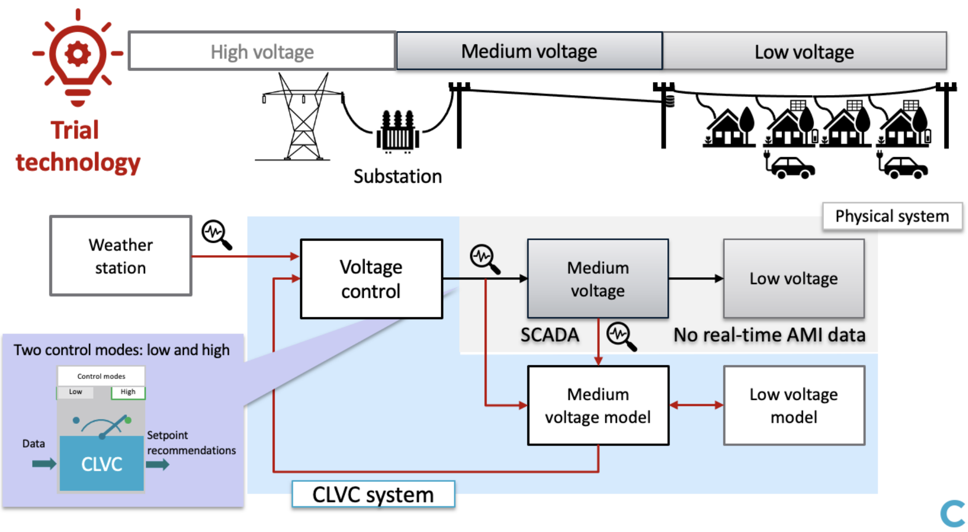
Closed-loop voltage control in limited-visibility distribution networks

Through the SA Government's Demand Management Trials Program, the Closed Loop Voltage Control project determined measures to support more distribution network installed rooftop solar and batteries, leveraging infrastructure from the SAPN Enhanced Voltage Management program.

This project developed a dynamic voltage control technology on SA Power Networks' distribution network to optimise network voltage by automatically controlling the substation voltage setpoint in response to real-time network state. This sought to emulate the work done by United Energy in Victoria, but without the benefit of a 100% visibility of customer voltage that the Victorian network-owned smart-meter infrastructure provides.

The closed loop voltage control (CLVC) approach was tested at the Hope Valley Zone Substation, which supplies 6500 customers. Data streams for up to 1085 smart meters were utilised, and an additional 10 distribution transformer monitoring units deployed. This very limited data set of external data sources, supplemented with data science and modelling provided more extensive estimate of conditions throughout the substation area.

The project successfully demonstrated that dynamic voltage control in limited-visibility distribution networks can support increases in DER hosting capacity and optimise voltage management to deliver demand response services while maintaining or improving customer power quality.



CSIRO

Project website: https://doi.org/10.25919/dta0-h847 **Project coordinator:** CSIRO

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GREEN POWERED FUTURE MISSION

Pillar 2
System Flexibility and Market Design

Case study #3 *from factsheet P2-01*

Market-based approaches to securing local services from DERs

GPFM member Canada

Q4 2018 → **Q1 2023**

Main Involved partners

Independent Electricity System Operator (IESO)

Alectra Utilities (Delivery partner)

TRL 8

Project Goal:

Investigate market-based approaches to securing local energy and capacity services from distributed energy resources (DERs).

Project Objectives:

- Design of a distribution-level Non-Wires Alternative (NWA) market for third party service providers that is interoperable with participation in the IESO's wholesale markets.
- Demonstration of new distribution-level functions and coordination with wholesale-level functions.
- Development of communication and dispatch protocols for IESO, local distribution companies, DERs and aggregators, and deployment of information and communication technology infrastructure needed.
- Development of an interoperability framework, assessing division of grid functions, transmission-distribution coordination requirements, technical feasibility, and cost-benefit.

Background:

In the province of Ontario, Canada, the wholesale (transmission level) electricity market is administered by the Independent Electricity System Operator (IESO). The IESO employs auction-based processes to procure capacity, energy, and operating reserves. Alectra is the local distribution company (LDC) that operates the distribution network in regions of Southern Ontario. LDCs in Ontario currently do not operate their own electricity markets. This demonstration was North America's first distribution-level local electricity market. The project took place in the York Region, near Toronto, where electricity demand is forecasted to outpace system capability. The project tested the potential of DERs to serve the region's electricity needs as a non-wires solution, and helped develop a better understanding of how to competitively procure and operate DERs. A "Total DSO" model was adopted that enables a DSO to procure and dispatch local services from DERs through auctions, in coordination with the Transmission System Operator (TSO).

Results:

Auction Periods were held in the fall of 2020 and 2021. Alectra, as the DSO, was responsible for operating the local auctions, coordinating resource activations, and facilitating payments. The project successfully secured the targeted amount of local capacity, energy, and reserve services from DERs. Capacity prices cleared at $0.64/kW-day (Y1) and $0.40/kW-day (Y2), and energy prices cleared at $1.81/kWh (Y1) and $1.19/kWh (Y2).

Affordability **Reliability** **Electricity Markets**

Innovation Priorities

Enhanced TSO-DSO coordination platform for flexibility markets optimisation | **IP 2.3.2**

Tools and solutions for DSO flexibility management | **IP 2.3.4**

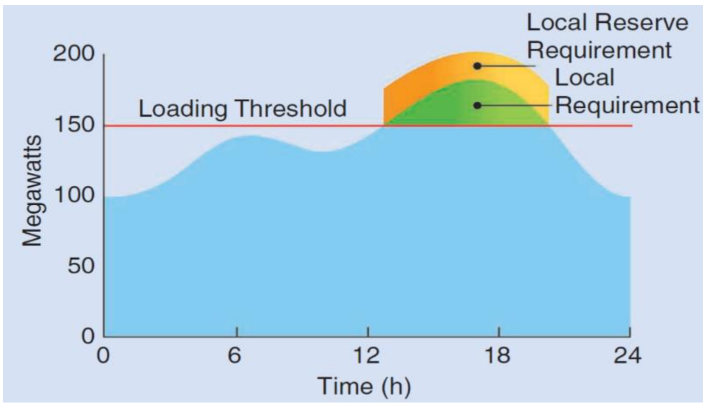
Flexibility markets for innovative ancillary services by VRE and storage | **IP 2.7.1**

The amount of DERs registered exceeded procurement targets, with clearing prices lower than the ceiling price and decreasing year-over-year decrease, reflecting the strong interest from DER providers in delivering grid services. Resource categories consisted of demand response and distributed generation and were offered by a diversity of participant types (residential, commercial, and industrial load customers, and aggregators). The procured resources committed to being available for a six-month summer period from May to October the ensuing years (2021 & 2022).Over those two operational years, participating DERs were activated on 15 occasions, providing 366 MWh in energy services, marking the first time in Canada that DERs secured through a local capacity auction were used to reduce local peak demand. All activations were driven by distribution-level needs. Participating DERs provided services without safety incidents, generally meeting activation requests and fulfilling distribution needs. The average availability metric was 83%, and when activated, the overall performance metric was 85% on a portfolio basis. A cost-benefit analysis suggests that DERs, providing multiple benefits in specific areas, can be cost-effective solutions to meet grid needs. Maximal value is realized with stackable services to both distribution and transmission, alongside effective coordination between them.

This project demonstrated that DERs can serve as available, reliable, and cost-effective non-wires solutions to address both distribution- and transmission-level needs.

Long-Term Outcomes:

Learnings from the York Region NWA Demonstration Project are crucial in shaping Ontario's future DER landscape and will aid towards building a modernized and decarbonized grid. The project has led to the publication of three whitepapers (below), the creation of an ongoing Transmission-Distribution Coordination Working Group and continues to inform the IESO's DER Market Vision and Design Project.



Source IEEE Power and Energy Magazine article, [Auctions for Nonwires Alternatives: Securing and Operating Dispatchable Distributed Energy Resources](#)

White papers:
- *"Non-Wires Alternatives Using Energy and Capacity Markets"* (2020)
- *"Development of a Transmission-Distribution Interoperability Framework"* (2020)

Project websites: https://www.ieso.ca/en/Sector-Participants/Engagement-Initiatives/Engagements/IESO-York-Region-Non-Wires-Alternatives-Demonstration-Project https://www.alectra.com/nwa

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***Case study #4** from factsheet P2-01*

Edge

GPFM member
Enel Grids

Q3 2023 ▶▶ **Q4 2024**

Main Involved partners

e-distribuzione

TRL 7

The Italian Regulation Authority (ARERA) started implementing the EU Directive 944/2019 provisions about local ancillary services, giving its general guidelines through the Consultation Document 322/2019. Subsequently, ARERA, through Resolution 352/2021, established the launch of pilot projects aimed at testing the procurement of flexibility by the DSOs and the related remuneration mechanisms. The resolution reaffirms the need for transparent, efficient, non-discriminatory procurement procedures which prevent entry barriers and allow broad participation, ensuring technological neutrality. ARERA did not provide binding guidelines – e.g. regarding the choice between short-term or long-term markets - leaving operators free to propose projects calibrated to their current needs and outlooks. So far, three projects have been approved, including EDGE of e-distribuzione (Resolution 365/2023).

Edge (*Energia da risorse distribuite per la gestione della rete di e-distribuzione*) is the pilot project proposed by e-distribuzione (ED) for 2024. It involves the medium and low-voltage networks under 63 primary substations in 4 Italian provinces (Foggia, Benevento, Cuneo, Venezia), with more than 550.000 connected users.

As per NRA's expectation, the focus of the pilot project is to test the design and procurement of 'active power' flexibility services to solve expected grid criticalities over long term forecast, under normal operating and N-1 operating conditions.

The flexibility forecast, to be procured for the pilot, was calculated through a Linearized Optimal Power Flow (LOPF) that exploits the flexibility of the nodes to bring the grid back within the correct operating parameters (current and voltage), minimizing the operating costs of the DSO.

The flexibility products to procure for solving the criticalities are defined through the parameters in table:

Parameter	Description
Availability window	Time frame (months/days/hours) in which the provision of the service can be activated
Quantity (kW)	Maximum active power variation (vs baseline) that can be requested 'up' or 'down'
Duration (minutes)	Maximum duration for which the provision of the service can be requested

Flexibility services

Distributed Energy Resources Management System (DERMS)

DSOs

Tools and solutions for DSO flexibility management | IP 2.3.4

Innovation Priorities

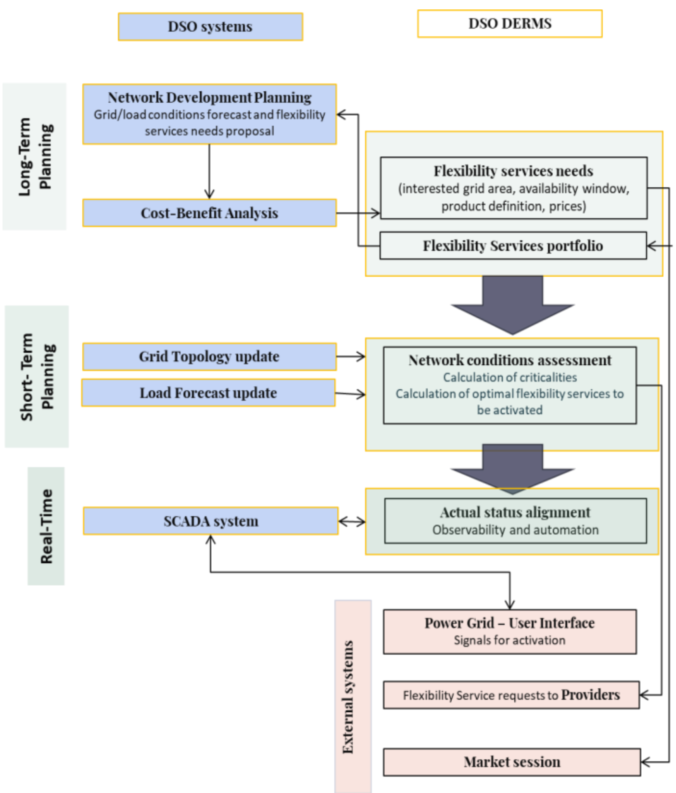
Edge project *(Energia da risorse distribuite per la gestione della rete di e-distribuzione)*

Taking into consideration the scope of the flexibility forecast calculation, i.e. the local flexibility products to procure over next year horizon, data input to the planning model was the following for any node under investigation:

- historical daily time series of demand and generation (at medium-voltage node level);
- trends in new connections;
- topology of the medium-voltage grid;
- planned network development interventions, expected to be completed by the end of 2024.

Based on the need forecast, the EDGE market approach is to issue public auctions through the Picloflex platform for contracting Flexibility Service Providers (FSP) to obtain seasonal availability with short activation time (1 hour). For the season 2024, 62 auctions were planned, aimed at contracting an overall Quantity ≈ of 10 MW over 7300 availability hours.

Even if both medium and low voltage users can apply, singularly or as an aggregate, to provide flexibility services, the main limit for suppliers' selection and service reliability is the need for (local) resources properly connected to the critical feeder. DERMS calculates the Load Flow (voltages and currents) for the given grid model, and the given load forecast. Based on the specified limits set on the model, the criticalities are identified in nodes and branches that exceed its limits. In the DERMS User Interface, the ED operator can see the graph and the list of all the forecasted criticalities for any grid element. The DERMS solution is able to submit the activation messages from ED to the FSP, based on an already existing and stabilized messaging system. Through the same messaging system, contracted FSP can interact with ED, automatically updating DERMS on FSP unavailability for a certain period of time.



