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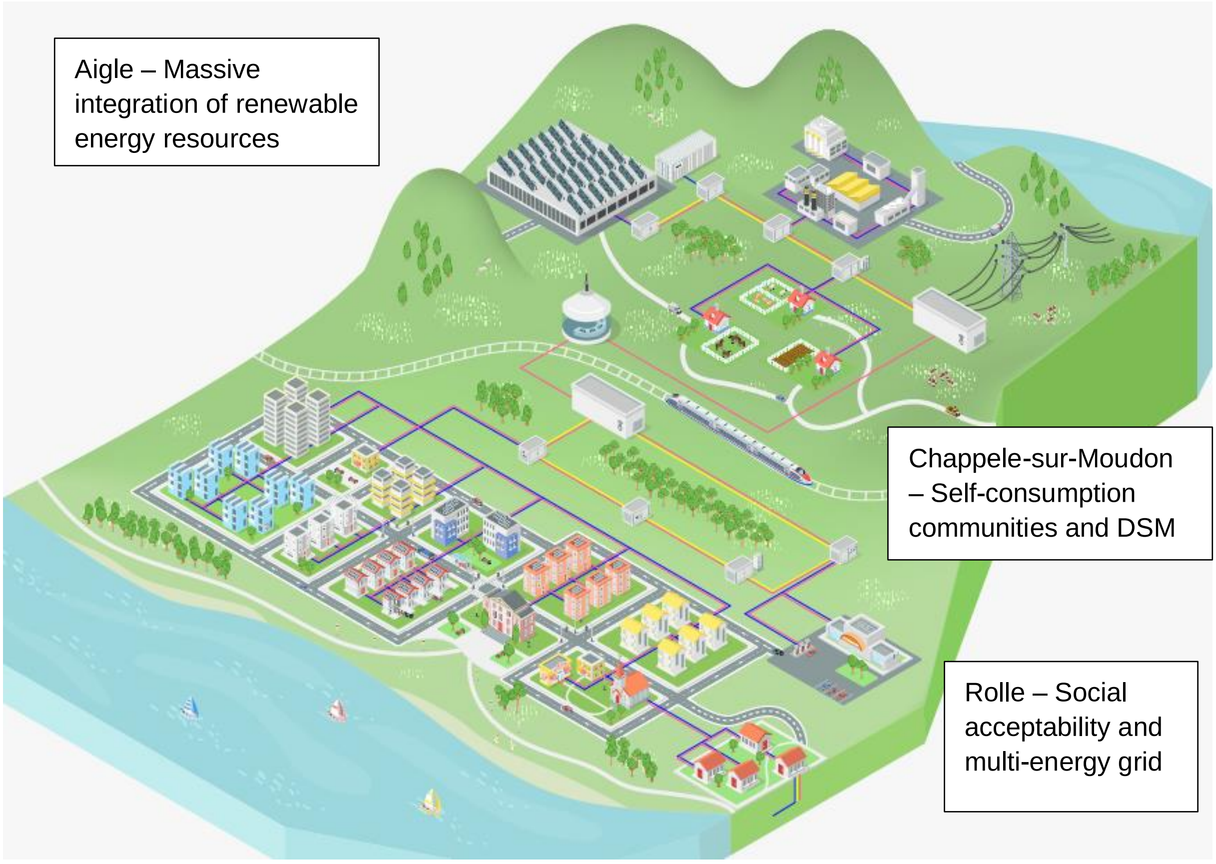
SCCER-FURIES Romande Energie ELectric network in local balance Demonstrator (REEL Demo)



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Summary

The transformation towards sustainable power systems is mostly affecting power distribution grids. While in the past solutions focused mainly on bulk power transmission networks, it is now evident the need of technologies specifically designed for the so-called *active distribution networks* (ADNs). In this respect, there is a consolidated research field specifically focusing on solutions for the planning, control and protection of ADNs with a strong interest from utilities to validate these solutions in real contexts. By means of a unique experimental platform at European level, the project aims at validating technologies capable to enable vast and seamless integration of renewable energy sources into the Swiss energy mix.

Concerning the planning, a methodological framework was developed for district-level energy systems planning and validated at the Rolle demo site. This framework is following a bottom-up approach based on individual buildings' design and potential in energy generation and efficiency improvement. The framework is also capable to consider power grid related constraints. The tool has been developed to enable energy actors to take evidence-based decisions. Typical examples refer to: (i) definition of incentives schemes that a local/cantonal authority can provide in a cost-efficient manner or (ii) a business model that a utility (or an aggregator) may promote for the valorization of local flexibilities. Beyond specific technological aspects, other conditions, notably socio-economic and legal aspects, for the implementation of demand side management (DSM) were also evaluated.

Concerning the operation and control, various control solutions were developed and validated for (a) the support of an energy community to increase its self-consumption and provide grid services, and (b) the optimal dispatch of a medium-voltage grid hosting substantial amount of stochastic generation from heterogeneous resources. In both activities, the control assets were composed by battery energy storage systems (BESSs). The focus of the former set of activities is to improve BESSs' operation by enhanced control methods that take into account weather forecasts, grid measurements, and battery ageing. The developed methods support energy community managers to control their resources in an economically viable way. By leveraging state-of-the-art distributed sensing technologies, state estimation and optimal power flow methodologies, the latter set of solutions focused on the use of BESSs to optimally dispatch medium-voltage power distribution grids hosting substantial amount of stochastic power generation. The coordination between transmission and distribution systems operators (TSOs/DSOs) for the provision of ancillary services to the upper grid was also studied. The obtained results are of great interest for DSOs[1] aiming at maximizing the renewables hosting capacity of their grids, while limiting their impact on the transmission grid and therefore respecting the operation regulation imposed by Swissgrid, and operators of storage system that aim to provide multiple services to various grid users and DSOs. Regarding the increase of renewables hosting capacity of power distribution grids, a novel device called *soft-open point*, was also developed in the frame of the project, and experimentally validated.

Cybersecurity associated to demand side management were also studies resulting in recommendations to DSOs and aggregators.

Résumé

La transformation vers des systèmes électriques durables affecte principalement les réseaux de distribution d'électricité. Alors que dans le passé, les solutions se concentraient principalement sur les réseaux de transport d'électricité, il est maintenant évident qu'il faut des technologies spécifiquement conçues pour les réseaux de distribution actifs (active distribution networks (ADNs)). À cet égard, il existe un champ de recherche consolidé spécifiquement axé sur les solutions de planification, de contrôle et de protection des ADN avec un fort intérêt des services publics pour valider ces solutions dans des contextes réels. Au moyen d'une plate-forme expérimentale unique au niveau européen, le projet vise à valider des technologies capables de permettre une intégration vaste et sans interruption des sources d'énergie renouvelables dans le mix énergétique suisse.

Concernant la planification, un cadre méthodologique a été développé pour les systèmes énergétiques à l'échelle du quartier et validé sur le site de démonstration de Rolle. Ce cadre suit une approche basée sur la conception et le potentiel de chaque bâtiment en matière de production d'énergie et d'amélioration de l'efficacité. Le cadre est également capable de prendre en compte les contraintes liées au réseau électrique. L'outil a été développé pour permettre aux acteurs de l'énergie de prendre des décisions fondées sur des preuves. Les exemples typiques font référence à : (i) la définition de programmes d'incitations qu'une autorité locale/cantonale peut fournir de manière efficace ou (ii) un modèle d'affaire qu'un service public (ou un agrégateur) peut promouvoir pour la valorisation des flexibilités locales. Au-delà des aspects technologiques spécifiques, d'autres conditions, notamment socio-économiques et juridiques, de mise en œuvre de la gestion de la demande (DSM) ont également été évaluées.

Concernant l'exploitation et le contrôle, diverses solutions de contrôle ont été développées et validées pour (a) l'accompagnement d'une communauté énergétique pour augmenter son autoconsommation et fournir des services de réseau, et (b) le plan prévisionnel d'exploitation des ressources (« dispatch plan ») d'un réseau moyenne tension hébergeant une quantité substantielle de génération stochastique à partir de ressources hétérogènes. Dans les deux activités, les moyens de contrôle étaient composés de systèmes de stockage d'énergie par batterie (BESS). L'objectif du premier groupe d'activités est d'améliorer le fonctionnement des BESS par des méthodes de contrôle améliorées qui prennent en compte les prévisions météorologiques, les mesures du réseau et le vieillissement des batteries. Les méthodes développées aident les gestionnaires de communautés énergétiques à contrôler leurs ressources de manière économiquement viable. En tirant parti des technologies de détection distribuée de pointe, de l'estimation de l'état et des méthodologies de flux de puissance optimales, le deuxième groupe de solutions s'est concentré sur l'utilisation des BESS pour répartir de manière optimale les réseaux de distribution d'énergie moyenne tension hébergeant une quantité substantielle de production d'énergie stochastique. La coordination entre les gestionnaires de réseaux de transport et de distribution pour la fourniture de services système au réseau supérieur a également été étudiée. Les résultats obtenus sont d'un grand intérêt pour les GRD visant à maximiser la capacité d'accueil des énergies renouvelables de leurs réseaux, tout en limitant leur impact sur le réseau de transport et donc en respectant la réglementation d'exploitation imposée par Swissgrid, ainsi que pour les opérateurs de système de stockage qui visent à fournir de multiples services aux divers utilisateurs du réseau et GRD. En ce qui concerne l'augmentation de la capacité d'accueil des énergies renouvelables des réseaux de distribution d'électricité, un nouvel appareil appelé soft-open point a également été développé dans le cadre du projet et validé expérimentalement.

La cyber sécurité associée à la gestion de la demande a également fait l'objet d'études donnant lieu à des recommandations aux GRD et aux agrégateurs.

Zusammenfassung

Die Transformation hin zu nachhaltigen Energiesystemen betrifft vor allem die Stromverteilnetze. Während sich die Lösungen in der Vergangenheit hauptsächlich auf große Stromübertragungsnetze konzentrierten, ist jetzt der Bedarf an Technologien offensichtlich, die speziell für die sogenannten aktiven Verteilungsnetze (active distribution networks (ADNs)) entwickelt wurden. In dieser Hinsicht gibt es ein konsolidiertes Forschungsfeld, das sich speziell auf Lösungen für die Planung, Kontrolle und den Schutz von ADNs konzentriert, mit einem starken Interesse von Versorgungsunternehmen, diese Lösungen in realen Kontexten zu validieren. Mittels einer einzigartigen experimentellen Plattform auf europäischer Ebene zielt das Projekt darauf ab, Technologien zu validieren, die in der Lage sind, eine umfassende und nahtlose Integration erneuerbarer Energiequellen in den Schweizer Energiemix zu ermöglichen.

Im Hinblick auf die Planung wurde ein methodischer Rahmen für die Energiesystemplanung auf Quartiersebene entwickelt und am Demostandort Rolle validiert. Dieser Rahmen folgt einem Bottom-up-Ansatz, der auf dem Design und dem Potenzial einzelner Gebäude bei der Energieerzeugung und Effizienzsteigerung basiert. Das Framework ist auch in der Lage, stromnetzbezogene Einschränkungen zu berücksichtigen. Das Tool wurde entwickelt, um Energieakteuren in die Lage zu versetzen, evidenzbasierte Entscheidungen zu treffen. Typische Beispiele beziehen sich auf: (i) die Definition von Anreizsystemen, die eine lokale/kantonale Behörde kosteneffizient bereitstellen kann, oder (ii) ein Geschäftsmodell, das ein Versorgungsunternehmen (oder ein Aggregator) zur Valorisierung lokaler Flexibilitäten fördern kann. Neben spezifischen technologischen Aspekten wurden auch andere Bedingungen, insbesondere sozioökonomische und rechtliche Aspekte, für die Implementierung von Demand Side Management (DSM) bewertet.