Project website: https://www.e-distribuzione.it/progetti-e-innovazioni/il-progetto-edge.html

Project coordinator: Serena Cianotti (Enel)

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GREEN POWERED FUTURE MISSION

Pillar 2
System Flexibility and Market Design

***Case study #5** from factsheet P2-01*

Blockchain for local energy markets

GPFM member Italy

Q1 2023 ▶ **Q3 2026**

Main Involved partners

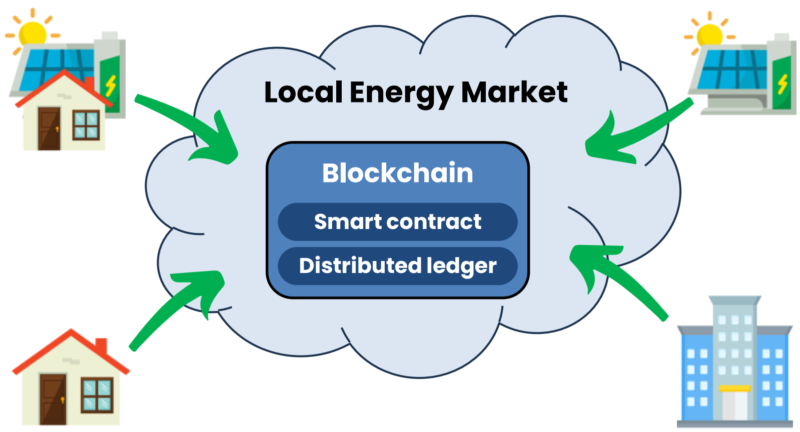
RSE Ricerca Sistema Energetico — we move rsearch

TRL 4

The energy system is evolving towards a progressive engagement of final users, due to the wide spreading of distributed energy resources capable of controlled power production and consumption (e.g. PV coupled with small scale energy storage, electric vehicles or heat pumps). Local energy communities are emerging as a way in which individuals, companies, institutions, etc. can actively contribute to the production and sharing of renewable energy. Blockchain technology can support the uptake of energy communities by means of reliable and transparent management of energy transactions.

Blockchain technology allows trusted recording of transactions on a digitalized shared ledger. The users have access to the ledger where all transactions remain visible and cannot be changed. Transactions are executed thanks to the definition of a set of rules called "smart contracts", which are also saved in the ledger. When a transaction occurs, it is recorded as a block and stacked with others sequentially forming a chain of data that ensures the immutability and security of the whole blockchain.

The key aspect of the utilization of the blockchain technology in local energy markets is the possibility of executing and managing trading mechanisms by the smart contracts. This is particularly important because their adoption can facilitate local energy exchange and flexibility services.



Furthermore, blockchain technology enhances transparency by facilitating the traceability of the energy flows, allowing users to know the original source and the final use of the produced energy. This level of transparency encourages mutual trust within energy communities and enables new ways to incentivise production and consumption of renewable energy.

Local energy communities | **Peer-to-peer trading** | **Energy and flexibility markets**

Innovation Priorities

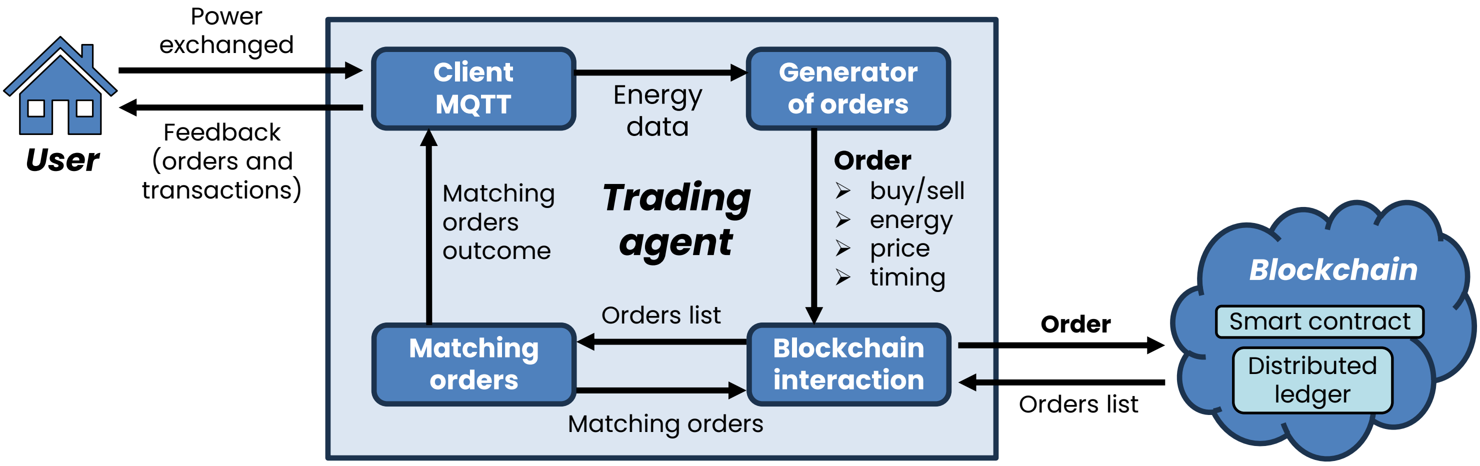
Tools and solutions for DSO flexibility management | **IP 2.3.4**

Flexibility markets for innovative ancillary services by VRE and storage | **IP 2.7.1**

Local trading system implementation

In this case study, an architecture based on blockchain technology has been integrated with a software that emulates final users' behavior to study market mechanisms for energy and flexibility trade within an energy community. The proposed architecture is based on the adoption of a "trading agent" which is responsible for monitoring the user energy flows and automatically generate buy or sell orders within the blockchain market platform. Each trading agent implements four functional blocks:

- **Client MQTT**: It enables the trading agent interaction with the user by the exchange of MQTT messages. It acquires energy data made available by the user and provides feedback regarding trading outcomes;
- **Generator of orders**: Based on the user's energy behavior, it generates buy or sell orders, which include energy quantities, prices and validity times;
- **Blockchain interaction**: It manages publishing the user's buy or sell orders and getting the overall list of orders registered on blockchain;
- **Matching orders**: It matches the last order emitted by the trading agent with the ones within the blockchain ledger. The transaction will be registered in the blockchain and forwarded to the user as trading result.



Project website: https://www.rse-web.it/en/projects/digitalization-of-the-integrated-energy-system/ **Project coordinator:** RSE - Italy

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GREEN POWERED FUTURE MISSION

Pillar 2

System Flexibility and Market Design

Case study #6 *from factsheet P2-01*

Data-driven operation of distribution networks to unlock flexibility services/ FlexOnGrid

GPFM member
Spain

Q3 2022 ▶▶ **Q3 2025**

Main Involved partners

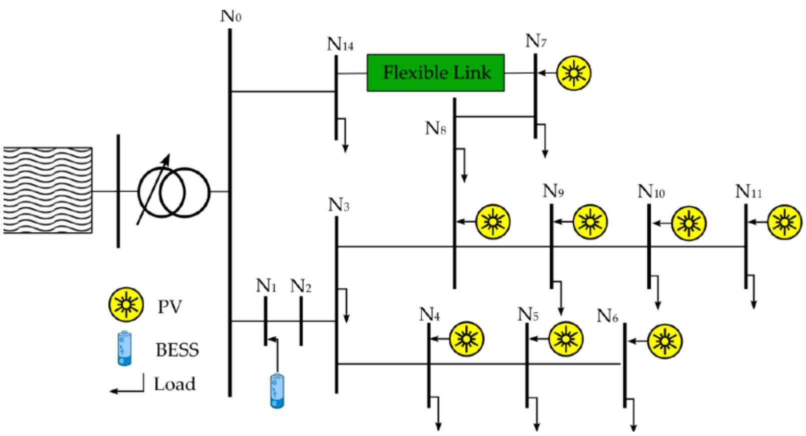
UNIVERSIDAD D SEVILLA 1505

TRL 6

An energy community offers numerous benefits to participants and the energy sector. It enhances public acceptance of renewable energy projects and attracts private investments. Citizens benefit from increased energy efficiency, lower electricity bills, and local job creation. The Energy Community optimizes multi-vector building energy systems to reduce heating and electricity costs by aligning operations with consumer behaviour and market price signals. This benefits individual consumers within the Community.

Variable renewable energy (VRE), like solar and wind, lacks the mechanical inertia of conventional generators, necessitating new ancillary services to stabilize grid frequency during disturbances until primary reserves kick in. The growing share of renewables requires technologies that enhance grid flexibility. Studying and testing such solutions, including VRE coupled with storage or novel dispatchable Renewable Energy Sources (RES) like Concentrating Solar Power, is crucial. RES integrated with Power to X (P2X) technologies improve overall energy system efficiency by converting renewable electricity into other forms like hydrogen or e-fuels. Coordination among systems and stakeholders is essential to overcome technical and regulatory challenges. Increasing intermittent RES poses challenges like over- or under-generation, requiring long-term energy storage solutions such as synthetic fuels or hydrogen to ensure grid reliability.

Off-grid microgrids support local renewable energy use and self-consumption through storage and management systems, benefiting rural electrification and economic development. Coordination among Transmission System Operators (TSO), Distribution System Operators (DSO), Flexibility Operators, and Market Operators is crucial for procuring flexibility from distributed energy resources. Mechanisms preventing double activation of services and minimizing negative impacts on networks are necessary. Distributed Flexible Resources (DFR) providers should sell services to both TSOs and DSOs. TSOs procure flexibility from large consumers and aggregators, while DSOs procure flexibility from various DERs to maintain service quality and supply security.



DER

Energy community

Microgrid

Innovation Priorities

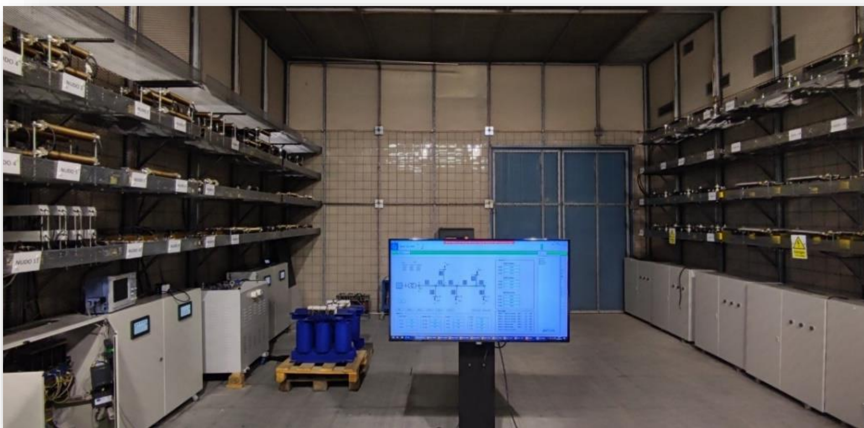
Tools and solutions for DSO flexibility management | **IP 2.3.4**

Tools and solutions for flexible power systems

This case will demonstrate automated trading of flexible energies (electricity, heat) in the context of energy communities. While energy communities can exist on multiple levels, this use case concentrates on prosumer-centric communities. While the community shall mostly comprise small prosumers (like residential homes) and small business entities (e.g. companies with generators or storage), VPPs, SMEs and local utilities are not excluded if they act as peers with the same rights and obligations. A specific role in the energy community can link it to other such communities and other energy markets. Governance policies and incentive mechanisms like special tariffs or pseudo-currencies will be explored. For the realization of this use case, the Flexibility Trading Platform will be coupled with the P2P market toolbox using Distributed Ledger Technologies.

Customers and distributed third-party energy resources that have the ability of changing their consumption or generation for short time could be aggregated, and their flexibility could be offered as ancillary service to TSO or to be used for DSO grid purposes. For commercial purposes, the flexibility operator offers ancillary services to the TSO (frequency control services and balancing). The flexibility operator pools flexibility of DER with the commercial VPP system. On the other hand, the same DERs' flexibility could be used by the DSO for non-frequency DSO needs (solving local congestions and voltage problems).

The traditional energy system silos for electricity generation and end-use, gas transport, heating & cooling needs, and for mobility / transport must be coupled and optimised as one overall, Integrated Energy System considering P2X, X2P and large-scale energy storage technologies in order to achieve the carbon targets at lowest costs. The coupling of such complex systems needs new services based on higher degrees of automated management and control of flexible energy network resources including the conversion between them.



Decarbonisation of the industrial sector, transport and end use energy demand at the building level, shall be supported by smart coordinated control of the interaction between energy sectors.

Project coordinator: Universidad de Seville

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GREEN POWERED FUTURE
MISSION

Pillar 2

System Flexibility and Market Design

Factsheet P2-02

Flexibility from electric vehicles

According to the IEA, electric vehicles (EV) are the key technology to decarbonise road transport, a sector that accounts for over 15% of global energy-related emissions, and the global electric vehicle fleet is set to grow twelve-fold by 2035 under stated policies. Therefore, electromobility will significantly influence power demand, its patterns and distribution.

This factsheet shares key case studies from GPFM members' projects assessing EV grid impact and flexibility potential, how it could be exploited by smart charging and Vehicle-to-Grid (V2G) solutions, and planning strategies for the deployment of the charging infrastructure, ensuring that the power system can support EV uptake and exploit its flexibility potential to support variable renewable integration.

GPFM Innovation Priorities in scope:

- **IP 2.5.4** - Demand response, EV services and grid impact assessment
- **IP 2.5.5** - Tools for optimal smart charging and V2G management
- **IP 2.6.5** - EV charging infrastructure planning and deployment

6 Case studies reported in this factsheet

29 Projects covering these IPs are included in the GPFM National Pilots report

National Pilots Report

For further details on **GPFM Innovation Priorities (IPs):**

GPFM Roadmap   **Action Plan 2022-2024**

October 2024, Brazil – CEM15/MI-9

GREEN POWERED FUTURE MISSION

Case studies

Case Study #1 Flexibility From Electric Vehicles: V2G and Smart Charging

The transition to electric vehicles (EVs) is revolutionizing the landscape of public transportation, offering a cleaner, more sustainable alternative to traditional fossil fuel-powered buses and trains. The Project aims to develop at a very high maturity level an effective and efficient tool to enable a positive interaction between Charging Stations for all kinds of EVs (cars, trucks, busses…) making them a primary source of Demand Response services to optimize the Rome's distribution grid operation. The pilot will also exploit the "Areti Smart Park", the Areti's laboratory for Electromobility equipped with RES generation, storage and advanced control system of charging stations for the Areti's EV fleet, to test specific Smart Charge and V2G technologies.

Link to case study's detailed description **Areti**

Case Study #4 Aggregated flexibility from company EV charging

Electric Vehicle (EV) charging points at workplaces presents interesting opportunities for the integration of EVs with the power system. Moreover, the highly predictable charging schedules gives huge potential for adoption of charging mechanisms like V1G and V2G to support grid flexible operation.
In this case study, a communication architecture based on the OCPP protocol was developed, allowing estimation of the flexibility potential according to EV charging needs and employee habits and constraints. The architecture developed allows a remote operator to forward smart charging signals to charging points from different manufacturer in order to optimize the overall charging program.

Link to case study's detailed description **Italy**

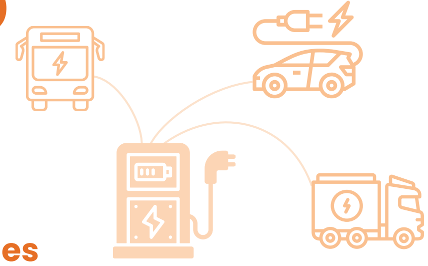
Case Study #2 NS Power - Smart Grid Nova Scotia Project

Nova Scotia Power's project focused on integrating and managing distributed energy resources (DERs). The project included testing a distributed energy resource management system (DERMS) and various DERs such as electric vehicle (EV) smart chargers, residential managed EV charging via telematics, bi-directional (vehicle-to-grid) EV chargers, and other residential, commercial and industrial loads. The project demonstrated the value of DERMS in delivering customer and grid benefits including affordability, reliability and environmental sustainability. NS Power aims to manage 150 MW of flexible load by 2030.

Link to case study's detailed description **Canada**

Circulating EV in 2035 globally according to the IEA APS scenario

1015 Million



EV global sales share in 2035 according to the IEA APS scenario

66%

Source: IEA

Case Study #5 Strategic transport and energy demand modelling for Vehicle to Grid (V2G)

This innovation project provides understanding of V2G's potential to reduce peak demand on the network and facilitate network planning, and can be used by infrastructure planners, EV Charging businesses, ESOs, TOs and DNOs.
Realising the potential of V2G will depend on many factors including consumer behaviour, developments in charge point technology, and understanding battery degradation. This project developed a series of models to study the impacts of V2G and smart charging across the GB system and to understand the impact of V2G on future electricity demand profiles under various decarbonisation scenarios.

Link to case study's detailed description **National Grid**

Key metrics

The EU decision makers effort towards EVs is paving the way for massive deployment of electric cars, commercial vehicles and buses.

E-mobility is considered a powerful resource to provide flexibility services to the energy system.

EV grid integration can support higher shares of RES, reshaping the energy demand curve and reducing system costs.

https://www.entsoe.eu/news/2021/04/02/electric-vehicle-integration-into-power-grids/

Case Study #3 Grid Integration and Control of Large-Scale EVs

The project targets China's electric vehicles (EVs) growth challenges, focusing on: 1) Analyzing individual-user charging demand and proposing a cloud-edge collaboration strategies, 2) utilizing a big data platform for real-time battery, vehicle, and charging pile monitoring with early warning systems, 3) exploring data-driven EV flexibility predictions and intelligent vehicle-grid interaction controls, 4) developing risk mitigation for large-scale vehicle-grid integration and secure terminals, 5) developing a "grid-operator dual-level" control system, researching business models and policies, and showcasing advancements across scenarios.

Link to case study's detailed description **China**

Case Study #6 Energy System Innovation programme: ESI E-Mobility Project

Terna launched an Innovation program named "Energy System Innovation" (ESI). ESI is the new system framework to set experimental initiatives with the objective to increase the technology readiness of new energy resources to provide flexibility services to the electricity grid. The first project, named ESI E-Mobility, aims to experiment and characterize the EVs and EVSEs resource performances to provide flexibility to the grid, solve interoperability issues, advocate for communication protocol standardization, etc. To do so, Terna's E-mobility Lab, serves as reference experimental facility for the testing phase of the project. 10 partners have already participated (EVs and EVSEs) and tests are ongoing.

Link to case study's detailed description **Terna**

Key findings

These case studies underline that the transition to electric mobility is revolutionizing the transport landscape, offering a cleaner and more sustainable alternative to traditional fossil fuel powered vehicles. Smart charging and Vehicle-to-Grid (V2G) tools offer innovative solutions to optimize grid operations while ensuring efficient and cheaper charging processes both for private and public transportation. To make this happen, ICT infrastructure and platforms for monitoring and controlling the EV charging need to be deployed. Moreover, the adoption of standardised communication protocols is essential to foster the adoption of smart charging schemes. Results from case studies assessing the behavior of different EVs shows that their potential as flexible resources is more in line with the requirements of long-time ancillary services. In particular, home charging implying long times could provide a good opportunity for flexibility through smart charging or V2G. A relevant issue addressed by the case studies is the potential concern about battery capacity loss due to V2G. In this view, the understanding of the factors leading to battery degradation would help to design schemes that avoid excessive battery aging, for example due to high temperatures or long durations at high states of charge.

- V2G will play a role in the decarbonisation of grids, if there is proper infrastructure investment and if suitable price schemes for cost reduction will be adopted
- Smart charging and V2G could foster grid operation optimization and pave the way for a more sustainable and resilient urban infrastructure
- Algorithms, platforms and well-suited communication protocols for monitoring and controlling the EV charging are needed to support the adoption of smart charging

About GPFM

The Green Powered Future Mission (GPFM), launched within the second phase of the global initiative Mission Innovation (MI2.0), is a public-private partnership with members from MI countries, private sector companies and international organisations. It aims to demonstrate that by 2030, power systems in different geographies and climates can effectively integrate up to 100% variable renewable energies, like wind and solar, in their generation mix, and maintain a cost-efficient, secure and resilient system.

https://explore.mission-innovation.net/mission/green-powered-future/

GPFM Coalition

GREEN POWERED FUTURE MISSION

Pillar 2
System Flexibility and Market Design

Case study #1 *from factsheet P2-02*

Flexibility From Electric Vehicles: V2G and Smart Charging

GPFM member
Areti

Q3 2024 ▶▶ **Q3 2027**

Main involved partners

areti

TRL 7

The transition to electric vehicles (EVs) is revolutionizing the landscape of public transportation, offering a cleaner, more sustainable alternative to traditional fossil fuel-powered buses and trains. As cities worldwide strive to reduce carbon emissions and combat climate change, the electrification of public transport systems has emerged as a pivotal strategy. However, the integration of EVs into existing infrastructures presents a unique set of challenges, particularly concerning energy demand and grid stability. This is where smart charging and Vehicle-to-Grid (V2G) tools come into play, offering innovative solutions to optimize grid operations while ensuring efficient and reliable public transportation services.

Smart charging refers to the intelligent management of EV charging processes using advanced algorithms and real-time data. This technology enables the dynamic adjustment of charging rates based on grid demand, electricity prices, and the availability of renewable energy sources. By charging EVs during off-peak hours or when renewable energy production is high, smart charging reduces electricity costs for fleet operators and alleviates grid stress, thereby enhancing its stability and resilience.

V2G technology facilitates a bi-directional flow of electricity between EVs and the power grid. In this system, EVs can act as mobile energy storage units, discharging stored electricity back into the grid during periods of high demand. This interaction transforms EVs into active participants in grid management, supporting grid stabilization and providing a buffer against fluctuations in energy supply and demand. For public transportation fleets, V2G offers an additional revenue stream, as fleet operators can sell surplus energy back to the grid, making the operation of electric buses and trains more economically viable.

Together, smart charging and V2G technologies represent a paradigm shift in how we approach the integration of EVs into public transportation networks. They not only foster grid operation optimization but also pave the way for a more sustainable and resilient urban infrastructure.

Smart charging | Grid flexibility | V2G

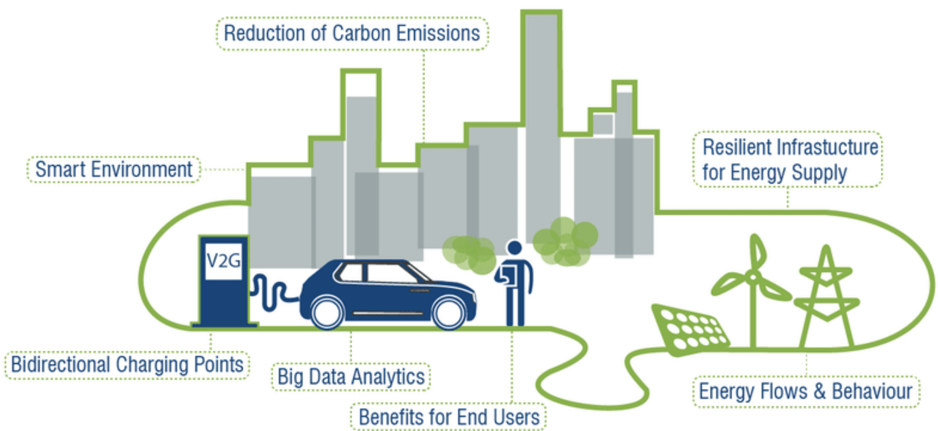
Innovation Priorities

Demand response, EV services and grid impact assessment | **IP 2.5.4**

Tools for optimal smart charging and V2G management | **IP 2.5.5**

Smart Charging and V2G Tools involving all EVs while focusing on Public Transportation to foster Grid Operation Optimization

- Rome will be the Italian city most affected by the transportation transition to the electrical vector, causing by itself a capacity peak increase of the Areti's grid of around 500 MW in the next ten years. Even though the impacts on the grid will be so significant, the benefits of CO_2 reduction will be crucial for the decarbonization of Rome, where almost 30% of total GHG production is due to transportation.
- The Project aims to develop at a very high maturity level an effective and efficient tool to enable a positive interaction between Charging Stations for all kinds of EVs (cars, trucks, busses…) making them a primary source of Demand Response services to optimize the Rome's distribution grid operation.
- The municipality of Rome is strengthening the electrification of public transportation and one of the scopes of the project will consist in the integration of the big charging stations for buses into the flexibility mechanisms of the Areti's grid, even increasing the local flexibility market liquidity.
- The pilot will also exploit the "Areti Smart Park", the Areti's laboratory for Electromobility equipped with RES generation, storage and advanced control system of charging stations for the Areti's EV fleet, to test specific Smart Charge and V2G technologies.



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GREEN POWERED FUTURE MISSION

Pillar 2
System Flexibility and Market Design

Case study #2 *from factsheet P2-02*

NS Power - Smart Grid Nova Scotia Project

GPFM member Canada

Q4 2018 ▶▶ **Q1 2023**

Main involved partners

Nova Scotia Power (NS Power), Government of Canada, Province of Nova Scotia, Siemens Canada, Town of Amherst.

TRL 8

Nova Scotia Power is the vertically integrated electric utility in Canada's province of Nova Scotia. Its smart grid demonstration and deployment project integrated distributed energy resources (DERs) and deployed a DER management system (DERMS), with the goal of assessing their value for both the grid and its customers. The project included the following components: a 2 MW community solar garden; a network of 100 in-home smart EV chargers and 2 bi-directional chargers accompanied by 160 EVs with telematics; three commercial building deployments of rooftop solar panels and battery storage systems; 134 distributed batteries; customer energy management engagement; and a DERMS managing the majority of the DERs.

Each DER type was evaluated based on their impact on the following criteria:

- ✓ Affordability: reducing upward pressure on revenue requirements.
- ✓ Reliability: reducing the number of interruptions and their duration.
- ✓ Environment: reducing greenhouse gas (GHG) emissions.

Among the DER types, the project investigated the benefits, to both the utility and customers, of EV smart charging and vehicle-to-grid integration. It was found that the benefits of the associated equipment –smart chargers, an EV charging app, and V2G chargers – mainly came from their demand response and load shifting capabilities.

EV smart charging demonstrated the following:

- ✓ an affordability benefit through load-smoothing with increased EV adoption rates;
- ✓ energy cost savings with customer adoption of dynamic tariffs;
- ✓ GHG benefits from load shifting; and
- ✓ no direct reliability benefits beyond managing load diversity.

Photo credit: Nova Scotia Power

During the demonstration project, curtailment events were sent at different hours of the day to EV chargers to control charging rates. The EV charging app used rate signals to influence user behavior to replicate these events. It was found that, generally, drivers use little energy during the day and are often plugged in. Thus, home charging sessions had minimal grid impact. However, the constant connectivity could provide a good opportunity to influence charging and provide system benefits with widescale V2G deployment. Generally, cost savings would be enabled through demand response and load shifting to avoid new generation capacity, defer transmission and distribution capital upgrades, and capture lower marginal cost energy from variable energy resources (VREs). Utility-controlled demand response appears to be the preferred option for local grid-aware coordination to mitigate load impacts.