In Bezug auf den Betrieb und die Steuerung wurden verschiedene Steuerungslösungen entwickelt und validiert, um (a) eine Energiegemeinschaft zu unterstützen, ihren Eigenverbrauch zu erhöhen und Netzdienstleistungen bereitzustellen, und (b) den optimalen Einsatz eines Mittelspannungsnetzes mit erheblichen Mengen der stochastischen Generierung aus heterogenen Ressourcen. Bei beiden Aktivitäten bestanden die Kontrollanlagen aus Batterie-Energiespeichersystemen (BESSs). Der Schwerpunkt der ersten Reihe von Aktivitäten liegt auf der Verbesserung des Betriebs von BESSs durch verbesserte Steuerungsmethoden, die Wettervorhersagen, Netzmessungen und Batteriealterung berücksichtigen. Die entwickelten Methoden unterstützen Energy Community Manager dabei, ihre Ressourcen wirtschaftlich sinnvoll zu steuern. Durch die Nutzung modernster verteilter Sensortechnologien, Zustandsschätzung und optimaler Leistungsflussmethoden konzentrierten sich die letzteren Lösungen auf die Verwendung von BESSs zur optimalen Disposition von Mittelspannungs-Stromverteilungsnetzen, die eine erhebliche Menge an stochastischer Stromerzeugung beherbergen. Untersucht wurde auch die Koordination zwischen Übertragungs- und Verteilnetzbetreibern (ÜNB/VNB) für die Bereitstellung von Systemdienstleistungen für das obere Netz. Die erzielten Ergebnisse sind von großem Interesse für VNB, die darauf abzielen, die Aufnahmekapazität für erneuerbare Energien in ihren Netzen zu maximieren und gleichzeitig ihre Auswirkungen auf das Übertragungsnetz zu begrenzen und somit die von Swissgrid auferlegten Betriebsvorschriften einzuhalten, sowie für Betreiber von Speichersystemen, die mehrere Dienste anbieten möchten verschiedene Netznutzer und VNB. Im Hinblick auf die Erhöhung der Aufnahmekapazität für erneuerbare Energien in Stromverteilungsnetzen wurde im Rahmen des Projekts auch ein neuartiges Gerät namens Soft-Open-Point entwickelt und experimentell validiert.

Cybersicherheit im Zusammenhang mit Demand Side Management waren ebenfalls Studien, die zu Empfehlungen an VNB und Aggregatoren führten.

Main findings

The main findings of the REeL project are presented below:

- The main research question addressed by the Aigle demo site is the following: *can we day-ahead dispatch and control in real-time a power distribution grid hosting stochastic renewables with a peak power equal to the local load?* On one hand, we seek to achieve specific global objectives, such as following a pre-defined day-ahead power profile (i.e., a dispatch plan), hence minimizing reserve needs for the power transmission grid. On the other hand, we aim to guarantee the distribution grid to operate within its technical constraints (i.e., preserving the local grid security and quality of service) and provide the energy market operators with grid visibility. In this regard, the main technical and methodological developments that have been validated in this demonstrator are the following.
    - Development and deployment of a pervasive sensing of the grid relying on Phasor Measurement Units (PMUs) to determine, in real-time, the estimation of the grid state. Such a function is critical for real-time controls operating at intra-day time horizons.
    - Development of day-ahead and short-term forecasting: the former is needed to compute a technically feasible day-ahead dispatch plan while the latter is required for the close tracking of the dispatch plan by the controlled assets (e.g., battery energy storage systems) during the intra-day operation.
    - Development of dedicated optimization frameworks to compute both the grid-aware dispatch plan and solve the intra-day optimal power flow (OPF) problem accounting for the day-ahead and shot-time forecasts of stochastic demand and generation.
- In the Chapelle demo site, it was demonstrated how much an energy community can both maximize its self-consumption and provide grid services when owning a local battery energy storage system (BESS). For this, the BESS should be controlled optimally considering weather and consumption forecast, grid measurements, and/or its ageing. This solution is more easily understandable and acceptable by the public that other flexibility-related solutions.
- In the Rolle demo site, it was demonstrated how the local utility can ensure the safe grid operation, without increasing drastically its CAPEX and OPEX, when optimally hosting large amount of heterogeneous energy resources such as photovoltaics, energy storage systems, electric vehicles, and heat pumps. Smart meters may support such an optimal integration. However, the deployment of those solutions is currently prevented by technical, economic (who brings the technologies at the clients premisses to be able to optimise his costs and have a behaviour that is useful for the grid? who pays?), and legal (data privacy issues) barriers that have been analysed and discussed.

Contents

Abbreviations

ADMM	Alternative Direction Method of Multipliers
ADN	Active Distribution Network
ADNs	Active Distribution Networks
AMM	Automated Market-Making Mechanism
AR-OPF	Augmented Relaxed Optimal Power Flow
BESS	Battery Energy Storage System
BM	Business Models
CAN	Controller Area Network
CAPEX	Capital Expenditures
CDF	Cumulative Distribution Function
CO2	Carbon Dioxide
COP	Coefficient Of Performance
CPU	Central Processing Unit
DERs	Distributed Energy Resources
DG	Distributed Generation
DHW	Domestic Hot Water
DNOs	Distribution Network Operators
DoD	Depth of Discharge
DSM	Demand Side Management
DSO	Distribution System Operator
EC	Energy Communities
EH	Electrical Heater
EMMA	Energy Management for Multiple Application
EMS	Energy Management System
ESSs	Energy Storage Systems
ETES	Electro-Thermal Energy Storage
EVs	Electric Vehicles
FLISR	Fault Location, Isolation, and Service Restoration
GA	Grid Agent
GCP	Grid Connection Point
GHI	Global Horizontal Irradiance
GIT	Global Irradiance and Temperature
GP	Gaussian Process
GU	Grid Usage
GWP	Global Warming Potential
HCA	Heuristic Control Algorithm
HIL	Hardware-In-the-Loop
HP	Heat Pump’s
IRR	Internal Rate of Return
KPIs	Key Performance Indicators
L-OPF	Linearized Optimal Power Flow
LGBM	Light Gradient Boosted Model
LPV	Linear Parameter Varying
MAE	Maximum-Absolute-Error
MILP	Mixed Integer Linear Programming
MPC	Model Predictive Control
MV	Medium Voltage
NWP	Numerical Weather Prediction
OPEX	Operating Expenditures
OPF	Optimal Power Flow
P2G	Power To Gas
PCC	Point of Common Coupling
PCR	Primary Frequency Regulation
PLF	Probabilistic Load Flow
PMU	Phasor Measurements Unit
RA	Resource Agent
RMSE	Root-mean-square error
RT	Real-Time
SCADA	Supervisory Control And Data Acquisition
SCI	Serial Communications Interface
SIA	Swiss Society of Engineer And Architects
SoC	State-of-Charge
SOE	State Of Energy
SOP	Soft-Open-Point
TSO	Transmission System Operator
UES	Urban Energy Systems
V2G	Vehicle To Grid
VPP	Virtual Power Plant
VSCs	Voltage Source Converters
PCC	Point of Common Coupling
PCR	Primary Frequency Regulation
PLF	Probabilistic Load Flow
PMU	Phasor Measurements Unit
RA	Resource Agent
RMSE	Root-mean-square error
RT	Real-Time
SCADA	Supervisory Control And Data Acquisition
SCI	Serial Communications Interface

1 Introduction

1.1 Background information and current situation

Fundamental changes are currently taking place in nowadays electrical infrastructure. The power system must satisfy conflicting requirements: providing reliable and secure services to an increasing number of customers, considering a rational use of energy and the protection of the environment. This last requirement drives major changes in electrical systems where increasingly renewable energy sources need to be connected to the grid. It is generally acknowledged that these sources need to be massive and distributed, to provide a non-negligible part of the consumed electrical energy. It is also generally agreed that such integration of renewables into existing grids depends on the successful combination of specific processes (e.g., demand side/response management, real-time consumption management, real-time local energy balance, accurate forecasting of renewables at continental, country and regional scales) and new technologies (e.g. smart meters, agent-based distributed controls). It is within this context that the implementation of the Swiss Energy Strategy 2050 foresees the massive integration of distributed resources into the grid.

To address the above-listed challenges, the Swiss Federal Office of Energy (SFOE) has proposed measurements to improve the framework conditions for the transformation and extension of the power network. The related Message has been adopted by the Federal Council on April 13th, 2016[2]. According to this Message, the awareness of the public on the importance of the grid should be raised to increase the social acceptability of the installation of new technologies. Also, the optimization of the network must be favored over reinforcement and extension. The implementation of smart solutions on the grid is among these optimization measures[3].

According to the SFOE Smart Grid Roadmap, the smart solutions will enable the development of new functionalities of the grid including the improvement of its observability, stability, and management and the quality of power supply. Also, they will improve the planning of grid exploitation and the development of new business models adapted to the new reality in terms of power supply and consumption. Pilot and demonstration projects are required for the increase of the maturity of these technologies; assessment of their profitability; and testing and validation of their compatibility with the conventional technologies.[4]

While there are such projects, the most of them are missing a holistic approach, requiring addressing one or more of the following challenges:

- *Temporal resolution*: while in the past, automation solutions focused mainly on bulk power transmission networks, it is now evident that specific solutions are needed for the so-called *active (electrical) distribution networks* (ADNs). These automation solutions require sub-second monitoring and control methodologies/technologies.
- *Spatial resolution*: the future power grid will not face one challenge at a time. For the realistic tackling of various grids' challenges, simultaneous validations of multiple solutions in real-life conditions are required.
- *Technology dimension*: there are various solutions for enhancing the grid performance with new functionalities required for the energy transition. However, it is not always clear which of those technologies is appropriate (and for which need) and whether it economically viable. Also, their compatibility with existing technologies is not always given.
- *Vertical integration:* projects tend to focus on a specific part of the grid. This can lead to myopic solutions that disregard the inter-dependencies among grid level and elements and/or lead to relocation of the problem to another part of the grid. However, multi-grid level project would require involvement of various grid stakeholders from the final customers to the DSO, TSO and authorities.
- *Sustainability*: the knowledge preservation and infrastructure accessibility for further research purposes are important elements for the maximization of the valorization of the research funding. While there are tools, such as aramis.admin.ch, addressing the former one, the latter is still a challenge particularly for real-grid infrastructures. This is a barrier for the validation of innovative solutions that can be overpassed with the development of long-term research platforms.

1.2 Purpose of the project

By means of a unique platform at European level, the project validates a set of technologies capable to enable vast and seamless integration of renewable energy sources into the Swiss energy mix.

The REeL Demo aims to respond to the research questions below.

- How the monitoring and management system of the future power grid can be enhanced with additional functionalities (as defined in the SFOE Smart Grid Roadmap) in order to enable the implementation of the Swiss energy strategy 2050?
- Which grid control solution is the most appropriate for each grid topology, considering management at the different level of the grid from the end user to the Low Voltage (LV) and Medium Voltage (MV)?
- Which is the optimal number of monitoring devices for an active power grid that enable the incorporation of the above-mentioned functionalities?
- Which is the most appropriate way to integrate into the grid large-Photovoltaic (PV) plant while satisfying various objectives, such as optimum grid control, maximum PV power integration, islanded grid?
- How the overall flexibility of the power system could be improved through the interaction among the various grid levels and energy-hubs?
- Which are the most appropriate business models for the promotion of these proposed solutions?

Therefore, it serves as open and permanent platform for:

- testing and validation solutions for the monitoring and management of the future active power grid, at different scales namely: city, grid, building or home.
- linking regulated operations and free market initiatives;
- interaction among the grid stakeholders and awareness raising of the general public on the smart grid technologies.

The target is to enable the vast and seamless integration of renewable energy sources into the Swiss energy mix.

Particularly, the REeL project responds to the current challenges of the power infrastructure (see 1.1) with respect to the following main points:

- *Temporal resolution*: the REeL demo project works on various time scales ranging from multiple years (i.e. planning), to day-ahead, intraday and sub-second (i.e. real-time monitoring and control), which make it unique within the Swiss/European contexts.
- *Spatial resolution*: the REeL demo project takes the innovative solutions out of the lab and validates them at the scale of small Swiss towns with complementary technical characteristics. More precisely, the demo site of Rolle is an urban area with DSM potentials; the demo site of Aigle a rural one with the production overpassing the consumption during summer and vice-versa during the winter; and the demo site of Chapelle-sur-Moudon is an energy community that aims to maximize both self-consumption while providing the grid with services. Apart from the innovative technologies and control methodologies that are going to be validated, specific activities are undertaken on the tackling of the socio-economic aspects of the grid such as new business models and tariff schemes too.
- *Technology dimension*: the REeL demo project focuses exclusively on solutions with high Technology Readiness Level (TRL) in order to facilitate their transfer to the market[5]. Furthermore, in the frame of

both the REeL project itself and the SCCER-FURIES as a whole, it allows the comparability of the proposed solutions with alternative solutions in order to define the most appropriate one per need.

- *Vertical integration:* the REeL Demo goes across grid levels from the costumers to the upper grid, given the interest of SwissGrid to enable in the future the concept of "controllable nodes". Furthermore, it involves other stakeholders of the energy grid such as local authorities of Rolle, Mont-sur-Rolle and Aigle and cantonal authorities of Vaud that are responsible for the energy planning of their region. This cross-levels collaboration contributes to the realistic representation of the future power grid and enable the transfer of knowledge to the appropriate target audience.
- *Sustainability*: Romande Energie is committed to maintain this unique platform for further validation of innovative solutions well beyond the horizon of 2022. This will further increase the impact of this project on the Swiss Energy Strategy 2050. Indeed, two projects have been associated to Aigle demo site: (i) a SFOE P,D&L in the frame of the program ERA-NET on EV charging stations grid integration that is currently taking place at the Aigle demo site of the REeL project and (ii) an ETH-Domain joint initiative on digital twin models of integrated urban energy systems.

1.3 Objectives

The SFOE Smart grid roadmap defines the functionalities that need to be integrated into the operation systems of the power infrastructure to enable the massive integration of stochastic and distributed resources. The REeL demo project's objective is to validate technologies that cover the full spectrum of these functionalities as enlisted below.

Table 1: Definition of functionalities and activities

Functionality cluster	**Functionalities to be added on the grid (with links to the functionalities of SFOE Roadmap)**	**Activities**
A. Situation awareness of medium voltage and low voltage networks	A1. Information of the DSO on the various elements of the grid and grid's status and decentralized production and consumption (A1-A3) A2. Information of the producers/consumers on the production/consumption (A4)	A1a. PMU-based situation awareness for MV networks integrated with fault location management processes and modeless situation awareness for LV networks integrated with power quality management A1b. Model-based identification of prosumers' behavior A2a. Provide PV power producers with information of their PV power production in real-time for the performance evaluation of their installation A2b. Provide producers/consumers with the best energy technology investment option based on techno-economic and geographic information
B. Grid stability and control; power quality and improvement of the efficiency at the daily operation of the grid	B1. Real-time control for heterogeneous resources at MV and LV level (B1-B3)	B1a. Real-time control strategies for heterogeneous resources at MV and LV level
	B2. Real time congestion management of MV feeders and fault location and services restoration (B4)	B2a. Real time congestion and load profile management; and voltage dynamic control of MV feeders with Battery Energy Storage Systems and PMUs B2b. Fault location with the use of PMUs
	B3. System services including ancillary services and flexibility (B5)	B3a. Distributed provision of flexibility with the use of BESS B3b. Study the provision of ancillary services among the various grid layers
	B4. Cybersecurity on the smart grid (B6)	B4a. Test cybersecurity on the entire system
C. Improvement of the system planning,	C1. Prediction of energy demand and production for the system planning (C1-C2)	C1a. Algorithms and models for the prediction of the day ahead energy demand of customers (24hours) and refining of

including operation and development		the local weather forecast for optimization of the decentralized production integration into the grid
	C2. Energy-hubs for improvement of grids' efficiency (C3)	C2a. Planning of multi-energy systems
D. Electricity market and services to the consumers	D1. Enable vast and seamless integration of customers and producers into the market (D1)	D1a. Develop communication between battery and Grid control devices
	D2. Optimized Demand Side Management (DSM) and interaction with the grid (D3-D5)	D2a. DSM strategies and assessment of their performance and cost-benefit analysis
	D3. Solutions for self-consumption's enhancement (D2-D3)	D3a. New business models based on self-consumption incentives relying on a multi agent energy storage concept. D3b. Customer behavior analysis and their willingness to join new business models so as to bias their consumption profile

While the activities are mentioned separately, synergies will be developed among them for the development of holistic and co-orchestrated solutions and the achievement of the optimal function of the grid. This will particularly rely on the communication among the different level of the grid both upstream and downstream sides of the meter.

2 Aigle demo site

2.1 Aim

The aim of the Aigle demo site is to dispatch a power distribution grid hosting a significant number of stochastic renewables with an aggregated peak power equal (or larger) of the aggregated local load. Our objective is to validate grid-aware predictive control strategies of a MV power distribution grid with the use of a utility-scale BESS and to investigate coordination schemes with the upper grid for the provision of ancillary services.

2.2 Overall approach

For achieving the above-mentioned aim, the following approach was undertaken. It consists of two-stages:
a) *Scheduling*: a dispatch plan is computed the day before operation. It accounts for the uncertainties of the stochastic resources forecasts and consists in a 24h power active profile at the PCC. The objective of the dispatch plan is to maintain an optimal level of flexibility on the controllable resources (e.g., the BESS) during the day of operation to always be able to compensate for possible variations of renewables production (with respect to the forecasts) that may result in a power at the PCC different from the day-ahead dispatch plan.
b) *Real-time operation*: the aim is to control the controllable energy resources (in this case the BESS) to track the dispatch plan at the PCC with the upstream grid. For the real-time operation, two different control frameworks were further developed and validated. One based on the Augmented Relaxed Optimal Power Flow (AR-OPF) and another one based on distributed agents, called COMMELEC[6].
These control algorithms are operating in real-time meaning a sub-second time scale. Indeed, stochastic resources can fluctuate significantly even in a seconds time scale affecting the performance and behaviour of the control. More specifically, a sub-second control is required for a timely response to those stochastic fluctuations[7].
For the optimal use of the BESS, and the viability of this solution, the dispatch errors should be minimized. As known, the control of the BESS is limited by the grid constraints (standard limits on the nodal voltages and branch currents), transformers capabilities, BESS constraints (converter's power capability and energy reservoir capacity), and uncertainty due to the stochasticity of renewable generation and demand[8].
In order to made visible the grid constraints to the RT control, an advanced sensing infrastructure based on Phasor Measurements Units (PMUs) was adopted and deployed at the demonstration site. This infrastructure

is able to provide the state of the feeder (i.e., nodal voltages, branch, and nodal currents as well as power injections and branch flows) with a refresh rate of 20ms, ensuring that major events are detected, particularly those that could result in a violation of the grid operational constraints. In this respect, during the project a PMU-based situational awareness solution (composed by a high-performance real-time state estimator) was further developed and adapted to the needs of the project.
For reducing the uncertainty due to the stochasticity of renewable generation and demand, methodologies were developed and validated for:
- the forecasting of the PV generation: this includes a PV generation model based on the PV capacity estimated using a suitably developed disaggregation method[9];
- high-refresh rate measurements and characterization of the nodal loads: loads were also estimated at the node level based on PMU- and weather devices- derived measurements.
Additional, control strategies for distributed resources were developed and validated in simulations.
Furthermore, activities were undertaken on the valorisation of the flexibility acquired thanks to the BESS control by providing it to the transmission system at the PCC.

2.3 Description of facilities

For the validation of the above-mentioned solution, a feeder that accommodates high renewable energy generation which matches the power consumption was identified in Aigle. The feeder #73 starts from Collombey (VS) and supplies users in both Vaud and Valais cantons. It has a nominal voltage of 21 kV, it is operated in radial configuration, and consists of 24 nodes. The feeder accommodates a total PV generation capacity of 3.2 MWp, including a 1.8 MW PV power plant at the Migros-Carports and smaller installations distributed along the feeder. It also hosts a total hydropower generation capacity of 3.4 MVA allocated in 4 hydropower plants, one of them of MW-scale. The power consumption can reach 4.3MW during the winter and 2.9MW during the summer. The topology is presented in **Error! Reference source not found.**.[10]

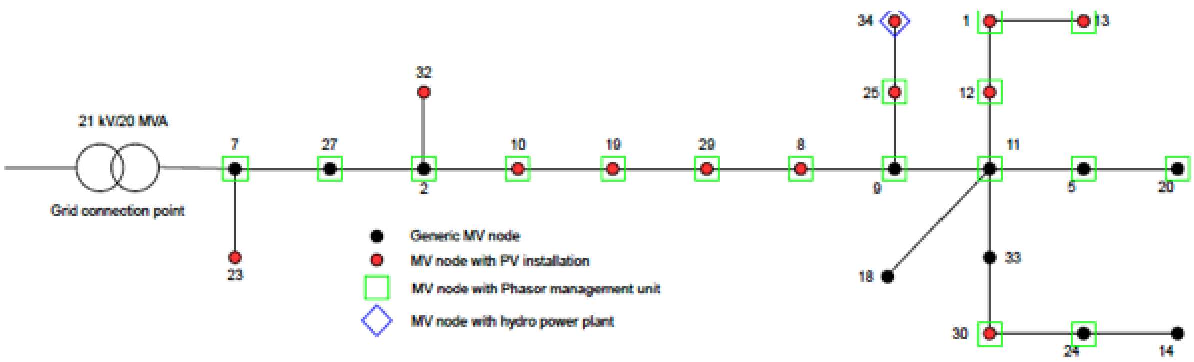

Figure 1: Grid layout of the considered 20 kV Medium Voltage (MV) distribution

Since the above-mentioned renewable power plants are uncontrollable, a controllable asset was installed in the frame of the project, namely a BESS with an energy/power rating of 2.5 MWh/1.5 MW. The technology provider (Leclanché) has been selected through a competitive process mainly based on the technical specifications, notably:
- the reactive power exchange capability, which is required to be both positive and negative, meaning that the converter should be a 4-quadrant converter;
- the capability of being controlled in a grid-feeding mode with a refresh rate of at least 100 ms and in a grid-forming operation mode with a refresh rate of at least 10 ms. The system can switch between the two control modes under on-load conditions[11].
Moreover, the Zaphiro's grid monitoring system (called "SynchroGuard") was deployed for measuring voltages and current flows at different points in the grid by means of unique hardware devices called SynchroSense. The goal of this monitoring system is to analyse the data collected from SynchroSense devices and provide an accurate estimation of the grid state in real-time. This system is based on the

measurements of synchrophasors which are time-synchronized and high-resolution measurements (up to 50 per second) of voltage and current AC signals. In the frame of the project, a PMU kit was developed to facilitate the installation while the devices were upgraded according to the BESS control needs. The performance of this system was validated in Aigle. The estimates of voltages, currents, and power flows were very close to the measurements, indicating the absence of bad data and residuals that are satisfying the standard normalised residual test[12].

For the implementation of the renewables forecasting, 5 GIT measurement boxes (the so-called meteoboxes) and 1 all-sky camera system were deployed at the EPFL for testing purposes and, then, transferred at the Aigle demo site. Each meteobox measures the GHI and the temperature of the PV modules. The all-sky camera system takes images of the sky and detects clouds and their movements via a dedicated segmentation process suitably developed for the project[13]. High-resolution image data are collected every 30 seconds during daylight hours at different exposures and saved on a dedicated server[14].

A local data storage system was designed, developed, and deployed too. The system is designed by means of several virtual machines running on a single server. The overall system takes care of (a) the interaction with the BESS for control and status monitoring (i.e., the actuation layer); (b) the acquisition, and streaming of grid measurement data from the PMUs installed along the local electrical distribution network (i.e., the PMU layer); (c) the computation of BESS set-points considering the information of the BESS status and the grid status (i.e., the control layer); and (d) the storage of relevant data in a time-series database (i.e., the database layer).

2.4 Activities

2.4.1 Forecasting of power consumption and PV generation

Given the major role that stochastic resources (i.e., PV and wind) play in the modern and future electrical infrastructure, the predictive and probabilistic assessment of PV power production variability, and the associated uncertainty, is essential[15].

At the demo site in Aigle, we have undertaken two different approaches for the forecasting of the PV generation, one for the 1.6 MW PV power plant at the Migros-Carports and another one for the distributed PV installations along the grid. The former approach aims to capture the variation of power generation among the various modules of a large PV plant and relies on real-time data locally collected by the GIT meteoboxes. The latter aims at utilising openly available data for PV generation forecasting. As a side note, it is worth mentioning that PV generation forecasts have been also used for the estimation of the power demand in the demo site.

2.4.1.1. **Forecasting *of the distributed generation and consumption***

A requirement for the safe integration of distributed PV generation is the availability of real-time production measurements from PV facilities. This is not always the case since installations are not always monitored or this type of data is not shared (or easily accessible) by the grid operator.