Affordability **Reliability** **Environment**

Innovation Priorities

Demand response, EV services and grid impact assessment | **IP 2.5.4**

Tools for optimal smart charging and V2G management | **IP 2.5.5**

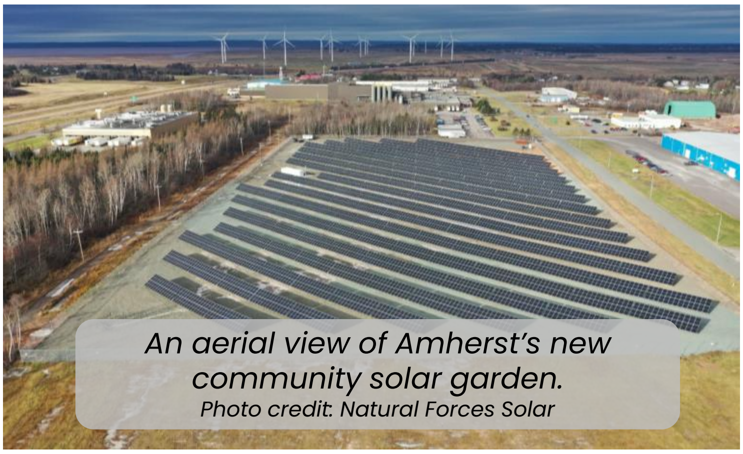
EV charging infrastructure planning and deployment | **IP 2.6.5**

Vehicle-to-grid (V2G) charging demonstrated the following benefits:

- ✓ increased affordability related to fuel costs savings during load shifting events (i.e., the ability to manage charging according to the type of generator being dispatched);
- ✓ participants bill reduction via lower demand charges (i.e., the fixed portion of an electric bill based on capacity charges); and
- ✓ GHG reduction from load shifting.

The demonstration included two V2G chargers installed at commercial buildings. Effective control and automation of the EV battery charging was essential for fully realizing the value of rate-based charging while meeting transportation needs. V2G provided affordability benefits by allowing participants to discharge energy to the building to manage utility demand charges. At the provincial level, the value of commercial V2G would improve with higher penetration rates resulting in greater availability and coordination, also bringing enhanced reliability.

The environmental benefits of smart charging and V2G are highly dependent on their ability to capture energy from VREs, given Nova Scotia's heavy reliance on fossil fuels for electricity generation. Smart charging demonstrated potential emissions reduction. When combined with VRE forecasts, the project demonstrated 3% reduction in CO_2e per year per MW of installed generation capacity. V2G assets are expected to follow a similar trend.



An aerial view of Amherst's new community solar garden.
Photo credit: Natural Forces Solar

References:

1. M09985 CI C0010778 Smart Grid Nova Scotia Project NS Power FINAL REPORT, Submitted to the Nova Scotia Utility and Review Board March 15, 2024,
2. NRCan Current Investments – Link

Project website: https://www.nspower.ca/cleanandgreen/innovation/smart-grid-nova-scotiab **Project coordinator:** Nova Scotia Power

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https://explore.mission-innovation.net/mission/green-powered-future/

GREEN POWERED FUTURE MISSION

Pillar 2

System Flexibility and Market Design

Case study #3 *from factsheet P2-02*

Grid Integration and Control of Large-Scale EVs

GPFM member
China

Q4 2022 ▶▶ Q4 2025

Main involved partners

NARI 南瑞集团 NARI GROUP CORPORATION

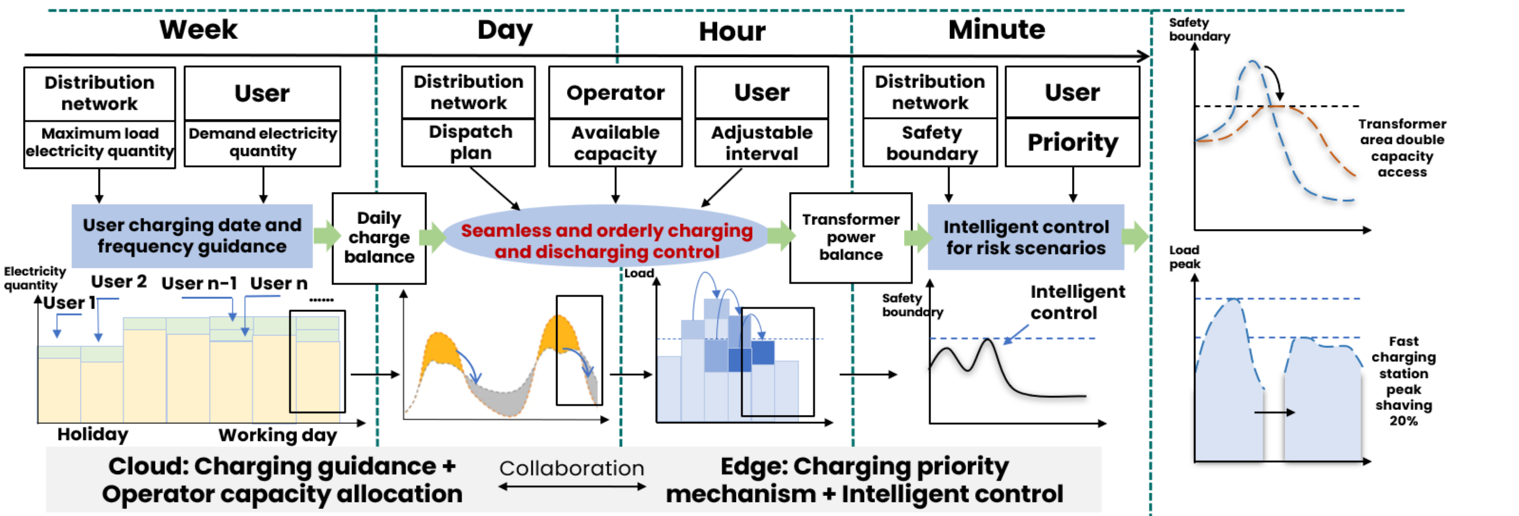
国家电网 STATE GRID 天津市电力公司 TIANJIN ELECTRIC POWER CORPORATION

国家电网 STATE GRID 国网智慧车联网技术有限公司 STATE GRID SMART INTERNET OF VEHICLES CO., LTD.

国家电网 STATE GRID 中国电力科学研究院 CHINA ELECTRIC POWER RESEARCH INSTITUTE

TRL 9

To address the challenges in predicting charging demand due to varied access scenarios of electric vehicles (EVs) and users' random charging behaviors, we analyzed the dynamic characteristics of users' charging demands across multiple time scales. This analysis is based on cross-platform data integration from vehicles, charging piles, and the grid. We quantified The flexible and adjustable boundaries of user charging and discharging on a "weekly-daily-hourly-minute" basis, providing essential boundary information for control. To facilitate grid-friendly integration of EVs into distribution networks, we propose a collaborative optimization design method for community and fast charging station access schemes. This method includes establishing a comprehensive evaluation index system that covers "safety, economy, and friendliness" for access schemes and executing thorough evaluations and decision-making processes. In response to insufficient capacity in distribution substations, we have developed a multi-agent cloud-edge collaborative control architecture. This architecture allocates the available charging capacity of substations to different operators in the cloud and proposes seamless orderly charging and discharging control strategies. At the edge, we suggest intelligent control methods focused on the safety of the substation grid to enhance grid-friendly access levels. To tackle the insufficient aggregated response capability of fast charging stations, we establish a model for the controllable domain of distributed flexible resources. We propose control strategies to coordinate the timing of flexible resources within stations, aiming to improve the peak shaving flexibility and primary frequency regulation support capability of fast charging stations. These measures optimize EV integration into the power grid, ensuring efficiency, safety, and reliability while maximizing renewable energy utilization.



Integrated PV Storage and Charging

Grid-Friendly Integration

Battery Safety and Diagnosis

Innovation Priorities

Demand response, EV services and grid impact assessment | IP 2.5.4

Tools for optimal smart charging and V2G management | IP 2.5.5

Advanced Planning and Grid-Friendly Integration

We developed spatiotemporal prediction technology for EV charging demand, considering individual user behaviors and traffic flow. This innovative approach allows for heuristic site selection methods prioritizing safety and convenience. The first lean planning system for charging stations integrates vehicle-road-network data, reducing annual lifecycle costs by over 10%. Adaptive virtual inertia anti-droop voltage stability control ensures stable grid operations. By inventing harmonic proportion control for photovoltaic storage and developing advanced energy management systems, the project achieved efficient grid integration with 98.3% efficiency, THD below 2%, and DC bus voltage fluctuations within 3%. This enhances the reliability and sustainability of the EV charging network, supporting broader renewable energy adoption.

Enhanced Safety and Intelligent Operations

We developed Real-time charging data anomaly detection using CNN-LSTM deep learning, achieving over 90% accuracy in battery fault warnings and 97% in identifying charging equipment faults. This reduces EV charging risks and enhances user safety. We also addressed data loss and noise in large-scale charging stations, creating a public service platform that benefits users, operators, grids, and governments.

The Jinnan Lake charging station, China's first "near-zero carbon" integrated photovoltaic storage and charging station, has cut carbon emissions by over 6,000 tons and maintains top utilization in Tianjin. The project is expanding across the city and 21 provinces, capturing over 35% of the domestic market and generating 2.35 billion yuan in benefits. This supports Tianjin's green energy transition and China's EV industry development.

Project coordinator: Wen Wang, Yunfei Mu, Guoqiang Zu

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Pillar 2
System Flexibility and Market Design

***Case study #4** from factsheet P2-02*

Aggregated flexibility from company EV charging

GPFM member
Italy

Q1 2023 ▶▶ **Q4 2024**

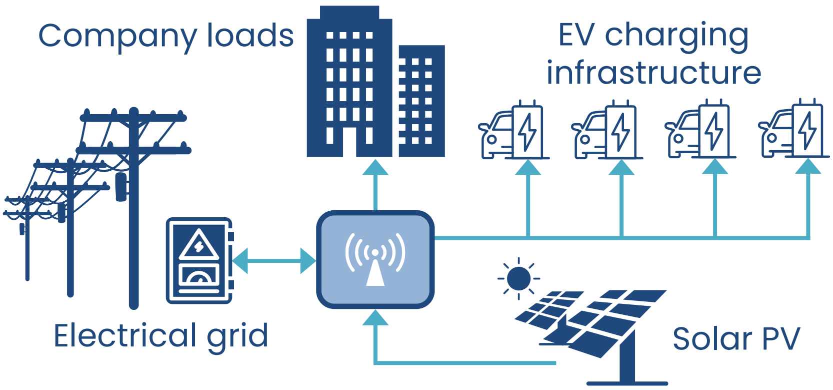
Main involved partners

RSE Ricerca Sistema Energetico – we move rsearch

TRL 7

Electric Vehicle (EV) charging points at workplaces presents interesting opportunities for the integration of EVs with the power system. Several companies are connected to the electrical grid with high-power contracts or directly at medium voltage, thus could take advantages of pre-existing grid infrastructure and/or cheaper electricity fees. Moreover, EV charging is directly linked with the work time schedule, providing highly predictable loads and huge potential to dynamically change the charging strategies for providing flexibility services to the electrical grid. Lastly, since the EV charging takes place during daylight hours, the electrical consumption naturally overlaps with solar PV power production. The deployment of such infrastructure would also give the possibility to those employees that don't have the possibility to recharge the EV at home to charge with fees typically cheaper than those of public charging points.

To enable the provision of flexibility services from companies' infrastructure and at the same time to optimally coordinate the charging with PV production and other loads consumption, a proper ICT infrastructure must be deployed. Algorithms and platforms for monitoring and controlling the EV charging, as well as the adoption of well-suited communication protocols would pave the way to the adoption of smart charging schemes (and/or vehicle-to-grid if supported) for providing grid services possibly generating additional revenues. To do so, the ICT infrastructure developed should enable the communication between the facility and an aggregator which orchestrate the delivery of flexibility.



In this view, in Italy, the Italian Electrotechnical Committee (CEI) published a standard for a device called CIR (Controllore Infrastruttura di Ricarica – "Charging infrastructure Controller") dedicated to the control of private users' EV charging infrastructure, optimising the use of locally produced and consumed energy and enabling the real-time modulation of the charging process from a remote operator.

Smart charging **Grid flexibility** **Data management**

Tools for optimal smart charging and V2G management | **IP 2.5.5**

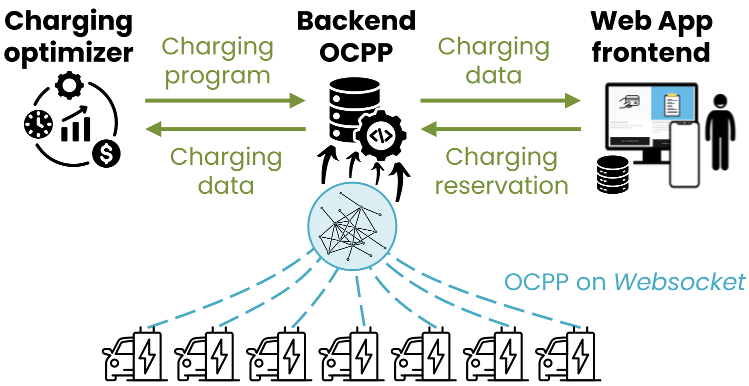
EV charging infrastructure planning and deployment | **IP 2.6.6**

Innovation Priorities

Management of company EV charging points via the OCPP protocol

The communication protocol OCPP (Open Charge Point Protocol) has been proposed proposed by a global industry alliance (Open Charge Alliance) to address the need of creating a network of interoperable and interconnected charging infrastructures. Using standardised messages, the OCPP enables the communication between charging points developed by different manufacturers with the monitoring and control backend. In this case study developed by RSE, the interoperability level of the OCPP standard has been tested by orchestrating charging points from five manufacturers. The major obstacle to interoperability was observed when delivering smart charging commands for the dynamic modulation of the charging power. To overcome this incomplete interoperability, the backend software for monitoring and control has been improved to manage the smart charging commands differently depending on the destination charging point. Thanks to this ad hoc development, it was possible to generate an interface for the complete control of all charging points of the infrastructure, allowing the development and study of advanced charging logics.

A data processing system was developed to compute the available flexibility from each charging session. To compute the flexibility potential, the maximum and minimum charging power is estimated at the beginning of the charging process, with vehicles' data and measurements from the charging points. The charging profiles are then optimized to satisfy the power modulation set by the aggregator (or by any external actors).



The EV charging programs takes also into consideration the employees' habits, evaluated by continuously monitoring the vehicles parking time to forecast when the infrastructure will be most likely used and when flexibility margins will be available. Finally, since possible unforeseen daily constraints would affect the planned delivering of flexibility, each EV user has the possibility to use the specifically designed frontend web app to communicate its charging reservation in terms of time of arrival, time of departure and energy (in kWh) to be charged.

Project website: https://www.rse-web.it/en/projects/sustainable-mobility-and-interaction-with-the-energy-system/ **Project coordinator: RSE - Italy**

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https://explore.mission-innovation.net/mission/green-powered-future/

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Pillar 2
System Flexibility and Market Design

Case study #5 *from factsheet P2-02*

Strategic transport and energy demand modelling for V2G

GPFM member
National Grid

Q4 2022 ▶▶ **Q1 2024**

Main involved partners

National Grid Electricity Transmission, National Grid Electricity System Operator, Frontier Economics, Imperial College London, University of Warwick

EV batteries can be used to balance supply and demand through Vehicle-to-Grid (V2G) technology. Understanding how consumers use their electric vehicles is vital to plan for the infrastructure requirements of V2G technology.

This factsheet summarises the findings from National Grid's V2G innovation project exploring the potential of smart charging and V2G technology. A series of models were developed to study the uptake and impacts across the entire GB network.

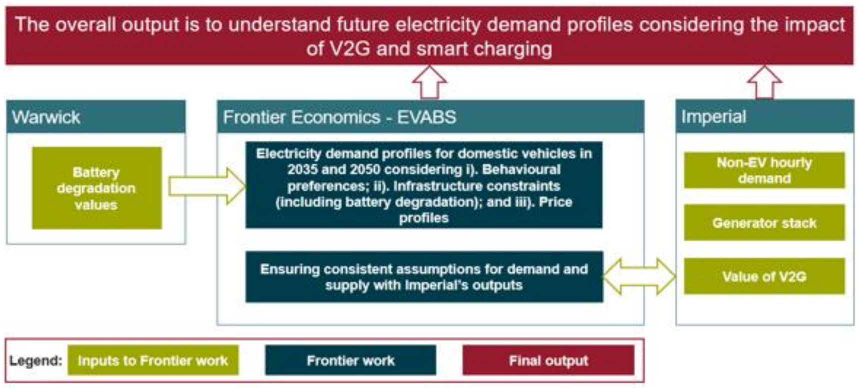
Methodology

Frontier Economics explored the role of EV consumer behaviour with the aid of **an EV Agent-based simulator (EVABS) model.** They used two contrasting net zero scenarios coupled with qualitative and quantitative research to inform the agent-based simulator. This modelled a 40kmx40km area in Nottingham, England, before scaling the results up to produce GB level outputs.

Results

With most EV charging likely to be done at home, the **cost of V2G-enabled chargepoints** must come down so that the value of the services they provide exceeds their cost. It is unlikely that these chargepoints will be installed by households if they aren't financially feasible. As such, technological advancements and incentivisation is critical to realise the potential peak demand reductions from V2G technology. The behavioural modelling also showed that consumers need confidence that V2G will not cause **battery degradation**.

Similarly, any **hassle associated with plugging in** will need to be reduced to ensure drivers are able to plug in frequently. Technology such as wireless charging or incentivisation may reduce this perceived hassle. Finally, our findings suggest there is significant potential for participation of EV batteries in **system ancillary services** across all scenarios, highlighting the usefulness of V2G technology in providing services to system operators.



Source: Frontier Economics

Figure 1. Overview of the National Grid Vehicle to Grid Innovation project, its partners, and their contributions.

nationalgrid

Demand modelling | **Infrastructure development** | **Consumer Behaviour**

Demand response, EV services and grid impact assessment | **IP 2.5.4**

Tools for optimal smart charging and V2G management | **IP 2.5.5**

EV charging infrastructure planning and deployment | **IP 2.6.6**

Innovation Priorities

Infrastructure must be developed considering realistic consumer behaviour & preferences to facilitate V2G's role in the energy transition

Battery Degradation

Battery degradation was identified as a limiting factor in V2G uptake. Understanding the factors leading to degradation is important when designing technology to ensure V2G operations are optimised to avoid excessive battery aging.

Methodology

The University of Warwick created a model for understanding capacity fade of EV batteries by combining 'calendar' and 'cycling' aging models. Calendar Aging is degradation of the battery in a resting state, dependent on storage conditions; whilst cycling aging occurs when the battery is charged or discharged. Laboratory test data from over 180 lithium-ion cells used in EVs across 400 days was used to test and validate the models.

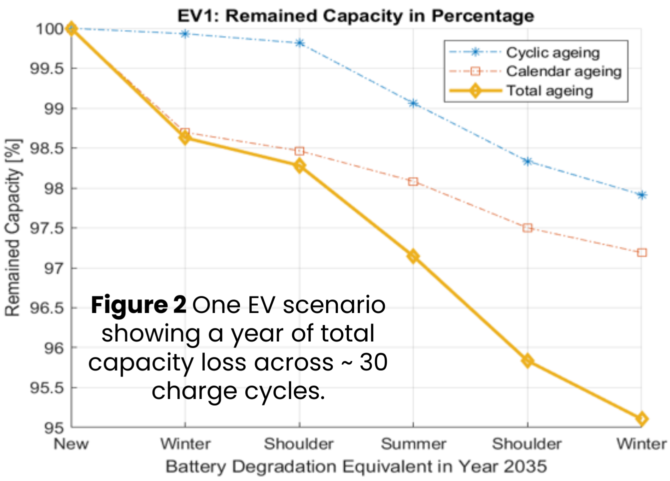


Figure 2 One EV scenario showing a year of total capacity loss across ~ 30 charge cycles.

Results

Higher temperatures and long durations at high states of charge lead to higher capacity loss. Capacity losses also increased with more charge cycles. This has implications for V2G technology, which will increase cycle counts. The model also helps understand how parking conditions, seasonal changes and charging behaviour affect battery degradation.

Summary & Conclusions

Consumers must decide to purchase V2G enabled chargepoints in significant quantities before system operators can rely on V2G for demand peak shaving, load levelling, or ancillary services. This study has shown price sensitivity, concerns on battery degradation, and perceived charging hassle to be factors in V2G uptake. As such, V2G chargepoint infrastructure and incentivisation will play a critical role in the popularity and success of the technology. The study on battery degradation revealed the potential of V2G to degrade batteries, therefore, further investment in battery technology and V2G system design is necessary to minimise degradation. Despite these factors, modelling showed V2G to have an economic benefit to the UK and has the potential to defer or replace network reinforcement projects, potentially saving billions on network investment costs. This shows with the right cost reductions and infrastructure investment, V2G could have a role to play in the decarbonisation of grids globally.

Project website: https://smarter.energynetworks.org/projects/nia2_nget0017 **Project coordinator** box.NG.ETInnovation@nationalgrid.com

To know more about the GPFM and the factsheet series
https://explore.mission-innovation.net/mission/green-powered-future/

***Case study #6** from factsheet P2-02*

ESI E-Mobility

GPFM member
Terna

Q4 2022 ▶▶ **Q1 2025**

Main involved partners

EV Makers:
- Ford
- Toyota
- Kia
- Iveco

EVSE Manufacturers:
- Enel X Way
- Bitron
- Eaton Elektrotechnika
- Gewiss
- Scame Parre
- Silla

TRL 7

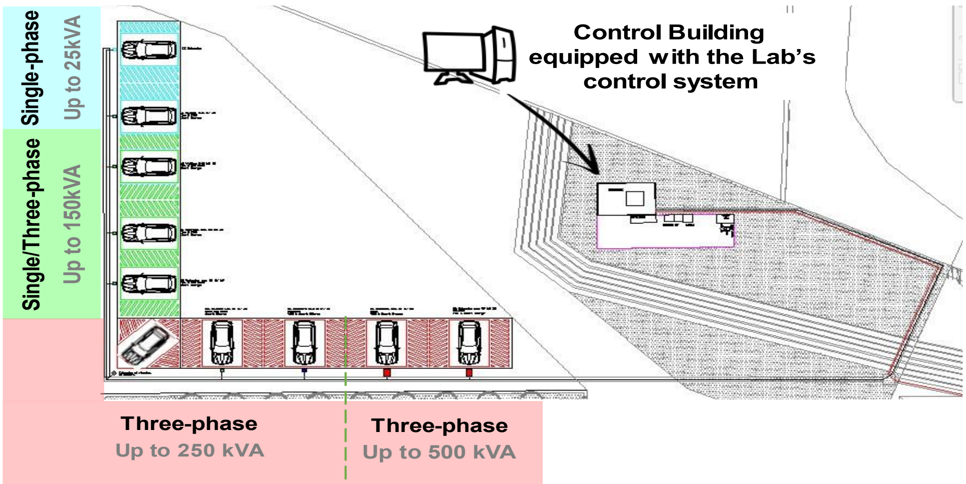
The progressive electrification of demand becomes increasingly important in today's energy system and surely necessary to achieve the national and international decarbonization targets. This context involves several players: from electric mobility (EVs and EVSEs) to thermal comfort (heat pumps, conditioning systems, …), batteries and renewable plants.

Based on its role as a TSO (Transmission System Operator), Terna launched an innovation program entitled Energy System Innovation (ESI) to set experimental initiatives with the objective to increase the technology readiness of new energy resources to provide flexibility services to the electricity grid. The goal is to create a system to face the energy transition challenges, promoting technological development and guiding the regulatory and legislative evolution for a grid and an Ancillary Services Market that are increasingly aligned with the external context.

The first ESI project will be specifically dedicated to the technical assessment of the flexibility potential of the electric vehicle (EV) - Charging infrastructure (EVSE) combination. The project is open to both V1G and V2G technologies, commercial products or prototypes.

So far, 10 of the technological stakeholders of the sector of the electric mobility (EV makers and EVSE manufacturers) have joined the project to test their assets to quantify their capabilities to provide flexibility services to the grid.

The results of the tests will be used to guide "near-term" technological developments so that the foreseen mass adoption of electric mobility in the coming years can be ready for grid integration "by-design", maximizing the benefits for developments aligned with the system needs.



E-Mobility

Demand Response

Testing Facility

Terna Driving Energy

Innovation Priorities

Demand response, EV services and grid impact assessment | **IP 2.5.4**

Tools for optimal smart charging and V2G management | **IP 2.5.5**

ESI E-Mobility: testing facility, tests, and 1st results

The ESI E-mobility experimentation is carried out in partnerships with the participants that have joined the activities. Therefore, all EVs and EVSEs tested in the initiative are lent to Terna with a Free Lease Agreement.

The testing facility is Terna's E-Mobility Lab, where the technical potentials and limits of V1G and V2G applications are tested. Testing is open to both commercially available technologies and prototypes. The Lab has 13 testing posts that are independently controlled by a local control system and the maximum connection power of the laboratory is 500 kW. The testing posts vary both in terms of connection power limit and type (from 25kW 1p to 500kW 3p) and are equipped with dedicated and independent measuring and protection devices.

Four different types of tests were defined:

- **Type 0 - Checks on interfaces and communications** → testing of communication protocols and the correct sending and receiving of signals and measurements.
- **Type 1 - Technical characterization of EVs+EVSEs** → tests to determine the technical nominal operational parameters of the resources combined (EV+EVSE).
- **Type 2 - Technical characterization of grid services** → tests to determine the technical performance of any EV+EVSE combination to provide flexibility grid services.
- **Type 3 - Evaluation of service-provision impacts** → tests to assess the impact of battery ageing on EVs after the provision of flexibility services.

So far, tests are showing that there's a great heterogeneity among EVs-EVSEs performances and are suggesting that their grid integration is more in line with the requirements of "slower" ancillary services.

Project website: ESI E-Mobility link **Project coordinator:** Innovation Factory SO (Terna)

To know more about the GPFM and the factsheet series
https://explore.mission-innovation.net/mission/green-powered-future/

GREEN POWERED FUTURE MISSION

Pillar 3

Data and Digitalisation

Factsheet P3-01

Data and Digitalisation for System Integration

The future global electricity system will consist of a huge amount of low-carbon and renewable infrastructure, significantly transforming how energy is generated and consumed. This evolution will be accompanied by a significant increase in the number of 'smart' digital assets and interactions between them. The industry currently lacks mechanisms for interoperable and secure data management and exchange, presenting significant challenges in an increasingly complex energy system.

This factsheet highlights 6 innovative projects from GPFM members which are addressing these challenges and working towards maximising the potential of a modern, digitalised power sector.

GPFM Innovation Priorities in scope:

- **IP 3.1.1** - Data discovery, access and licensing
- **IP 3.1.4** - Data security standards and data privacy
- **IP 3.3.1** - Interoperable markets, devices and data

6 Case studies reported in the factsheet

26 Projects covering these IPs are reported in the GPFM National Pilots report

National Pilots Report

For further details on **GPFM Innovation Priorities (IPs):**

GPFM Roadmap **Action Plan 2022-2024**

GREEN POWERED FUTURE MISSION

Case studies

Case Study #1 **Eco-synergy Data and Tech Integration Platform for Solar & Wind Power System**

An integrated ecological synergy technology platform has been built to facilitate the collaborative planning, design, operation, and monitoring of solar and wind power systems, while focusing on ecological protection. This platform aims to optimize costs, enhance power generation efficiency, and improve the environment. It has been developed for demonstration sites that include a wind farm, two photovoltaic power stations, and a solar thermal power plant. Key features of the platform comprise remote data collection and analysis, energy-efficient design optimization, and ecological intelligent warning systems. By utilizing this platform, the optimization of design, intelligent operation, and ecological coordination of the solar and wind power generation systems can be effectively achieved.