As an alternative to the direct monitoring of PV systems, we proposed to adopt disaggregation methods to estimate the PV generation from the aggregated active power measurements of a group of prosumers. Four estimation algorithms are proposed and compared[16]: the first assumes that the variability in the aggregated power flow measurements is mostly given by variations of the PV generation, the second and third leverage a model of the demand to improve estimation disaggregation performance, and the fourth assumes that there is a certain frequency range in which the aggregated power flow measurement is dominated by PV generation components. All four algorithms use a transposition model to project GHI into several pre-defined differently oriented tilted planes to take into account production from sites with different configurations. The effect of the air temperature was modelled by pre-processing GHI values with a model-based approach. The algorithms are designed to not require measurements of the PV power profiles to be trained. For three algorithms, the convexity of the underlying optimization problem, important to assure tractability, is verifiable a-priori by inspecting the input data. Reconstructing the PV power output leverages an algebraic relationship resulting into deterministic computation processes with a low processing power making them suitable for the

implementation into embedded devices. Algorithms' performance was tested with data from a real-life setup, with PV generation from multiple sites with different configurations and different demand profiles.
Results show that the best-performing algorithms estimate PV generation with a root mean square and mean estimation errors in the ranges 3.4 - 8.8% and 0.5 - 2.3%, respectively, and that performance is minimally affected by the level of PV penetration in the prosumption mix.[17]
<u>Related deliverable</u>
1d. Development of models for prosumers behaviour identification

2.4.1.2. **Forecasting** ***of the generation of the MW-scale PV power plant***

This activity focuses on developing forecasting methods based on the integrated use of time series, all-sky camera images and generation models of PV systems, considering short-term temporal horizons (below one hour) and fine spatial resolution (single site installations). The aim is to improve the efficiency of forecasting methods developed for the project[18] through prediction of clouds movement and associated cover of the sun disk. For this, we developed and validated different machine-learning techniques relying on the integrated use of GHI time series, all-sky image processing and cloud motion identification[19]. Furthermore, a methodology to estimate the irradiance from all-sky images is proposed, investigating the possibility of using all-sky cameras as irradiance sensors[20]. Then, the power generation of a PV is forecasted when using different sensors[21].
For this, the GHI estimations from all-sky images are benchmarked against the Heliosat-2, a well-established method to estimate the GHI from satellites (e.g., Meteosat in Europe). Results show that the all-sky camera-based GHI estimations proposed in this work outperform the Heliosat-2, with a RMSE relative improvement of 20-45%. In particular, this happens when fast irradiance dynamics are present (e.g., during partly cloudy conditions) and is due to the fact that satellites-based models do not have the spatial and temporal resolution needed to capture localized fluctuations. For the estimation of the PV power generation, the use of local measurements of the irradiance (namely pyranometer and proposed method) leads to better estimations of the PV generation because they are representative of the local power generation. On the other hand, satellite estimates of the GHI denote temporal and spatial averages, therefore they are less representative of local conditions.[22]
<u>Related deliverable</u>
4c. Tools for multi time horizon PV point forecasting and prediction intervals

2.4.2 Real-time control strategies for heterogeneous resources at MV

For the installation of the BESS in Aigle, a holistic approach was undertaken to ensure that the developed solution will address a real market need. This approach includes the following steps:
- Study of the targeted feeders' operational limits: this step aims at defining whether the feeder operates close to its limits or not and therefore, whether there is a need for supporting the feeder.
- Sizing and siting of a utility-scale (or distributed) BESS: for the feeders that need support, this step aims at identifying the appropriate size of BESSs and their location.
- Operation of the BESS for grid control, and feeder dispatching: once the BESS is deployed, this step aims at properly controlling it to provide the services that it is meant to in an optimal way. Two different control frameworks were used for this purpose.
Those steps are highly interlinked since, for instance, the sizing of the BESS is considering the capabilities of the control algorithm[23].

2.4.2.1. Study of targeted feeders' operational limits

The goal of this activity is to study the operational limits of the electrical distribution feeder of the demo. The load and distributed generation time series were collected and analysed in the demo networks. Coarse data provided by Romande Energie (RE) were integrated with refined data available from the photovoltaic installations of the EPFL-DESL. The operational limits of the selected RE networks are assessed using a Probabilistic Load Flow (PLF) developed at the DESL and based on standard methods existing in the literature[24].

As a result, the Aigle grid may face nodal over-voltage and lines congestions due to the massive injections coming from a single multi-MW PV plant. On the other hand, the low voltage grids in Rolle are robust against the planned PV installations, i.e., the grids will not suffer any security constraint violations[25].
Related deliverable
4a1. Study of targeted feeders' operational limits.

2.4.2.2. Sizing and siting of a utility scale distributed battery energy storage system

This activity focuses on the development of a practical and scalable methodology for the planning and operation of Active Distribution Networks (ADNs) with particular reference to the integration of Energy Storage Systems (ESSs) owned, and directly controlled, by the DNOs.
In this respect, an exact convex formulation of the OPF problem, called Augmented Relaxed OPF (AR-OPF), is first proposed for the case of radial power networks[26]. The proposed formulation considers the correct model of the lines and, therefore, the full AC load flow equalities. Moreover, the security constraints related to the nodal voltage magnitudes, as well as the lines ampacity limits, are incorporated into the AR-OPF using a set of more conservative constraints. Sufficient conditions have been identified to guarantee that the solution of the AR-OPF formulation is feasible and optimal. Moreover, by analyzing the exactness conditions, it is revealed that they are mild and hold for real distribution networks operating in the feasible region.
Then, by making use of the AR-OPF method, a specific optimization problem was formulated which is associated with the optimal resource planning and operation in ADNs with reference to the case of BESSs. The objective function is augmented aiming at finding the optimal trade-off between technical and economic goals. The proposed procedure accounts for: (i) network voltage deviations, (ii) feeders/lines congestions, (iii) network losses, (iv) cost of supplying loads (from the external grid or local producers) together with the cost of ESS investment/maintenance, (v) load curtailment and (vi) stochasticity of loads and renewables production. The use of decomposition methods for solving the targeted optimization problems with discrete variables and probable large size is also investigated. Benders decomposition and the Alternative Direction Method of Multipliers (ADMM) techniques are successfully applied to the solution of the targeted problems.[27]
The developed technique is applied to the siting and sizing problem of the BESS in the electrical distribution feeder of the demo site in Aigle. The benefits of the BESS, suitably controlled by the AR-OPF, to smooth the voltage fluctuations on top of respecting the grid operational constraints were demonstrated[28].
Related deliverable
4a2. Sizing and siting of a utility-scale distributed battery energy storage system

2.4.2.3. OPF-based control

The objective of this activity is to validate a grid-aware RT control algorithm for tracking a predefined power profile (dispatch plan) at the GCP of a distribution network hosting heterogeneous multiple uncontrollable, and controllable energy resources. The dispatch plan involves the active power trajectory that the targeted distribution network should follow at its GCP during operations. The design requirements of the dispatch plan are:
- stochastic variations due to distributed generation and demand should be compensated by the controllable resources while respecting their operational constraints;
- the battery restores to certain SoC to guarantee the reliable tracking of the dispatch plan during the day of operation.
The RT control problem is formulated as a MPC and computes the active and reactive power setpoints of the BESS such that it tracks the dispatch plan at the GCP while obeying the constraints of the grid and those of the BESS.
The grid constraints are modeled by convex OPF models. Specifically, we consider two different OPF models: the first is the Linearized Optimal Power Flow (L-OPF) model that expresses the grid states (such as nodal voltages, lines currents and net grid losses) as linear functions of power injections[29]. The second is the AR-OPF, which is an exact convex relaxation of the original non-linear non-convex OPF[30]. The performances of the proposed RT controls with different grid models are compared against an a-posteriori non-approximated power flow. The comparison is assessed in terms of modeling error on the nodal voltages, lines currents and

grid losses as well as the computation time. The two OPF models are compared using the MAE and RMSE metrics while computing the nodal voltage, lines currents, and losses. The AR-OPF model performs better on the lines' current magnitude and grid losses. The error on the voltage magnitudes is slightly higher for AR-OPF. However, it is below 5.5e-3% on maximum magnitude error. Furthermore, both schemes achieve computation time below 30 seconds, namely AR-OPF-MPC max computation time is of 2.49sec and for the L-OPF-MPC is of 2.46sec. Therefore, the AR-OPF was used for the experimental validation on an actual 24-node medium voltage (MV) distribution network in Aigle as it is more accurate than the L-OPF.[31]
To avoid BESS SOC saturation due to injections uncertainties, two approaches are used: (a) a single-MPC layer with a battery offset profile designed to keep the battery at optimum SOC level[32], and (b) a two layer MPC. This last is composed by a farsighted (upper) MPC layer imposing a SOC budget, and a lower layer responsible for the fine-tracking of the dispatch plan. Both layers require forecasts of the nodal power injections. The upper layer MPC uses forecasts of the nodal power injections at 5-minutes time resolution, whereas the Lower layer MPC uses forecasts at 30- seconds time resolution [33].
The single-layer MPC scheme was validated for two typical situations: a weekday with cloudy conditions characterized by high variation of the PV generation and a weekend day with relatively clear-sky conditions. The voltage and current modeled by the real-time OPF were compared with the PMU measurements on the site. The maximum error on the voltage and current modelling are less than 0.01 pu and on the losses less than 0.2kW for 99 % of the time. This comparison confirms that the OPF used to model the grid constraints in real-time is realistic[34].
The control performance of the two-layer MPC scheme was compared for two other cases:(i) without control, where no compensation from BESS is performed, and (ii) with a single-layer MPC where the MPC problem is solved without any BESS SOE budget. Validation is undertaken for two typical days representing different characteristics in terms of power injection patterns. On the first day, the system imports net power, whereas on the second day, it exports net power during the middle of the day[35].
Comparing tracking performance among the two MPC, the single-layer MPC is slightly better than the two-layer MPC. However, the latter always restores the BESS to an appropriate SOC avoding potential SOC saturations, whereas the single-layer MPC does not exhibit this feature. Furthermore, the two-layer MPC achieves lower tracking error with a higher probability[36].
Related deliverable
Single-layer MPC: 4a3. Operation of the battery storage systems for grid control, feeder dispatching
Two layers MPC:

- 2c. Simulation and experimental validation of linearized and exact convex optimal power flow methods using the feeder data (with the use of PMUs)
- 4d. Validation of an advanced control algorithms based on short-term forecasting of PV generation

2.4.2.4. COMMELEC-based control

The goal of the activity is to develop a COMMELEC-based framework for the real-time control of the 1.5 MW/2.5 MWh BESS in Aigle to follow a dispatch plan computed day ahead. COMMELEC is a framework proposed in the literature[37,38] for the real-time control of power grids. It uses a hierarchy of agents to compute explicit active and reactive power setpoints for the resources connected to the grid. Each resource is equipped with a resource agent (RA) whose job is to translate the internal state of the resource into a device-independent format (advertisement). The advertisements are collected by the grid agent (GA), which computes the optimal power setpoints that optimize a global objective. The global objective is the weighted sum of various objectives, including tracking a predetermined dispatch plan at the slack bus, minimizing grid's nodal voltage deviations from the nominal value, limiting the line currents below the respective ampacities, and achieving target internal states for the resources. Attention is paid to choose the right weights of the individual objectives, to ensure the desired optimal behaviour of the control.
The activity involves the development of all the software agents needed to achieve the proper communication of the control framework with the BESS and the grid state estimator[39]. Then the COMMELEC framework was validated at the demo site of Aigle, and its performance assessed by comparing the CDFs of the absolute dispatch tracking error with and without BESS control. COMMELEC tracks the dispatch plan with the user-defined bound on the PCC power[40].

Related deliverable
2b2. Successful response of the entire feeder with the use of Commelec agents
2b3. Successful deployment and impact measurement of Commelec-based control on MV grids

2.4.2.5. Comparison between MPC BESS control and COMMELEC control

While the MPC and COMMELEC controls are conceived to serve different purposes, their performance in terms of controlling the BESS according to the dispatch plan was compared. In general, one must note that COMMELEC has the joint objective to achieve a target BESS SoC, which is independent of the dispatch plan, meaning that when the BESS SoC is close to the limit, the tracking performance may be reduced. However, in both cases, the active BESS control resulted in significantly more contained errors than in the uncontrolled cases, confirming the high performance in tracking the dispatch plan with both the proposed control frameworks[41].
Related deliverable
2overall- Compilation of real-time control strategies for heterogeneous resources at MV and LV grids.

2.4.3 Distributed control strategies

The objective of this activity is to analyse the impact of the integration of distributed generation (DG) units into distribution power grids and propose feedback control solutions to guarantee frequency and voltage stability as well as active and reactive power sharing among the distributed generation units. A data-driven methodology is used to identify a large set of models for different system configurations using PMUs data. The models are then classified according to some scheduling parameters which are estimated in real-time operation from PMU data. New centralised and distributed control algorithms are developed that are robust with respect to the variation of the scheduling parameters or adapted in real-time using the estimated dynamics[42].
The main results of this activity are the following:
A comprehensive data-driven distributed combined primary/secondary controller design method for microgrids is proposed. This method provides transient and steady-state performances, including power sharing and voltage and frequency restoration while guaranteeing stability for fixed communication delays. Measured data are directly used for controller design, and no knowledge of the model structure or the physical parameters of the grid is required. Moreover, no assumption is made on the X/R ratio of the feeders. All control specifications are formulated as frequency-domain constraints on the two-norm of weighted sensitivity functions. Then, using a frequency domain robust control design method, a distributed fixed-structure controller is synthesized in one step. The performance of the obtained controller is validated using hardware-in-the-loop (HIL) experiments. The results show considerable improvement in transient performance while providing power sharing and voltage and frequency restoration with a distributed implementation.[43]
Furthermore, a data-driven multivariable Linear Parameter Varying (LPV) controller design method is proposed. The synthesis process is based on frequency-domain data corresponding to different operating points of the power grid. The H_∞ performance and also stability constraints for frozen scheduling parameter are convexified around an initial stabilizing controller and solved using a convex optimization solver. This method has been applied to the combined primary and secondary controller design problem of electrical microgrids. The performance of the proposed method has been validated through simulating a microgrid including a synchronous generator, a battery storage and a photovoltaic unit. The results show that using this method, high performance is achieved in different operating points.[44]
Reactive power sharing for PV units in islanded microgrid is formulated as a robust control design problem and is solved using convex optimization method. In addition to reactive power sharing, the disturbance rejection for voltage and active power are formulated using infinity-norm constraints on the sensitivity functions and considered in the design. The proposed method uses only the measurement data of the power system with no need for a parametric model of the power grid equipment. The size of the problem is independent of the order of the plant which makes it applicable to power systems including a high number of buses and equipment such as synchronous generators, batteries, and inverters. In the proposed method,

the communication system can be considered in the control design process for centralized, distributed, and decentralized structures. The proposed method has been validated through the simulation of a microgrid encompassing a synchronous generator, switching inverters, and a storage system. The results show that this method has successfully shared reactive power among different PV units while providing disturbance rejection for voltage and active power.[45]

Related deliverables

2a2. Identification and Validation of dynamic grid model for distributed controller strategy

2a1. Experimental validation of voltage control of inverter interfaced grids in grid connected mode (with the use of BESS)

2a3. Experimental validation of frequency and voltage control of inverter interfaced grids in islanded mode (with the use of BESS)

2.4.4 Coordination between DSO and TSO (provision of ancillary services)

This activity focuses on the valorisation of the flexibility acquired in the previous activities of this demo site from the control of DERs located in an ADN. Relying on this flexibility, the ADN can be able to provide power flexibility to the transmission system at the PCC. The power flexibility is defined as additional bi-directional active/reactive powers a resource can provide to the grid by adjusting its operating point[46]. In this respect, this work presents a two-stage method to firstly schedule and then control an ADN to provide power flexibility at the PCC. Based on the power flexibility request of the TSO, the first stage determines the optimal amount of power flexibility that an ADN operator should procure from each DER considering the corresponding offer curves as well as the uncertainties stemming from the short-term forecast errors of demand and renewable generation. The constraints and losses of the grid are accounted for by exploiting a linearized power flow model[47], whereby the first stage is implemented as a linear scenario-based optimization problem. Then, in real-time operation, relying on a linear optimization problem, the second stage adjusts the power flexibility injection of controllable assets (e.g., BESSs) to mitigate the imbalance at the PCC inherent in the above-mentioned uncertainties[48]. The performance of the proposed method is tested at the demo site in Aigle[49].
The method is applied to the sunniest day of 2018, i.e., 7th July, while the day-ahead forecast error[50] is assumed +10% and the active/reactive power flexibility request of TSO is set at -100 kW and 0 kVAr. This validation illustrated the capability of the method for not only satisfying precisely the flexibility request of the TSO at the PCC but also mitigating the impact of the day-ahead forecast error on it. The method succeeded to move the BESS's SOE toward the middle between SOE minimum and maximum bounds, while mitigating the power imbalance at the PCC[51].

Related deliverables

4f1. Definition of schemes and needed coordination for the provision of ancillary services from small distributed resources

4f2. System-wide modelling and optimization of ancillary services provision and system impact

4f3. Validation of the Model On the Demonstrator - Optimal Scheduling and Control of Active Distribution Networks for Power Flexibility Provision at TSO-DSO Interface

3 Chapelle-sur-Moudon demo site

3.1 Aim

The aim of the demo site in Chapelle-sur-Moudon (or Chapelle for the sake of simplicity) is to investigate the role of energy communities (ECs) in the provision of grid services. It concerns mainly Demand side management (DSM) activities (initially foreseen for Rolle but moved to Chapelle following the low acceptance of DSM solutions in Rolle). Furthermore, the site presents specific conditions, namely two distribution stations with a significant difference in installed capacity of renewables (mainly PVs), that enable the testing of a novel solution for grid management, called the Soft-open-point (SOP). The SOP main purpose is to permit a meshed (or looped) operation of radially operated distribution networks, i.e. open loops. The validation of this technology represents an additional objective of this site.

3.2 Overall approach

The approach which is undertaken at the Chapelle demo site builds upon the conclusion drawn from the DSM activities in Rolle. Particularly, it is considered that, at least in the short term, one of the most viable solutions to maximize self-consumption and valorise the EC flexibility is an optimally controlled BESS. First, the applicability of this statement in Chapelle is evaluated. Then activities are undertaken for the BESS location and optimal control, which are similar to those at the Aigle demo site, namely:
a) study of the targeted feeders' operational limits: this is achieved based on the hourly statistics of the monitored nodes of the grid for voltages and active powers (undertaken by DEPSys);
b) sizing and siting of the battery energy storage system (undertaken by Aurora's grid);
c) operation of the BESS for grid control and self-consumption maximization.
For the BESS control, four project partners developed (or adjusted) and validated their methodologies, namely DEPSys, Aurora's grid, SUPSI, and EPFL-LCA2 (COMMELEC).
Furthermore, a series of algorithms and tools were developed and validated for the valorization of the BESS assets, particularly demonstrating its CO_2 footprint benefit. Specific activities that were undertaken in Chapelle for this purpose include:
- BESS ageing: investigate ageing phenomena on Lithium-ion battery to optimize the BESS control and maximize its cycling.
- Ageing-aware vs standard control: assessment of the carbon footprint of providing several services to a building or a microgrid with a Lithium-ion battery coupled with a photovoltaic system while using a BESS ageing-aware control.
- Control strategies to maximize CO_2 savings: development and validation of an algorithm capable to define the best time window to use the renewable energy stored in the batteries based on the CO_2 footprint.
- Virtual power plant (VPP): investigate the possibility to connect two BESSs in VPP mode to increase the peak-shaving capability of the renewable injection toward the grid.
Furthermore, activities were undertaken on cybersecurity aspects.
For reaching the demo aim related to the SOP, a SOP hardware was built up and installed in Chapelle. Various control modes of this equipment were compared and the most performant was selected to evaluate the impact of the SOP on the grid operation.

3.3 Demo site

For the implementation of the above-mentioned DSM-related approach, the district Champ Monnet in Chapelle. This site has been chosen for three main reasons:

a. its high number and variety of controllable resources. This includes PV installations of more than 300 kWp including inverters of 72 kWp that can be used for grid purposes, a water heating system, including a heat pump of 60kW, and 3 electric boilers with a total power of 34kW, with a partially flexible electric load. Also, this district consists of 57 residential blocks and 9 farms for a total of 88 consumers.
b. The village of Chapelle-sur-Moudon is fed by two LV networks with a 250 kVA MV/LV transformer each. The solar PV generation installed in these networks is unevenly distributed with 317kVA vs. 87kVA in each of them which presents a good case study for testing the SOP[52].
c. Chapelle hosts a property of an early-adopter of smart grid solutions: the hardware integration of GridEye monitoring technologies is slightly invasive in the installation of the final customer. Therefore, an early adopter of smart grid solutions that owns a significant number of flexible resources had to be selected. The local network is already equipped with GridEye devices for the last 3 years. This site was not included in the proposal but was added to accommodate microgrid-related activities in the project.

For achieving the demo aim related to the EC, two BESS were sized, ordered from EATON through a competitive process, and installed in Chapelle. These storage systems serve different purposes, the

50kWh/20kW BESS aims to maximize self-consumption, and the 300kWh/200kW one to provide services to the grid.
Furthermore, the existing GridEye infrastructure was modified to support the research activities. In this respect, 9 GridEye devices provide measurement data on 10-min basis for LV grid monitoring, analysis of quality of supply, forecasting of consumption, and LV grid control. Another 8 GridEye devices were installed, providing measurement data on a 1-second basis for the project activities related to the DSM, SOP control, and BESS control. The 1-second data are timestamped voltages, currents, and active and reactive powers. An external API is developed to send these measurement data to the project partners, e.g., HEIA-FR, SUPSI, Aurora's grid, and Commelec. This monitoring system was linked to the supervisory control and data acquisition system (SCADA) of the local distribution system operator (DSO), namely Romande Energie, to improve efficiency in monitoring and responsiveness in interventions.[53]
In addition, the existing installation for the control of a boiler and PV inverters was replaced by a new hardware concept. This newly developed concept includes GridEye units and other devices, for the control of required controllable devices. The updated infrastructure is used for the control of the existing PV inverter and boiler as well as two new battery storage systems that were installed in 2020.[54]
In term of SOP, a reduced scale LV prototype rated for 15 kVA was designed, built, and tested. The key characteristics are the following: 2-level Voltage Source Converters (VSCs) (based on the PENELER converter[55]), 15 kVA, 230/400V, LCL filters, possibility to add a battery storage via a custom-made DC/DC converter, Controller Area Network (CAN) and serial communications interface (SCI) communication protocol available. Its aim was to test different situations and scenarios as compared to a direct deployment into a real system where the topology cannot be changed, and faults cannot be freely introduced into the system[56].
For the deployment in Chapelle, another SOP hardware, rated at 50 kVA, has been developed from scratch in the frame of the project through an iterative process of design, simulation, laboratory test and then field test. Compared to the 15kVA LV prototype, the new prototype, has increased nominal power, and exhibits improved characteristics in term of flexibility. It is designed to act as a full 4 terminals (three phases + neutral) device, it can work in either current source or voltage source configuration[57], it has an improved output filter design, and it allows active control of the neutral unbalance.[58]

3.4 Activities

3.4.1 Operational limits of the feeder

The impact of the PV production in Chapelle on the grid was assessed against the values that grids should operate. The statistics show that PV production has a significant impact on the grid, resulting in high voltage values close to the maximum acceptable level (i.e., 230V +10%). Moreover, the transformer loading reaches its nominal capacity in production (i.e., negative active power) and consumption (i.e., positive active power) for a limited duration.
The voltages are close to the maximum acceptable limits and overloads for a short duration, asking for the management of voltages and lines' congestion. For addressing all these issues, a grid reinforcement is currently used. An alternative, faster and sometimes cheaper, to the grid reinforcement solution is the use of distributed flexibilities for management of power flows and voltage levels. Compared to other solutions that can provide flexibility, the BESS is the most reliable one in terms of availability and reactivity when the flexibility is requires. [59]

3.4.2 MV topology discovery

The objective of this work is to identify the MV grid topology using GridEye measurements, by determining the HV/MV substation that each installed GridEye at LV side of MV/LV transformers is connected to. In this project, the MV topology identification is studied for the MV nodes with installed GridEye that are located between the feeders of Moudon (56), Chapelle (FR) (51, 53, 54), and Puidoux (57, 58) HV/MV substations. The inputs of the developed algorithms are i) three phases voltage measurements, ii) name of devices measuring HV/MV substation, iii) vector group of transformers.