Link to case study's detailed description

China

Case Study #4 **The Virtual Energy System Programme**

In 2021, to tackle decarbonisation challenges and leverage the potential of digitalisation, the ESO launched the Virtual Energy System. This ambitious programme's vision is to enable an ecosystem of connected digital twins of the entire GB energy landscape, working in parallel to the physical system. The ESO is imminently starting a pilot phase to test the solution, focusing on an outage planning use case. This pilot will be followed by a minimum viable product (MVP) phase throughout 2025 focusing on a use case of strategic planning. This is a truly transformative piece of innovation in the data sharing world.

Link to case study's detailed description

National Grid ESO

Case Study #2 **Open Energy**

Open Energy enables the discovery and usage of data across the sector. Governance-led, it streamlines data sharing and automates compliance through a multilateral, collaborative process. Distribution network operators, startups, researchers, and related stakeholders can deliver compliance, drive efficiencies and unlock innovation while avoiding centralising data. Operated by IB1, it is funded by public and private sectors, for and on behalf of the sector. IB1 is an independent non-profit making data work harder to deliver net zero. Open Energy helps underpin an open market design for data governance in national data infrastructure.

Link to case study's detailed description

Icebreaker One

25 billion

Predicted number of smart devices connected to the power system globally in 2030

Predicted savings in grid investment that digital technologies could bring by 2050 (USD)

1.8 USD trillion

Source: *IEA*

Case Study #5 **DATA CELLAR**

DATA CELLAR aims to create a federated energy dataspace that will support the development and management of local energy communities in the EU. The data space population will be facilitated via an innovative rewarded private metering approach, with a focus on easy onboarding and interaction, guaranteeing a smooth integration with other EU energy data spaces, providing LEC stakeholders with services and tools for developing their activities. DATA CELLAR will develop a dynamic, interoperable data platform to support the uptake of the Energy Communities leveraging a blockchain-based tokenization scheme for the remuneration in data and pre-trained AI models provisioning/acquisition cycle. DATA CELLAR will support the need for common dataspaces, focusing on user-friendliness for non-experts thanks to the availability of a data marketplace.

Link to case study's detailed description

Spain

Key metrics

Global investment in digital electricity infrastructure and software has grown by over 20% annually since 2014, reaching USD 47 billion in 2016.

An interoperable, digital power system can unlock flexibility and huge cost reductions

Effective use of data helps to improve energy efficiency and security

https://www.iea.org/energy-system/decarbonisation-enablers/digitalisation

Case Study #3 **AI techniques to detect cyber attacks to electrical infrastructures**

AI-based algorithms applied to cyber security would make it possible to detect attacks that are difficult to block with conventional strategies. This is particularly important to improve defence measures against cyber attacks to electrical infrastructure since they are carried out by syntactically and semantically but not operationally correct instructions. This case study involves the application of five AI algorithms for the classification of DoS-type cyber attacks. The results showed that the applied methodology produced models with an accuracy in line with literature results trained with the same dataset. This allows replicability of the developed methodology in view of selecting the best model to use.

Link to case study's detailed description

Italy

Case Study #6 **Interoperable Domestic Flexibility: Standards and Innovation**

To help promote innovation and uptake of smart technologies, the UK sponsored the development a technical specification (PAS1878:2021), led by the British Standards Institution, and guided by the core principles of delivering interoperable, cyber-secure domestic demand side response (DSR), whilst respecting data privacy and maintaining grid stability. An innovation programme was launched in parallel to develop and test the first energy smart appliances and DSR service platforms built to this specification. Learnings from the innovation programme are now being used to iterate the standard, demonstrating how innovation and standards development can work together to accelerate the development and uptake of smart products and services for energy flexibility.

Link to case study's detailed description

United Kingdom

Key findings

These case studies show that the transition to a digitalised power system is essential for improving flexibility, reliability, and sustainability in the energy sector. Enhanced system flexibility allows faster response to fluctuations in supply and demand, and consumers benefit from improved services and greater access to real-time data, empowering them to adopt sustainable practices.

As the digital revolution accelerates, the volume of data generated from smart devices is rapidly increasing. To fully harness this data's potential, it is crucial to establish robust standards, security measures, and interoperability among devices and systems, ensuring better integration within the power system. Data and technology can also be utilised to strategically integrate new solar and wind farms with the surrounding environment.

In conclusion, the global power sector must embrace data-driven approaches and digitalisation by leveraging innovative technologies and strategies to ensure a sustainable future.

- Digital technology can be used to efficiently plan and operate renewable energy systems while improving the integration with the ecological environment
- Establishing standards frameworks for data accessibility and compatibility is vital, alongside innovative strategies to address cybersecurity threats
- A robust digital infrastructure, at national level and beyond, is necessary to navigate the complexities of an interconnected, net-zero power system

About GPFM

The Green Powered Future Mission (GPFM), launched within the second phase of the global initiative Mission Innovation (MI2.0), is a public-private partnership with members from MI countries, private sector companies and international organisations. It aims to demonstrate that by 2030, power systems in different geographies and climates can effectively integrate up to 100% variable renewable energies, like wind and solar, in their generation mix, and maintain a cost-efficient, secure and resilient system.

https://explore.mission-innovation.net/mission/green-powered-future/

GPFM Coalition

GREEN POWERED FUTURE MISSION

Pillar 3
Data and Digitalisation

***Case study #1** from factsheet P3-01*

Eco-synergy Data and Tech Integration Platform for Solar & Wind Power System

GPFM member China

Q1 2022 ▶▶ Q4 2026

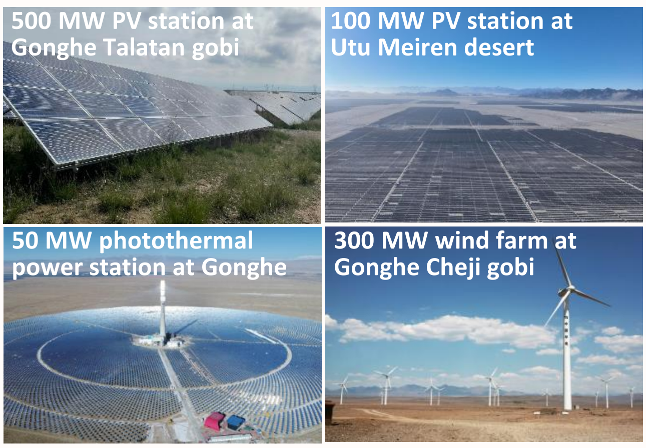
Main involved partners

TRL 9

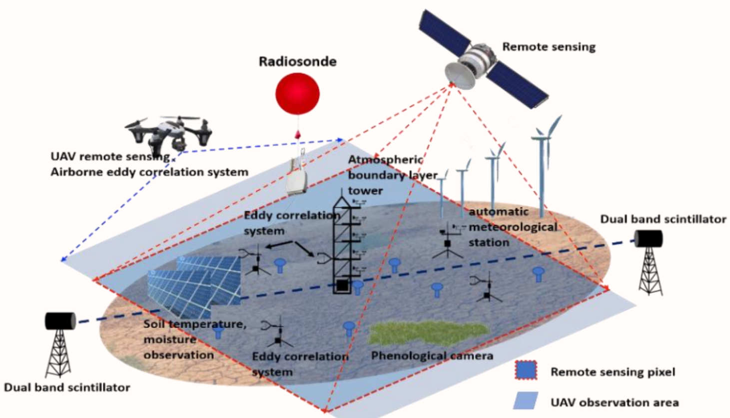
The construction of large-scale solar and wind power generation bases in desert areas is an important initiative to support China's efforts to achieve the goal of carbon peaking and carbon neutrality, and to promote a clean and low-carbon energy transition. The gobi and desert regions of the Tibetan Plateau (TP) is abundant in solar and wind energy resources, which have great potential for the development of renewable energy. However, the ecological environment of this region is fragile, the impacts on the local ecology system should be fully considered during the utilization of renewable. The solar and wind power plants should also be synergized with the ecological development. Therefore, an ecological synergy and technological integration platform for solar and wind power generation systems is built for the intelligent planning, design, operation and ecological monitoring of the solar and wind power plants, based on large number of real-time monitoring and numerical simulation data, in order to obtain significant ecological, economic and carbon-reducing benefits during the power generation.

The platform consists of two parts: the physical site and the digital analysis system for three types of renewable power stations (photovoltaic, photothermal and wind power). The physical sites include four demonstration power plants: the 500 MW photovoltaic plant at the Talatan gobi in Gonghe county, 100 MW photovoltaic station at the Utu Meiren desert in Haixi state, 50 MW photothermal power station at the Talatan gobi and the 300 MW wind farm at the Cheji gobi in Gonghe county, and each of them has a comprehensive monitoring system at multiple levels (above ground, surface and underground) and scales (point, line and surface) as shown in the following figure.

Four demonstration power plants



Comprehensive monitoring system with multi-levels and multi-dimensions



Design & Operation

Protection & Restoration

Synergetic Development

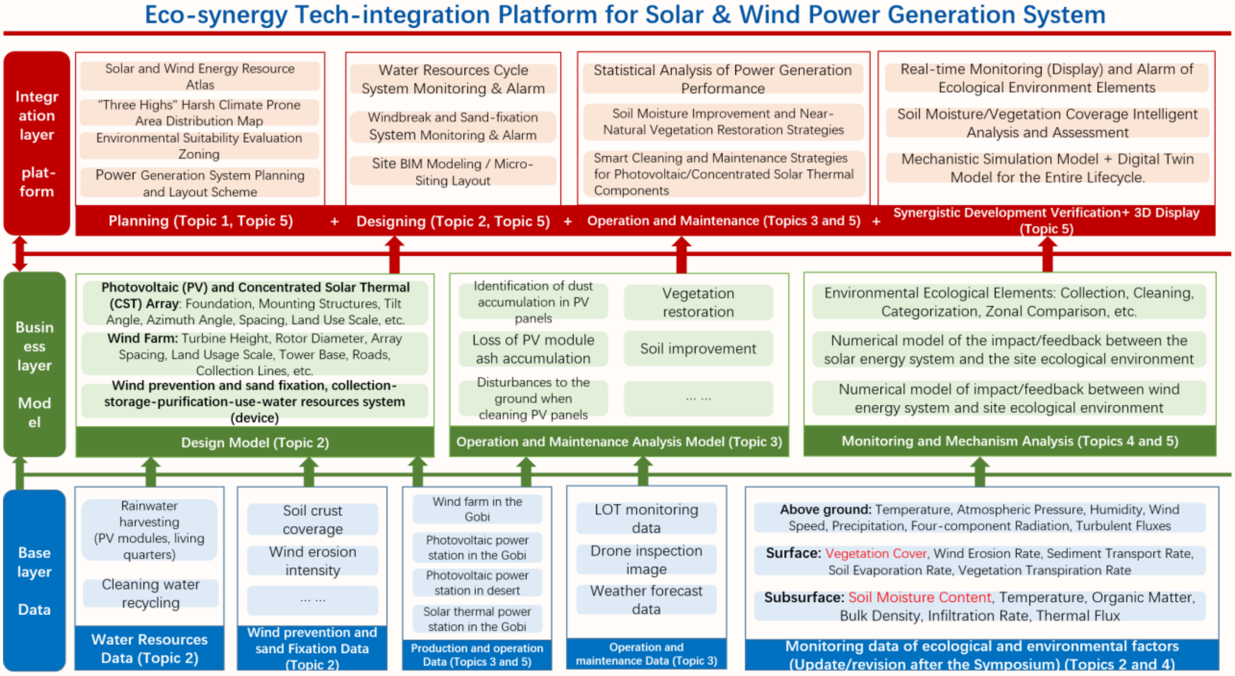
Innovation Priorities

Interoperable markets, devices and data | **IP 3.3.1**

Eco-synergic Technology integration with renewable energy system supported by multi-source monitoring data

The digital analysis system can collect the real-time ecological, meteorological, hydrological and operational monitoring data of the four demonstration power plants. With the field data processing and numerical simulation, the digital analysis system will implement the following features: (1) Visual output of the planning and layout schemes for the solar and wind power plants in the typical ecological zones within the TP, (2) optimization of the eco-synergistic design of the photovoltaic power plant, solar thermal power plant and wind farm, (3) the application and remote monitoring of the water collection and reuse system and windproof and sand-fixing system at the photovoltaic power plant, (4) intelligent identification of sand and dust pollution on PV modules with guidance of cleaning strategy, (5) real-time monitoring and alarming of the ecological, meteorological, hydrological elements and energy generation data for the demonstration sites, (6) digital twinning of energy generation and ecological variation (soil temperature and moisture, vegetation coverage, etc.). The main body of the platform hardware is deployed in the remote centralized control center of Power China Northwest Engineering Corporation Limited in Xi'an, China. The framework of the platform is shown as following.