The algorithm is tested at two instances on 30.09.2021 (the summer topology) and on 03.12.2021 (the winter topology). The identified topologies are validated with the snapshots of the SCADA system of Romande Energie. The developed algorithm in this section allows identifying MV grid topology in less than a few minutes. This information can be used to determine the open/close status of switches.[60] The up-to-date and accurate information of grid topology is important for the secure grid operation and taking decisions for optimal grid operation.
Related deliverable
Extra_ Final depsys report for REeL demo project[61]

3.4.3 Monitoring of the grid

The sensitivity coefficients are used in many power systems related analysis and control approaches. They contain important information on the grid's behaviour and its characteristics. For instance, the voltage sensitivity coefficients reflect the impact of power change at a particular node on the variations of voltage at all nodes. The model-less approach for determining the sensitivity coefficients only uses measurement data and does not require the grid parameters. This is important for determining the sensitivity coefficients in distribution grids for which often an accurate and up-to-date model of the grid is not available. [62]
In Chapelle, for the model-less evaluation of the quality of supply in LV grids, the voltage sensitivity coefficients were calculated using three different methods, namely Jacobian, model-less power flow, and model-less measurement. The average value of the Jacobian coefficients is used as the reference for the calculation of +/-10% and +/-50% margins. The key outcomes of this study are the following: (a) the variation of the Jacobian sensitivity coefficients is around 10%, (b) the "Model-less power flow" method is very close to the average value of the Jacobian method by showing an average 4.6% difference while in some cases, the difference between "Model-less power flow" and "Jacobian average value" reaches to around 10% margin, and (c) the "Model-less measurement" method is also close to the average value of the Jacobian method by showing an average 7.1% difference. In some cases, the difference between "Model-less measurement" and "Jacobian average value" becomes slightly above 10%. Noting that this difference might be due to neglecting the impacts of the fuses/joints/connections impedances and the aging of cables on the grid parameters.[63]
Furthermore, GridEye measurement data were transferred to the SCADA system of Romande Energie in order to facilitate the use of those data in the company's operations. Two mechanisms were developed for this purpose. The first mechanism continuously transfers GridEye 10-minute measurement data to the SCADA system. The second mechanism transfers GridEye measurement data with 10-second time interval for a period of 5-minutes to the SCADA, according to SCADA's standard practices. The second mechanism is triggered by a rate of change of current.
Related deliverable

1c. Validation of model-less approach for estimation of sensitivity coefficients

3.4.4 Forecasting of weather and consumption

3.4.4.1. Weather forecasting

Many electrical loads are influenced by meteorological variables, such as temperature and irradiance, but representative measurements from dedicated sensors are often not available, and satellite-based estimates can be inaccurate due to low spatiotemporal resolution. The possibility of using low-quality sensors data, notably Netatmo stations[64], was investigated in terms of increase of the 24-hours ahead forecast accuracy of electric power demand.
A two steps procedure was applied. At first, numerical weather prediction (NWP) forecasts for atmospheric temperature were corrected with the observations from the Netatmo stations. As a second step, the corrected temperature was used to create a representative temperature for the pool of end-users we are interested in by using two different strategies: (a) the average of the sensors' reading weighted for the fraction of end-users near each sensor and (b) a preliminary smoothing the low-quality sensor data with a Gaussian Process

(GP) fitted with maximum likelihood criterion, based on the geographical coordinates of the Netatmo sensors. Then, the increase in performance of the final energy forecasters was assessed.[65]
The GP performed better than the strategy of a weighted average of the sensors' reading. At the assessment of the increase in performance of the final energy forecasters, the results show a good improvement in the forecast accuracy during evening and morning periods. The effect of using a GP to smooth the noisy temperature data is negligible, with respect to performing a simple weighted average.[66]
Related deliverables
3d2. Improvement of numerical weather prediction at local scale using aggregated low-quality sensor data

3.4.4.2. Consumption forecasting

This activity consists of two parts.
a) Design of models for the prediction of the day ahead energy demand and production of households in the distribution grid (24hours). This involves the assessment of the performance of different forecasters in predicting 24 hours ahead power consumption and production, in terms of accuracy and computational requirements[67]. For a group of 100 prosumers, considering different level of aggregation and for one-year data, the Holt-Winters forecaster is the only one that is embeddable in a smart meter, due to the low computation time, and has acceptable level of accuracy.[68]
b) Prediction of aggregated power profiles, with particular attention to the hierarchical setting, as this is the case in which the Chapelle batteries are operated and can be used to preserve privacy of the users while obtaining sum-consistent forecasts. For this, different forecasters were compared, and the regressors were tested by means of deterministic and probabilistic key performance indicators (KPIs). The analysis showed that the Light Gradient Boosted Model (LGBM) model was the most accurate under all the KPIs for all the different time series and level of aggregations. Additionally, combinations of two different hierarchical forecasting techniques were tested. These were coupled with two different methods for estimating the covariance matrix of the forecast errors. The results show that hierarchical reconciliation significantly increases accuracy for the aggregated times series. In general, we see the possibility of using innovative reconciliation techniques, as a promising direction for future works.[69]
The data used to train the forecasting algorithms have been made freely available to the scientific community[70].
Related deliverables
3d1. Algorithms and models for the prediction of the day ahead energy demand of households and the distribution grid (24hours)

3.4.5 BESS Control of the grid for self-consumption and grid purposes

3.4.5.1. Forecast- and communication-based control algorithms

In this activity, the effectiveness of different forecasting models that were mentioned under section 3.4.4 was tested and assessed in combination with a MPC, in a closed loop. The evaluation was done both in terms of forecasting accuracy and in terms of the economic results of different combinations of forecasters and control algorithms. Two coordination schemes were tested, associated with two alternatives tariff schemes: implicit coordination, which does not include communication but only forecast of the energy prices, and an explicit coordination scheme, which is based on a repartition mechanism of economic benefits according to the contribution of each user in the minimization of this system-level objective. The performances were evaluated in an environment simulating thermo-electric appliances, building heating systems and thermal dynamics, and power flow on the local low voltage grid. Results show how the first step ahead accuracy has a higher impact on the economic results under both the implicit and explicit coordination and remuneration schemes. Switching from the implicit coordination to the explicit one shows a slight increase in financial performance. This performance difference is expected to increase with increasing penetration of controlled batteries since the implicit coordination cannot fully handle correlations in the user's control actions.[71]
The replicability of the best forecaster methods was validated by applying different distributed DSM algorithms using these methods in two demo sites: Lugaggia Innovation Community (LIC)[72], a self-

consumption community located in Lugaggia, a small village near Lugano, and in Chapelle. While the LIC demo site is a self-consumption
community, the Chapelle demo site is composed of a private battery and a district battery operated to perform peak shaving. In the LIC case, a distributed control can be applied to model the costs of the LIC community with an automated market-making mechanism (AMM) and solve the associated Nash Equilibrium[73]. A net benefit for the market participants is measured. Moreover, participants with highly controllable flexibility, such as batteries, can further optimize their cost-saving, even when the DSO imposes additional costs by activating the local flexibility market. In Chapelle, a lexicographic approach was used to allow cooperative coordination, ensuring that the privately owned battery does not degrade its economic performances due to coordination. This kind of coordination was compared with other types of control strategies to investigate the existence of win-win coordination strategies. Results show that, even if the different strategies result in substantially different scheduling for the privately owned battery, the aggregate power distribution is marginally affected. This is to impute to the small size of the end-user battery compared to the district-level one.[74]
Then, the performance of the forecasting and control algorithms was assessed when applied to the management of the two BESSs in Chapelle. The testing phase lasted 2 months, from October 24th to December 20th, 2021. The main objective of the control was to reduce power fluctuations at node 100, through an objective function that quadratically punished them. The control quality is assessed based on ideal conditions by using perfect forecasting. The algorithms effectively reduce the power excursions at node 100 and flatten the profile while it does not perform as well as the ideal case. This happens primarily because the forecasts are not perfect which leads the battery to deplete too early, and a peak in consumption. For the reduction of the peak, the performance of the algorithms for peak shaving was analyzed. In this case, the reduction of the proposed algorithms was compared to the potential reduction in daily peaks with a sampling of 1-minute and 15-minute peaks. The algorithm reached slightly above 1/4 of the maximum possible peak reduction in 1-min resolution, and slightly above 1/3 of the maximum reduction in 15-min resolution.[75]
As a final step, the investment cost of controllable BESS was assessed and compared with grid refurbishment. For this, the effect of the BESS' operations on the overall power profile at the LV/MV transformer during the pilot test period was analyzed, along with the impact on cables and transformer degradation. The economic benefit of such a degradation decrease was extrapolated on the DSO total costs. Also, the cost reduction associated with the power peak tariff was considered. The results show that the use of the BESS can contribute to an increase of lifespan in the range of 5-8% for the cables and 1-1.5% for the transformer which translates to a cost reduction between 1.16 kCHF and 9.1 kCHF.
Also, the real battery achieved around 10% of the cost reduction achievable with the perfect knowledge of the monthly peak (CHF37 vs CHF 442 per month). These results were calculated for the specific testing period and could highly vary notably based on weather conditions and BESS operation.[76]
Related deliverables
3b. Assessment of the performance of the decentralized battery control strategies
3d3. Design and test of distributed DSM algorithms that use communication and new forecasting models
3f. Assessment of investment costs of controllable batteries and comparison with grid refurbishment
3 Overall - Cross-site Comparison of the performance of different DSM strategies. Investigation of the possible conflicts (LIC and Chapelle-sur-Moudon) and sub-optimality issues

3.4.5.2. Grid measurements- based LV grid control using flexibilities of grid and home batteries and PV inverters (without weather forecasting)

In the frame of the project, DEPSys developed algorithms that use the GridEye's measurements data for (a) forecasting of loads and generations, (b) evaluation of the voltages and power flows, and (c) determination of the optimal set-points of the flexible resources. The real-time control algorithm calculates a new setpoint for controllable devices (e.g., batteries, PV) every 10-min, based on the forecast for the next 24-hours with a 10-min time interval using the last GridEye measurement data.
The developed algorithms are applied on the control of the Chapelle BESS. The objectives of control are maximization of self-consumption at the transformer level and at the local community level. To assess the

accuracy of the real-time control mechanism, the results are compared with the optimal values calculated by the actual data, called after-the-fact analysis, where the actual net-load for the entire time horizon is known. The analysis shows that the application of updated real-time grid monitoring data without weather-based features can predict the net-load pattern accurately even for the days with high volatility in PVs' generation. The accuracy of the proposed forecasting method in terms of 10-minutes ahead and peak load forecasting are 2.4% and 4.1%, respectively. The proposed forecasting method has successful performance for both sunny and cloudy days.
When compared with the after-the-fact results for the two batteries, the real-time control method traces efficiently the after-the-fact scheduling. According to the forecasted net-load and the determined charging/discharging powers of the batteries, it is concluded that the batteries are charged when there is surplus PV production, and they are discharged when the net-load is positive.
The average error of "10-min ahead forecasted values" is 0.37% (%n MAE). The proposed real-time control with real-time monitoring data has increased self-consumption by 21.7% while the maximum potential increase (based on the after-the-fact scheduling without forecasting error) is 28.3%. Moreover, the implemented objective function shaves the peak load.[77]
Related deliverable
Extra_ Final depsys report for REeL demo project

3.4.5.3. Ageing-aware BESS control framework

The main purpose of this activity is to reduce the PV injection from the LV to the MV grid by properly controlling the Chappelle 300kWh/200kW BESS. Since most of the buildings at this demo site are residential, their energy consumption during the day is limited and, consequently, the PV injection toward the MW grid can be relatively high. The total installed PV power is around 323 kW, presenting a risk for the LV/MV transformer (with nominal power of 250 kVA) to be overloaded.
The algorithm of peak-shaving has been integrated into the main Energy Management for Multiple Application (EMMA 2.0[78]) provided by Aurora's Grid. This algorithm can reduce the peak injection into the MV feeder by storing it into the BESS for later use while undertaking an ageing-aware strategy. For the estimation of the benefits from the implementation of this strategy, computation of the equivalent cycles was performed with the existing energy management system (EMS) without any ageing-aware strategy, and the reduction in the average C-rate both in the charge and discharge phase was calculated. There was no need for extra measurements or a weather forecast.
The key results of this activity are (a) peak power injection reduction by 16%, (b) local renewable self-consumption increase by 16%, and (c) lifetime of the BESS increase by 25 %.
The same algorithm was implemented in the Chappelle 50kWh/20kW BESS too. The deployed power was reduced both for charging and discharging the BESS while the self-consumption has been made before 10 p.m. until the evening, meaning at the highest retail tariff. The lifetime of the BESS increases even more (33%) since there is no need of pulsed power for the peak-shaving which involves a faster ageing process of the BESS.[79]
Related deliverable
4b3. First Industrial Validation of Energy Management for Multiple Applications EMMA 2.0

3.4.5.4. COMMELEC-based BESS control

This activity aims at developing a central controller, based on the COMMELEC solution[80,81], that considers the safe operation of the grid under its control. COMMELEC control framework consists of two types of agents: resource agent and grid agent. The resource agent senses the state of the resource and, based on this state and characteristics of the resource, it creates and periodically sends the advertisements to the grid agent. The advertisement consists of the power flexibility, willingness, and uncertainty of a resource. Based on the information in the advertisements and other objectives set by the user, the grid agent computes optimal power setpoints each resource should implement. These optimal setpoints are then communicated back to the corresponding resource agents, which implement these power setpoints in the resource they manage.[82]

In Chapelle, a shadow agent was developed and tested. The shadow agent periodically (every 1 second) pings the GridEye server and gets power measurements corresponding to four different nodes in the grid at Chappelle. Based on these measurements, it computes the advertisement that is sent to the COMMELEC grid agent to control other flexible resources in the grid. The shadow agents were able to correctly forecast the interval in which the next measurements (for the period of 1 second or 10 seconds respectively) would fall. In terms of the central processing unit (CPU) and memory usage, the four shadow agents consume less than 2% of CPU when running on an Intel(R) Xeon(R) Bronze 3104 CPU @ 1.70GHz with 6 cores and 60MB of memory for a period of 10 days.[83]
Related deliverable
2b1 Successful communication and control of one DSM device with the use of Commelec agent in 1 feeder

3.4.6 BESS applications

The set-up at the demo site enabled the development and validation of a series of algorithms and tools for the valorisation of the BESS assets. Indeed, one of the outcomes of the Energy community activity at the Rolle demo site is that the social acceptability of the BESS solution is significantly lower than this of PVs and EVs. The demonstration of the BESS' environmental benefits, particularly in terms of CO_2 footprint, is required to increase the social acceptability of BESS solutions. Specific activities that were undertaken in Chapelle for this purpose include:

a) Ageing factors: investigate ageing phenomena on Lithium-ion battery to optimize the BESS control and maximize their cycles.
b) Ageing aware vs standard control: assessment of the carbon footprint of providing several services to a building or a microgrid with a lithium-ion battery coupled with a photovoltaic system while using a BESS ageing aware control algorithm.
c) Control strategies to maximize CO_2 savings: development and validation of an algorithm capable to define the best time window to use the renewable energy stored into the batteries based on the CO_2 footprint.
d) Virtual power plant: investigation of the possibility to connect the two BESSs in VPP mode for increasing the peak-shaving capability of the renewable injection toward the grid.