Eco-synergy Tech-integration Platform for Solar & Wind Power Generation System



Project coordinator: Huaiwu Peng

To know more about the GPFM and the factsheet series
https://explore.mission-innovation.net/mission/green-powered-future/

GREEN POWERED FUTURE MISSION

Pillar 3
Data and Digitalisation

Case study #2 *from factsheet P3-01*

Open Energy

GPFM member
Icebreaker One

Q3 2024 ▶▶▶ 2026

Main involved partners

Icebreaker One
demand logic
ELEXON
Data Communications Company
Scottish & Southern Electricity Networks

TRL 8

Open Energy is a non-profit initiative, co-funded by the UK Government, industry and philanthropic investment and has been collaboratively developed over the past four years. It unlocks access to data held by organisations and institutions to enable an open marketplace and support our net-zero future. Its non-profit services make it easy to search, access and securely share energy data (both commercial and open data).
Access to both industry and consumer data is at the heart of the UK's journey to a healthy, growing net-zero economy. This will impact the energy sector, transport, water, agriculture and the built world, and how they are financed. Open Energy supports the development of the national Green Finance Programme.
Net zero interventions are needed to address resilience and innovation: from enabling double-digit improvements in retrofit efficiency to demand response to better balancing of decentralised flexibility markets.
Equally important is that businesses and consumers stay in control. Through collaboration on **open standards** and **trust frameworks**, organisations across the UK can unlock sector-wide efficiency and innovation that can enable their own data strategies.
This reduces the cost of data sharing and transforms access to data by creating **cohesion and interoperability** - competition should focus on impact, not the rules of the game.
Operated by IB1, an independent non-profit, **Open Energy** is part of its approach to address data governance to enable data sharing across industry, finance and the environment.
It has developed and commoditised implementation frameworks for the energy sector, to modernise access to the energy data across industry and address decarbonisation and the climate crisis via economic innovation. Roll out of Open Energy and its principles will enable actors in the energy industry to interact better with each other, allowing governments, investors, businesses and consumers to make better decisions to drive to **Net Zero**.

Overview
Open Energy enables the discovery and usage of data across the sector. Open Energy makes it easy to search (via https://openenergy.org.uk), discover, access and securely share energy data using a Trust Framework. Trust in data is essential. Open Energy co-created a 'Trust Framework' to unlock sector-wide efficiency and innovation that can enable their own data strategies.

Methodology
Open Energy's core innovation focused on culture change as much as innovative technical development. Key to the development of Open Energy was promoting interoperability of data whilst recognising the various standards and technologies in use across the energy industry, as well as ensuring interoperability with data from outside the energy sector. This work was enabled by a robust and open engagement process.

Icebreaker One

Data Standards | **Interoperability** | **Collaboration**

Innovation Priorities

Data discovery, access and licensing | **IP 3.1.1**

Data security standards and data privacy | **IP 3.1.4**

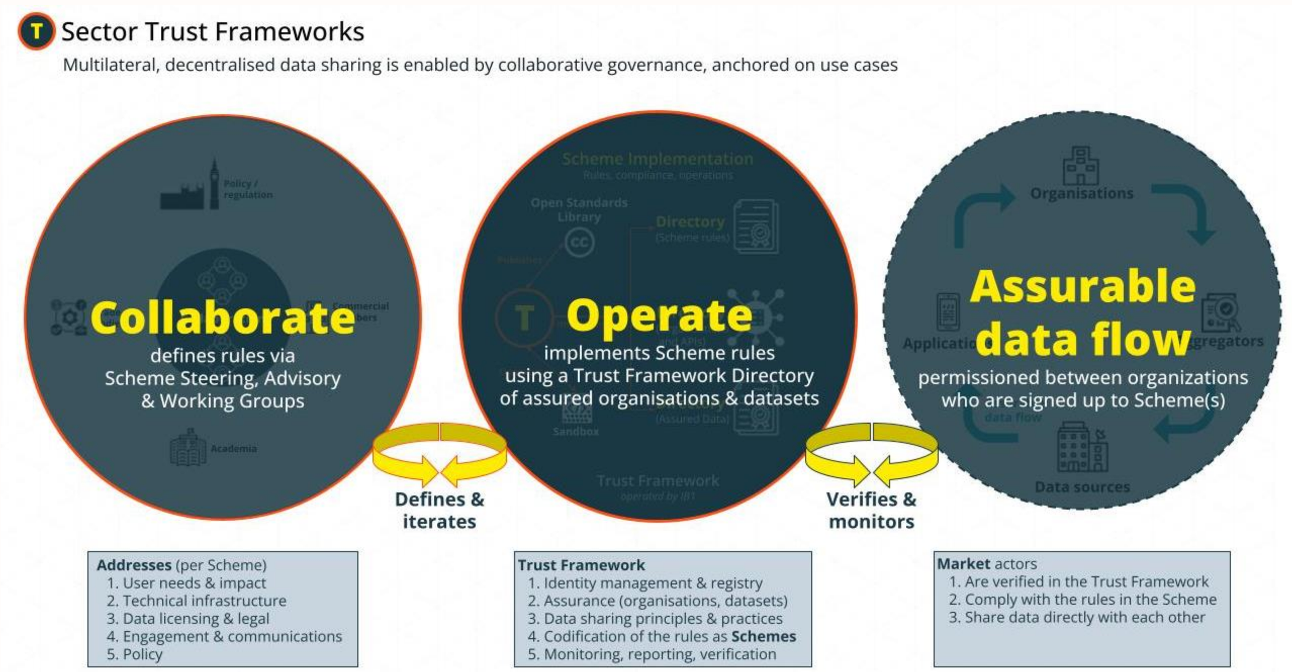
Interoperable markets, devices and data | **IP 3.3.1**

Results

Our research shows future development must consider the following principles:

1. Data increases in value the more it is connected. Incentives must exist to mandate participation by the sector in open standards that enable interoperability and drive behaviours towards an open marketplace for data.
2. All solutions must be considered from a perspective of maximising cohesion and interoperability. Specifically addressing the needs for machine-integration for application developers, as well as direct service users. Machine definitions of data licensing must be developed as in-scope.
3. All digital services are iterative in nature.
4. Collaboration is critical to the development of this work from both a technical perspective (solutions must meet user needs) and from a cultural perspective (solutions must be co-designed, adopted, used and iterated upon with market participants)

The key innovation is in data governance, verification and assurance: enabling a decentralised approach where data and metadata can be shared by being maintained and managed across a distributed ecosystem, on each data custodian's own infrastructure.
It addresses technical (e.g. metadata) and non-technical (e.g. legal, IP, policy) in a cohesive framework, collaboratively designed by value chain participants.



Project website: https://ib1.org/open-energy-uk/ **Project coordinator:** Gavin Starks

To know more about the GPFM and the factsheet series
https://explore.mission-innovation.net/mission/green-powered-future/

***Case study #3** from factsheet P3-01*

AI techniques to detect cyber attacks to electrical infrastructures

GPFM member
Italy

Q1 2023 ▶▶ **Q4 2024**

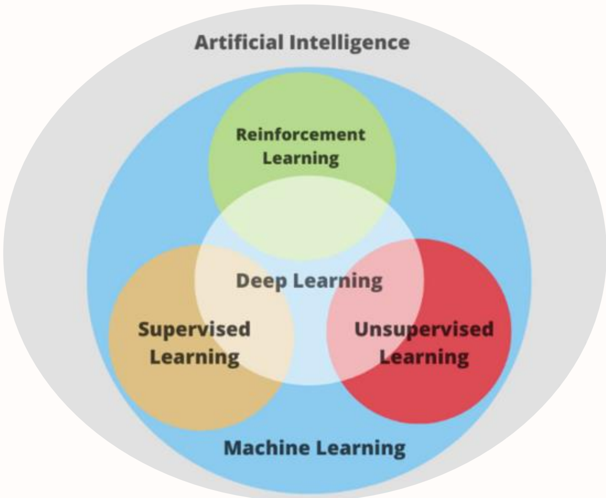
Main involved partners

RSE Ricerca Sistema Energetico – we move rsearch

TRL 4

Power systems will be increasingly exposed to cyber attacks as they become more and more digitalised. Every communication interface which is essential to the future power system operation represents a potential access point to cybersecurity threats. Preventive measures can reduce the probability of success of cyber attacks, but they are not sufficient to block all kind of malicious actions, especially those not already well known and hard to contain. In this view, AI-based technologies can represent a powerful solution to automatically predict attack steps and quickly react for preventing them from becoming a serious risk to the power system operation.
Defense strategies for Operational Technology (OT) deployed in electricity infrastructures differ from the ones of the Information Technology (IT). Attacking OT networks requires that the malware gathers information about power processes and their operating conditions. Once the malware has acquired the information needed to understand which measures and commands are exchanged by which devices, the attacker has the capability to send signals to the right targets which are syntactically and semantically correct, but not operationally. The malware activity would result legitimate to the target and conventional tools for intrusion and anomaly detection would become ineffective. Typically, malwares remain silent for a certain period during which there is the possibility to detect anomalies before that the target step to the power control device occurs. One possible strategy to contrast such OT attacks is to equip the control infrastructure with 'decision-making' capabilities preventing the injection of fake measures and the execution of unexpected commands.

AI-based algorithms can provide these capabilities, but to obtain accurate predictive models the adoption of high-quality datasets for the training phase is essential. The availability of good datasets is a great challenge for the application of AI to the cybersecurity of electricity systems. Indeed, there are not many datasets in the literature and those available don't consider very relevant aspects that are crucial to develop models that can be successfully applied to various kind of cyber attacks, including the so called *zero-day attacks.*



Artificial Intelligence | **Cyber security** | **Cyber attacks**

Innovation Priorities

Data security standards and data privacy | **IP 3.1.4**

Application of AI algorithms to classify cyber attacks to electrical infrastructures

In this case study five algorithms were selected to recognize cyber attacks, all requiring supervised training:

- **Decision Tree (DT):** It aims to predict the class label of new coming data, by depicting the relationship between the predictors and the target variable of the training data;
- **Random Forest (RF):** It consists of several decision trees, each of which predicts the class of the new coming data to be considered correct;
- **Naïve-Bayes (NB):** It is based on the Bayes theorem, computing the conditional probability of an event according to the available data about another correlated event;
- **Support Vector Machine (SVM):** Its goal is to find the N-dimension plane that best separates the data classifying them distinctly into their respective classes;
- **Multilayer Perceptron (MLP):** It is a class of fully connected and feed-forward artificial neural networks able to learn a function by training on a set of features and an objective variable.

The *Phyton* code that was developed to implement these algorithms has been initially trained and tested using the *NSL-KDD* dataset available in the literature. After the training dataset have been analyzed and prepared, the five classification algorithms were trained.

For each of the algorithms the accuracy score was computed (defined as the ratio between the number of correct attack detections and their total number). With this metric, the goodness of the model inference in classifying the test data is assessed.

The applied methodology produced models with accuracy in line with the results obtained in the literature on the NSL-KDD IT dataset.

AI algorithms accuracy score

MLP	90.3%
SVM	86.9%
DT	83.4%
RF	79.2%
NB	76.9%

Then the same classification algorithms have been trained on OT datasets generated by GANs (Generative Adversarial Networks). Despite of the critical issues detected on the synthetic datasets, the methodology applied to produce cyber attack classification models is correct and can be applied to other datasets, allowing to select the best model to use.

Project website: https://www.rse-web.it/en/projects/integrated-project-for-energy-system-cybersecurity/ **Project coordinator: RSE - Italy**

To know more about the GPFM and the factsheet series
https://explore.mission-innovation.net/mission/green-powered-future/

GREEN POWERED FUTURE MISSION

Pillar 3
Data and Digitalisation

Case study #4 *from factsheet P3-01*

The Virtual Energy System Programme

GPFM member
NESO, UK

Q4 2021 ▶▶ **Q4 2025**

Main involved partners
NGET, SPEN, SSEN Transmission, SSEN Distribution, NGGT, NGN, Arup, ESC, Icebreaker One

TRL 4-6

Digitalisation is crucial for a secure and resilient energy system, enabling improved simulation and forecasting abilities and efficient, whole-energy-system decision-making, supporting the long-term vision of operating a zero-carbon energy system. These digitalisation activities need to be underpinned by the secure, resilient, and scalable sharing of data across the sector which reduces the socio and technical friction and barriers of data sharing. The governance of these sector-wide digitalisation activities is critical for their effective and efficient identification, prioritisation, and implementation.

The Virtual Energy System (VirtualES)

To address challenges around decarbonisation and leverage the opportunity of digitalisation, the ESO launched the Virtual Energy System in 2021, an ambitious programme with a vision to enable an ecosystem of connected digital twins of the entire GB energy landscape, working in parallel to the physical system.

The VirtualES will provide the common framework with agreed access, operations, and security protocols, fostering industry collaboration and ensuring data security. Over time, this framework will help integrate digital twins of physical energy assets, such as power plants and grid infrastructure.

The Data Sharing Infrastructure (DSI)

As first step in its implementation, the VirtualES is developing the data sharing infrastructure; an open-source solution to enable scalable and secure data sharing between organisations. In 2023, the UK Government procured a feasibility study to examine the opportunities, risks, and potential architectures of developing an energy system 'digital spine' (precursor concept to the DSI). Upon the study's conclusion, the ESO established collaborations with key cross-industry programmes, such as the National Digital Twin Programme, to progress the foundational elements of the energy system DSI..

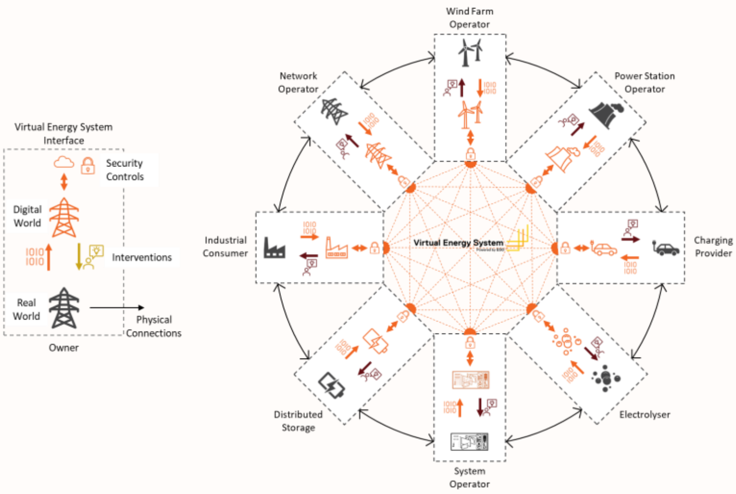


Figure #1: The Virtual Energy System concept

Digital Twins **Data Standards** **Data Sharing**

Data discovery, access and licensing | **IP 3.1.1**

Data security standards and data privacy | **IP 3.1.4**

Interoperable markets, devices and data | **IP 3.3.1**

Innovation Priorities

Digital services, standards and tools to support cross-sector exchange of data

High Level Design of the Data Sharing Infrastructure

The DSI is made up of two components: the Data Preparation Node (DPN) and the Data Sharing Mechanism (DSM).