3.4.6.1. Ageing analysis of BESS

The aim of this activity is to provide a comprehensive overview of the ageing phenomena of Lithium-ion batteries, with a specific focus on the effect of storing temperature, C-rate, and depth of discharge. First, the main ageing factors, such as the extracted current, the temperature, and the SoC are analysed. Then, for each of these ageing factors specific, the capacity fading, which limits the autonomy of the battery, and the increase of equivalent series resistance, which limits the delivered power, are estimated.
An ageing model was developed, accounting for all the ageing factors, namely C-rate in charging and discharging, middle SoC, temperature, and depth of discharge (DoD). Simulations are run for an environment of a specific building and BES of different sizes to compute the advantage in terms of increased energy self-consumption. Notably, considering these ageing factors, the evolution of the economic benefit associated with the BESS for five different cases was investigated, including one without accounting the ageing of the BESS and four others excluding different ageing factors. The most interesting result is the case associated with an-ageing-aware strategy. By correctly limiting the C-rate during the charging and discharging phase, the DoD and the middle state of charge can mitigate the ageing phenomena, mitigate the capacity reduction and indirectly increase the energy self-consumption and the overall profitability of the BESS.[84]
Related deliverables
4b. Ageing analysis of a BESS

3.4.6.2. Ageing aware vs standard control

This work aims at assessing the carbon footprint of providing several services to a building or a microgrid with a lithium-ion battery coupled with a photovoltaic system. The analysis includes the energy exchanged between the battery, the PV system, and the grid for the three following services: self-consumption, peak-shaving of PV injected into the grid and primary frequency regulation (PCR). The analysis looks at those three services for three different configurations which differ in the load consumption profile, PV production profile, and therefore battery size. For each configuration, simulations are performed with two different EMS, (a) a standard one and (b) Aurora's Grid EMS which reduces the ageing of the battery system. Also, two charging options were considered, namely with or without the possibility to charge the battery with the grid for the supply of peak-shaving and PCR.[85]

In the self-consumption configuration, Aurora's Grid EMS allows a decrease in the carbon footprint impact of the self-consumption. This decrease is due to the restrictive limits set by the EMS in order to reduce the ageing, meaning that more energy has to be bought from the grid to supply the consumption.

When it comes to peak-shaving, as the energy reserves are entirely coming from the PV or the grid, the difference in CO_2 savings is even bigger with the Aurora's Grid EMS. The impact of using the battery for peak-shaving is very small compared to the usage of the battery for self-consumption.

The results for PCR show a higher carbon footprint because in the case where the battery is charged by PV and the grid, the electricity charged by the grid has a higher carbon footprint than the electricity coming from the PV. By comparing the results with the standard EMS and Aurora's Grid EMS, we can see that the impact is slightly higher with Aurora's Grid EMS and this is due to the dynamic limitations of the battery use which cause the battery to be a little less charged with PV, and therefore the grid is used a bit more.[86] It should be noticed that in the case of a battery connected behind the meter with PV generation, the charging from the grid would affect the guarantees of origin.

We saw that for the self-consumption of the building the energy discharged by the battery system allows for an approximate 35% reduction in carbon impact. Also, charging a battery with the grid to provide peak-shaving or PCR increases by almost 200% and 25% respectively the impact for this service.

In overall, providing self-consumption, peak-shaving, and frequency regulation with the help of renewable power plants can greatly reduce the carbon footprint of these services. With the falling prices of renewable power production and the large penetration of renewable power plants, storage devices can help further to reduce the carbon footprint of the grid.[87]

<u>Related deliverable</u>

4b2. Life cycle management of the BESS

3.4.6.3. Control strategies to maximize CO_2 savings

At the two BES located in Chapelle, an algorithm capable to calculate the CO_2 footprint of the grid and of the BESS operation were implemented to define the best time window to use the renewable energy stored in the batteries. Two strategies that were tested are:

1) maximisation of the self-consumption before 10 p.m. in the evening, so the revenue is maximized;
2) postponing of the self-consumption even after 10 p.m. to maximize the decarbonization of the energy community.

The CO_2 footprint of the energy grid was estimated through collection of the power exchange, between Switzerland and the surrounding countries, computation of the configuration of local national energy as well as the energy/power flows, and (c) computation of the CO_2 footprint of the energy produced nationally from Switzerland and the CO_2 footprint of the energy eventually imported from the other countries. The CO_2 earning are calculated by the difference of CO_2 of the grid and CO_2 associated with the BES deployment.[88]

In Strategy 1, 10 kg of CO_2 savings were achieved while the whole self-consumption occurred before 10 p.m. so at the highest retail rate meaning the highest revenues. Strategy 2 achieved 190% more CO_2 saving compared to strategy 1. Even more, with strategy 1, the self-consumption between 6 p.m. and 10 p.m. occurs during the lowest CO_2 footprint of the network and consequently lowest CO_2 compensation should be expected for the energy community.[89] This means that the current double-tariff structure is no longer suitable and need to be revised considering CO_2 footprint.

<u>Related deliverables</u>

NEW-Green energy credits and virtual power plant battery connection

3.4.6.4. Virtual power plants

Within this activity, the possibility of connecting the two BESSs in VPP mode for increasing the peak-shaving capability of the renewable injection toward the grid was investigated. This would allow the use of the two BESSs having 340 kWh-290 kW of capability for being integrated into a secondary frequency market pool. A software platform was developed that is capable to couple and synchronize the setpoint of the two inverters within a delay time of 10 milliseconds. The simultaneous operation of the two batteries for PV peak shaving was investigated.

As a result, 25 kW more of PV peak power shaving was achieved; 40 kWh per day charged with renewable energies and self-consumed simultaneously by the energy community before 10 p.m. (maximization of revenues), and the peak rejection of 175 kW has been avoided thanks to the VPP connection.

Related deliverables

NEW-Green energy credits and virtual power plant battery connection

3.4.7 Protection of electrical infrastructure from cyber-attacks

With the digitalisation of the energy system, concerns related to cyberattacks increase. Indeed, cyberattacks, such as Stuxnet, demonstrate that cybersecurity is not just a feature of energy system management but a necessity. The focus of this activity was to improve the overall IT security within the DSM system as a first step and then protect the entire electrical infrastructure.

The overall DSM system in Chapelle is quite complex and involves many different subsystems from various partners. It includes devices such as boilers, batteries, photovoltaic systems, measurement nodes, and sensors. Such components generate data and/or need to be controlled.

Initially, this activity focused on the GridEye server in Chapelle which is currently controlling the battery. Although some systems were not accessible, some flaws were discovered. Two different systems were analysed: (a) a Raspberry Pi and especially the code of the control software of the battery, which mainly involves Aurora's Grid and SUPSI, and (b) the GridEye-based monitoring system of DEPsys. The current system used in Rolle or Chapelle already has passed a security audit. While the overall security of both systems seems to be on a good level, some issues have come to attention. The details of these issues and possible resolutions have been provided to the responsible people.[90]

As a second step, the focus of the activity was enlarged to the entire power system. To improve the clients security within the DSOs' networks, a malware and its behavior were analysed. This led to new methods to mitigate targeted attacks by determining their intention, namely introduction of permissions for applications. The effectiveness of the proposed approach was verified. A prototype which recognizes a subset of all actions is implemented. Using this prototype, we can detect malware which is undetectable by commercial anti-malware software[91].[92]

Related deliverable

3a2. First results of control of DSM Units by GridEye

3a4. Protection of electrical infrastructure from cyber attacks

3.4.8 Congestion management with the use of SOP

Before the installation of the SOP, a series of research activities were undertaken in order to identify its control mode (which would affect its design), and the communication infrastructure as well as to assess its impact on the grid.

Suitable system control modes were designed to reduce the adverse effects of distributed generation (voltage variation and component maximum loading), using either few dedicated measurement points or interfacing an existing GridEye system deployed for multiple applications. In a first step, the three grid control modes have been compared to each other in simulations for 6 representative load situations. The scoring considers the voltage variations during operation, the maximum loading of cables and transformers as well as the network losses (including the SOP). Two benchmarks are used for the comparison (a) the current situation without an SOP, and (b) the addition of an ideal line instead of the SOP. It was shown that the addition of the SOP would improve the voltage and loading situation, whereas the "Voltage profile shifting & transformer balancing" strategy is the most promising in this case. [93]

One of the requirements for the SOP protection and control system is to have a fail-safe way to detect a fault condition. Since no sufficient communication is pre-existing at either the SOP location or the transformer stations, a system using a radio link for the transmission of IEC 61850 traffic between the measurement points at the transformer stations and the SOP was developed.[94]
For the evaluation of the impact of the SOP on the power grid, a simulation of the situation without the SOP has been made, by approximating the grid loading (load allocation) for the same period. It was shown that the transformer loadings would have been different in that case ("Before SOP" curves in the figures). To check the simulation assumptions, the situation with the SOP is also simulated, using the same load allocation as for the case without the SOP. The results confirm that the load allocation leads to results similar to the measurements.[95]
Furthermore, for ensuring the normal operation of the 50 kVA prototype, various points on the line were verified, namely grid synchronisation to 50 Hz grid frequency, voltage amplitude of 230 VRMS (line to neutral) ± 10%, power injection and absorption capacity and accuracy on each side, up to 50 kVA, harmonic distortion and undervoltage and overvoltage protections functioning. The capability of the SOP to follow different power setpoints for each converter was successfully tested too. The tests confirmed SOP ability to provide real and reactive power up to 50 kVA on both sides with sufficient accuracy. The distortion tests confirmed that signal distortion at the output of SOP is compliant with harmonic distortion standards.[96]
<u>Related deliverable</u>
6a1. Preliminary study for soft-open point deployment into REEL Demo
6a2. Design principle of soft-open point
6b. Laboratory test of Soft Open Point Prototype
6c1. Report on soft-open point deployment
6c2. Field test verification

4 Rolle demo site

4.1 Aim

The aim of this demo site is to facilitate the integration of renewable energy solutions in the urban environment. There, it covers a twofold objective:
a) to develop and validate tools for the planning of multi-energy systems. These tools will cover energy planning needs of various stakeholders, notably utilities, authorities, and energy community managers.
b) to develop business models for the harvesting of flexibility at the LV, with a special focus on electricity only. These models will consider techno-economic and social aspects and will be validated under real conditions.

4.2 Overall approach

For the achievement of these objectives, the following approach was undertaken:
a) Set grid monitoring systems in place for fault location and system restoration, grid control, and support of planning activities.
b) Analysis of the current and future grid operational limits and identification of the grid operation bottlenecks
c) Identification of load shifting potential and definition of the possible ancillary services for enhanced grid operation and implementation of the most effective ones at the demo site
d) Development of techno-economic methods and tools for the optimal deployment of specific flexible technologies, such as PV and storage systems, EVs, and heat pumps
e) Development of socio-economic methods and business tools for the increase of the practical flexibility towards the theoretical flexibility
f) Evaluation of the performance of the proposed solutions at the demo site in Rolle and development of tools, guidelines and recommendations for various stakeholders.