The DPN is a software application node that can be deployed in an organisation's own infrastructure. It prepares data into a minimum operable data standard, specific to each data type and use-case, and presents it through standard APIs, access, and security controls.

The DSM is the connectivity and control plane to facilitate data exchange. It provides the security, governance, trust services, schema assurance, data cataloguing and DPN node management components.

The core principle driving the design for the DSI is a decentralised architecture, where the goal is to enable seamless access to data for multiple users, regardless of its physical location. Data sharing follows a federated approach whereby the following features and benefits can be realised:

- Ownership and governance: the locality and ownership of the data remains with the energy organisations providing that data –rather than with a central entity in a central repository.
- Scalability: enables increased data demands without overwhelming a centralised storage system.
- Performance: latency can be minimised leading to faster data retrieval and processing – especially in scenarios requiring near real-time data.
- Availability: the failure of one computing instance or datastore is less likely to affect the entire data infrastructure – as it would with a centralised approach.

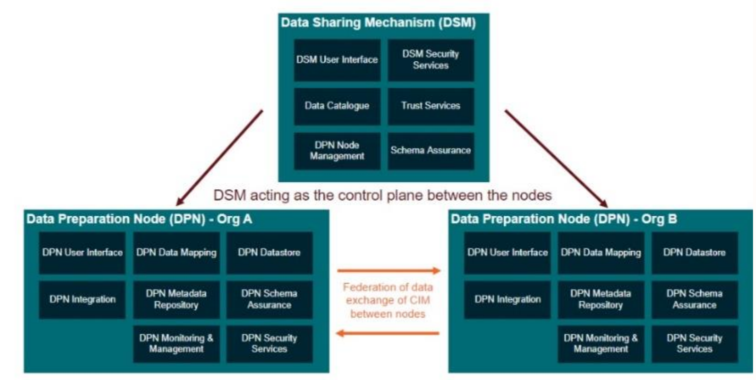


Figure #2: The outline logical architecture of the DSI

Project website: [VirtualES Website] **Project coordinator**: VirtualES@nationalgrideso.com

To know more about the GPFM and the factsheet series
https://explore.mission-innovation.net/mission/green-powered-future/

GREEN POWERED FUTURE MISSION

Pillar 3
Data and Digitalisation

***Case study #5** from factsheet P3-01*

DATA CELLAR: a compatible-secure energy data space

GPFM member Spain

Q3 2022 ▶▶ **Q4 2025**

Main involved partners

circe · CTIC centro tecnológico · FAEN Fundación Asturiana de la Energía · zabala INNOVATION · edp

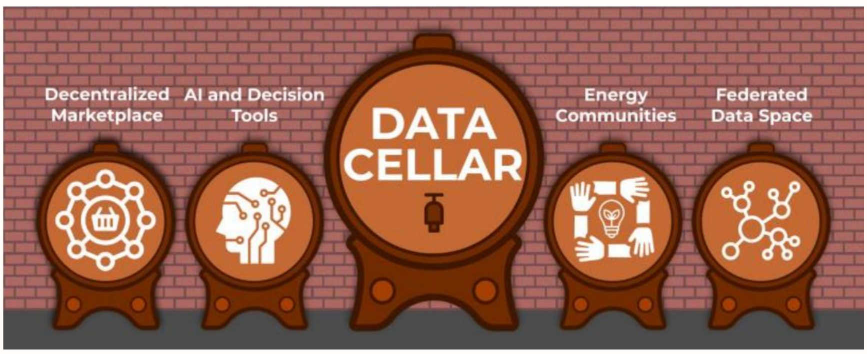
TRL 7

A greener energy system is crucial for the future prosperity and livability of European citizens. This requirement is at the heart of the DATA CELLAR approach where LECs have been recognized by the European Commission as a pivotal measure to play a key role in driving the energy transition of the European Union (EU). At the same time, the digitization of the EU energy system and the proper exchange of data between energy actors appear crucial to foster the exchange of best practices and the creation of a knowledge community to tackle one of our society's most pressing global crises: climate change.

In this context, DATA CELLAR aims to implement a collaborative platform that will provide an interoperable and secure energy data space capable of delivering access to datasets and Artificial Intelligence (AI) models to serve and support the spread of energy communities in the EU, leveraging on experience gained during the development of other European projects. DATA CELLAR will create a decentralized data space to store streams or historical data coming from private metering, but it will also provide a data federation integrating data coming from both external companies and EU federation spaces. The data space will be populated by a series of services dedicated to energy utilities, energy communities, private businesses and citizens. Furthermore, DATA CELLAR will provide a decentralized and open marketplace for energy datasets and pre-trained AI models to serve and support LECs.

Main objectives of the project:

- Development, validation and demonstration of a Dynamic data hub
- Implement privacy and cybersecurity-by-design measures.
- Provide Access to AI models and data-driven energy
- Create and sustain a highly engaged data sharing ecosystem of EC data providers.
- Evaluate DATA CELLAR novel business models



Data

Interoperability

Digitalisation

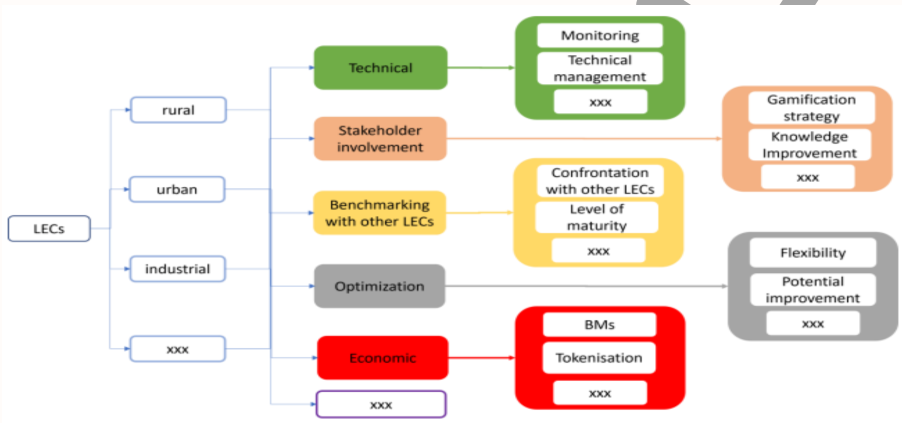
Data discovery, access and licensing | IP 3.1.1

Interoperable markets, devices and data | IP 3.3.1

Innovation Priorities

Project structure, validation cases and deliverables

The ambition of DATA CELLAR will be to analyze the most interesting and valuable applications for the involved stakeholders to push the state of the art for these applications by matching the technological expertise with the domain expertise present within the consortium, but also to implement a tool that can allow easier access to these models also to people that do not have this technological expertise. To achieve its objectives, DATA CELLAR is divided into 9 WPs with different objectives, tasks and deliverables. WP1 has, as main objective, the assessment of the Validation Cases (VCs) and of other existing dataspace / ongoing energy communities experiences..



The DATA CELLAR data space will be validated in 9 Validation Case which represents different Energy community at different level of maturity in terms of status of the energy community.

The Validation Cases represents a wide range of possible European energy communities that are managed by different stakeholders. They will crowd the data space with existing data around energy communities which will cover different energy (electricity, heating and cooling, gas, water…) and non-energy vectors (mobility, transport, user behaviours, …).

The deliverables of the project will be:

D6.1 Energy Data Analytics Visual Tool

D6.2 DLT Architecture and Governance Model

D5.1 AI models and libraries for energy communities

D5.2 Digital Twin based on DATA CELLAR Data for Energy Communities developers

D6.3 Token-based Incentive Schema and Marketplace Components Integration

D5.3 DATA CELLAR users' interaction: HMI and DSS for energy communities' developers

D7.2 EU Energy Scenarios and role of energy communities investigated thanks to DATA CELLAR

D8.4 DATA CELLAR Final Policy positioning paper

Project website: https://datacellarproject.eu/ **Project coordinator**: RINA CONSULTING SPA

To know more about the GPFM and the factsheet series
https://explore.mission-innovation.net/mission/green-powered-future/

GREEN POWERED FUTURE MISSION

Pillar 3
Data and Digitalisation

***Case study #6** from factsheet P3-01*

Interoperable Domestic Flexibility: Standards and Innovation

GPFM member UK

Q2 2021 ▶▶ **Q4 2025**

Main involved partners

bsi

TRL 4-5

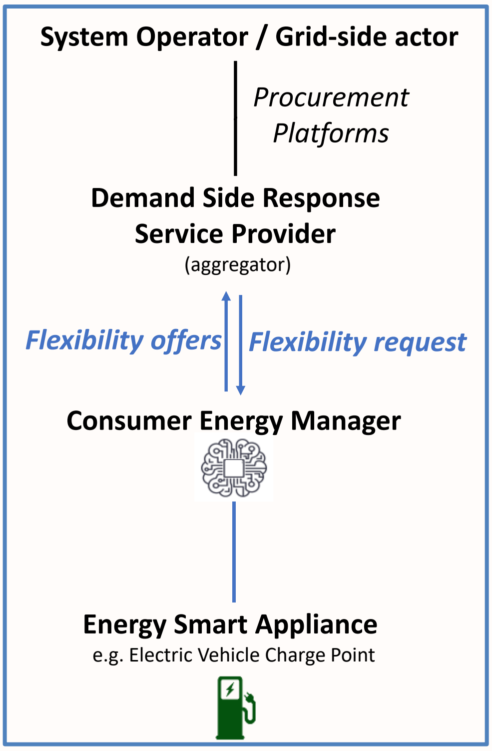
Increased flexibility could help enable the transition away from fossil fuels to more renewables-based grids and reduce electricity system costs, by better managing how and when we use energy. One key source of this flexibility is domestic demand-side response (DSR) – the process of changing when electricity is used or produced by consumers in response to needs of the electricity system.

In our modelled scenarios, increasing flexibility in the system could:

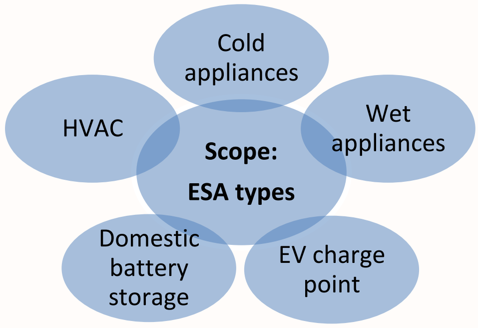
- save up to £10 billion per year by 2050
- reduce system costs between £30-70bn from 2020 to 2050
- Create up to 24,000 jobs by 2050

Though currently a nascent market, standardisation can help to lower development costs and promote innovation in technologies, while accelerating the uptake of secure and interoperable smart products and services.

In 2021, the Department for Energy Security and Net Zero sponsored the development of an open common set of standards, including the technical specification: PAS1878:2021 Energy smart appliances – System functionality and architecture (free to download), to specify the classification of Energy Smart Appliances (ESAs) for facilitating the delivery of interoperable, cyber-secure domestic DSR, subject to explicit consumer consent, which promotes grid stability and respects consumers' data privacy.



Core Principles	
1. Interoperability	the ability of an ESA to work seamlessly across any DSR service operated by any system player.
2. Data privacy	the secure storing of data on the device or with any controlling party.
3. Grid-stability	the prevention of outages on the grid caused by erroneous operation of ESAs.
4. Cyber-security	the prevention of unauthorized access to an ESA by third-parties.



Standardise

Innovate

Iterate

Data security standards and data privacy | **IP 3.1.4**

Interoperable markets, devices and data | **IP 3.3.1**

Innovation Priorities

Innovation

Forming part of the Department for Energy Security and Net Zero's Net Zero Innovation Portfolio, the Interoperable Demand Side Response innovation programme aims to support the development and demonstration of energy smart appliances for the delivery of interoperable demand side response services.

As part of this innovation programme eight projects were awarded funding to develop energy smart appliances and demand side response service provider platforms to deliver interoperable demand side response in accordance with PAS 1878 and the principles of PAS 1879.

Following development, the products (which included electric vehicle charge points, batteries, heat pumps, storage heaters) entered into a phase of laboratory-based conformance testing which sought to assure products and platforms individually and in combination, ensuring that one project's appliances were able to interoperate with another project's service provider. Upon successful completion of tests in the lab, the devices will then enter a demonstration phase where multiple products and platforms will be operated in combination in a setting indicative of the real world.

Phase 1 (18 months):
Design and development of demand side response systems to PAS 1878

Phase 2 (9 months):
Laboratory Testing and Demonstration

Phase 3 (6 months):
Demonstration in Settings Indicative of the Real World

Energy Smart Heat Pump - participant organisations Samsung Electronics UK, Passiv UK

This close link between the standards development activity and the innovation work has enabled rapid iteration, with learnings from the development and testing phases of the innovation programme now feeding directly into the second iteration of the standard, PAS1878:2025, as well as contributing to wider policy development.

By promoting the uptake of smart appliances and domestic DSR through supporting standards development and innovation in smart technologies, we can maximise flexibility to help save on the costs of a fully decarbonised electricity system and help to minimise consumer bills.

Project website: https://tinyurl.com/2r9sp8an **Project coordinator**: DESNZ, UK

To know more about the GPFM and the factsheet series
https://explore.mission-innovation.net/mission/green-powered-future/