The evaluation of the techno-economic methods is based on big-data approaches gather mainly openly accessible data while the evaluation of the socio-economic methods required the establishment of an energy community with the involvement of habitants of the demo site and the local authorities.
This was a highly multi-stakeholders approach actively involving local companies, authorities at the municipality and cantonal level, and the general public, notable self-consumers.

4.3 Demo site

For the field validation of the abovementioned activities, a district was required in the network of Romande Energie with a significant share of renewables installation and a few thousands of customers allowing the creation of an energy community, and preferable favorable to the energy transition (as derived from the results of the vote of 21st of May 2017 on the energy law)[97]. A district of the community of Rolle, which unifies these characteristics, was selected as the demonstration site. This area includes two 20 kV outgoing feeders in an open loop, covering the power needs of 2'000 both commercial and residential customers connected to 32 distribution stations. 23 PV units (430 kVA) have already been installed along with optic fiber that connects the 32 stations.
For the purpose of the project, a PMU-based advanced monitoring infrastructure, the SynchroGuard, was installed in all the 32 distribution stations.[98] This infrastructure aimed at (a) serving for fault location activities and (b) providing other teams with the state of the grid for planning purposes. For enabling the system restoration after the fault location, 7 substations were updated to be remotely controlled.
Furthermore, a GridEye-based advanced monitoring infrastructure was deployed on the LV side of MV/LV transformers devices and at some LV nodes, i.e., street cabinets. In total 62 GridEye devices are installed in the Rolle demo site. The GridEye measurements are used to evaluate the quality of supply across the LV grids in Rolle and by other project partners to accomplish their activities related to DSM, multi energy grids simulations, and LV grid storage sizing.[99]
During the project 679 smart meters were installed and are operational at the Demo site of Rolle. This represents 100% coverage in smart meters for the 6 LV grids, namely Bourdonnette, Bourgeoises, Gare, Hôpital, Martinet, Rte de la Prairie. This installation was used to investigate the valorization of the smart meters' deployment for grid monitoring purposes.[100]
For the management of the significant amount of data generated, a project server was configured and installed at the premises of Romande Energie in the data room of the company.

4.4 Activities

4.4.1 Grid monitoring

4.4.1.1. MV monitoring and fault location

The performance of the FLISR function (fault location, isolation, and service restoration) based on synchrophasor measurements provided by PMUs was experimentally validated. The fault location method integrated into SynchroGuard[101] combines multiple synchronized measurements coming from different PMUs located at strategic points in the grid. It firstly separates the monitored grid into multiple areas where a fault can be located based on the measurement placement. In each area, the fault locator continuously calculates a fault indicator and compares it with a threshold that is dynamically updated based on grid loading and measurement accuracies. A fault is detected in a few seconds when the fault indicator rises over the threshold and is and communicated to the utility operator. The method works for many types of faults, in underground and overhead networks, and independently of the network topology and the neutral treatment. The exact location of short-circuits within a line can be also provided.[102]
At the Rolle demo site, three faults occurred between 2019 and 2021. SynchroGuard was not connected to the SCADA system, so in the first two cases the fault location between SynchroGuard and current operation could be compared. In the third case, the information from SynchroGuard was taken into consideration by Romande Energie for the intervention. The events were the following[103]:

- Fault in the line Hopital – Bellefontaine (03-05-2020): The fault evolved into a phase-to-phase fault with high short-circuit currents (about 4 kA), which caused an immediate opening of the breaker at the root of the feeder and a service interruption in the entire feeder. It took about 1.5 hours to reconnect all the customers of the feeder and several manual switching manoeuvres had to be undertaken to find the faulted line, while SynchroGuard located the earth fault after a few seconds.
- Fault in the substation Ch-Combe (18-01-2021). Romande Energie injected an earth fault in the medium-voltage feeder 60 in Rolle. The fault was located and its current was estimated by SynchroGuard fault locator as 12.9 A, which is very close to the 12 A measured at the fault point by Romande Energie with an amperemeter.
- Fault in the line Rolle – Route de la Vallée (26-06-2019): The fault event was composed of multiple stages comprising intermittent faults, an earth fault in phase L3, and a final phase-to-phase fault. SynchroGuard recorded and detected all these events and raised early alarms on intermittent faults enabling the reparation of the fault before it evolves into a permanent fault.

Related deliverables

1a. Asset monitoring study (topology, voltages, currents and flows) at 50 fps

1b. Experimental validation of the FLISR functionality

4.4.1.2. LV state estimation with smart meters and GridEye

Originally, state estimation is an iterative process, that tries to minimize the objective function within a linearized point by a Newton-Raphson solver. Developed for the HV network, which contains more measurement units than the LV one, its advantages lie in cases of high measurement redundancy. The proposed method valorizes data from aggregated smart meters already installed on the grid, combined with a limited number of grid monitoring units, in our case GridEye devices. These additional measurements aid to build a linear reformulated matrix. GridEye devices are installed at MV/LV transformer and some LV cabinets and provide quality information every 10 minutes enabling the smart meter allocation within the network. Smart meter measurements are provided, including their energy three-phase consumption on a 15-minute timeframe basis and their location either at the node level or at the cabinet level (for privacy reasons). This work, thus, focuses on acquiring high-resolution 10-minute outputs, by correlating the total of aggregated smart meter inputs to the GridEye device installed on the transformer, enabling state estimation at 10 minutes timeframe (instead of 30 min). The performance of the algorithm is tested in LV network of Rolle-Hôpital.[104]
The first outcome of the analysis is that the combination of data provided by different measurement systems (GridEye and smart meter) improves the quality of state estimation results. The computation time is faster for the linear state estimation compared to the nonlinear iterative state estimation methods. The 10-minute state estimation is more insightful than a 30-minute one, allowing the observation of some voltage and current peaks that otherwise would be unnoticed.[105]

Related deliverable

3c. Validation of the use of voltage and frequency measurements of smart meters for grid control

4.4.1.3. MV waveform estimation using LV measurement

Considering the outcomes of the above-mentioned activity on LV state estimation with smart meters and GridEye devices, the utilization of LV measurements for MV purposes was further explored. This activity focuses on the estimation of MV voltage and current waveforms using GridEye measurements at the LV side of MV/LV transformer[106]. The idea of the proposed methodology is based on taking measurements of voltage and current on the LV side of the transformer and, by using the mathematical description of a typical model of single-phase transformer, calculate (as an estimate or projection) what are the values of the voltage and current on the MV side of the transformer. In this sense, the MV side of the transformer is emulated in silico; and its digital twin is implemented. The proposed MV waveform estimation method is tested using two GridEye devices. The mean voltage and current errors between the estimated and measured waveform were less than 3%. This demonstrates the potential of the digital twin of the transformer for the monitoring of distribution systems at high time granularity.[107]

Related deliverable

4.4.2 Current and future grid operational limits and operation bottlenecks

This activity aims at developing a methodology for the identification of current and future operation bottlenecks in a specific power network considering energy system optimisation. As optimization of energy systems is a computationally demanding task, clustering has been proven to be an accurate and effective way to reduce computation time while maintaining results quality[108].
This aim is achieved by following a stepwise approach, including
(a) implementation of two clustering approaches for the reduction of computational burden, namely (a) selection LV-grid based on specific criteria defined for buildings (age, reference energetic surface, purpose), thermal energy (heating system, average thermal power consumption), and electricity (solar potential)[109], and (ii) temporal clustering based on temperature and irradiation[110]
(b) implementation of a double weighted decision too based on the above-mentioned criteria for the selection of the subsystem that will be considered in the next steps
(c) identification of the most promising renewable energy technologies for this subsystem considering previous work[111], implementation in a building energy system model, and generation of scenarios based on the renewable energy integration,[112]
(d) investigation of a single building multi-energy system optimisation and generalisation to the subsystem level by aggregating the optimal energy technology configuration at building scale given as a function of the investment capacity, and
(e) assessment of the potential bottleneck of renewable energy integration for the subsystem taking into account the grid constraints such as the transformer loading, the maximum voltage deviation, the line ampacity, the frequency deviation, and harmonics.[113]
This methodology is highly reliant on data both collected with the monitoring infrastructure, notably the GridEye[114], and gathered from open resources. The data heterogeneity is tackled by the development of a tool allowing to automatize this approach and therefore provide a basis for a generalization of the approach at the Swiss scale.
<u>Related deliverable</u>
5b. Design of Sizes for Buildings Energy Systems as a Function of the Grid Evolution
5d1. (New) Development of Future District Scenarios and Definition of Modeling Cases
5d2. (New) Detailed evaluation of the grid operation bottlenecks and load shifting potential for the reference system

4.4.3 Load shifting potential and possible ancillary services

This activity aims at defining the load shifting potential at the demand-side (customer behavioral flexibility) and supply-side (integration of PV panels, heat pump, thermal and electrical storage) as well as the operational level (use of model predictive control). It builds upon the previous activity on the operational bottlenecks identification (section 4.4.2) while supplying data to both techno-economic and socio-economic activities that follow, regarding the potential provision of ancillary services and the gap between theoretical (i.e., based on techno-economic assessment) and practical flexibility (i.e., considering customer behaviour) respectively.
In the frame of this activity, the PV generation potentials have been further developed considering the optimal roofs area and orientation, and the allocation of uncontrollable load based on real aggregated measurement. The effect of the theoretical potential of behavioural flexibility on the hosting capacity of a Rolle district is assessed. The load shifting potential has been evaluated against the consumers behaviour, and the technical and operational flexibility. The assessment of the latest relies on a model generating optimal design and operation of energy technologies in buildings. For comparison purposes, the load shifting potential has been expressed as an equivalent virtual" storage capacity, therefore defining a new metric for the evaluation of the flexibility reserve available at the supply-side, and demand-side as well as the technical and operational level.[115]
The results show that PV penetration could be increased from 73% to 87% while the total cost of energy used only increases by 0.9%. A sensibility analysis of the levelized cost of the PV energy showed that

flexibility is always a better solution than curtailing the excess PV generation. However, flexibility becomes profitable only if the levelized cost of PV is smaller than 175% of the cost at which the distribution grid operator buys the exceeding PV generation. For this same district, it has been estimated that the demand behavioral flexibility is currently at the same order of magnitude compared to the flexibility that could be gathered from the domestic hot water heating. These results showed that flexibility is difficult to obtain from households simply by providing financial incentives.[116]

The impact of advanced tariff structures on grid planning and operation was further investigated. Future loads in the LV grid are forecasted based on the technology scenarios in buildings. For addressing overloading issues, possible methods for the provision of ancillary services are reviewed, and a list of the most effective ones is proposed for the Rolle Demo site. The impact of the proposed methods on the grid is then evaluated at the level of the transformer of the reference case study of the Rolle demo site. The impact on the grid is assessed by solving the load-flow problem and evaluating voltage deviations, line loading levels, and the load duration curve at the transformer. This includes the implementation of different tariff structures, the use of MPC, and the application of load constraints in the power grid and building to district control. The results show that future technology mix increases grid congestion but enables new economic models.[117]

Related deliverables

5d2. (New) Detailed evaluation of the grid operation bottlenecks and load shifting potential for the reference system

4e1. Determination of the flexibilisation potential of the electricity demand

5d3. (New) A list of possible ancillary services for enhanced grid operation and implementation of the most effective ones at the REEL demo site

4.4.4 Optimal deployment of PV and storage systems, EVs and heat pumps

The aim of this activity is to investigate the potentials of the grid integration of the promising technological solutions for shifting flexibility, namely storage systems (coupled with PV installations), EVs and heat pumps. For the former technology two distinct approaches are undertaken.

4.4.4.1. Deployment recommendation for large penetration of PV and distributed storage

High PV penetration in LV grids may lead to over-voltage and lines or transformer overloading. To mitigate these issues, this activity aims to assess whether a selected regulation for PV power injection into the grid could ensure a safe grid operation for a LV network in which all roofs are covered with PV while maintaining a reasonable payback period for all distributed PV and battery system owners. This problem requires to find out the optimal operation of those systems under the constraint of the regulation and to assess the resulting impact on the network.

The optimal design and operation of a PV and battery system is formulated as Mixed Integer Linear Programming (MILP) problem. Given a set of parameters such as the electricity consumption profile, PV potential capacity bounded by the roof areas, as well as PV, battery and electricity costs, the optimization returns the optimal design and operation of the system considering both investment and operation costs in the objective function. This optimization is typically executed on a full year at a resolution of 15 min.[118]

A performance indicator named Grid Usage (GU) was defined which gives how high is the export or import peak relative to the original peak of the consumption. To assess the effectiveness of the proposed method, the load duration curve at the transformer is used as an indicator for the grid operation[119].

The evolution of a grid usage-based operation constraint is considered, in function of the PV deployment rate to ensure a safe grid operation. An assessment is undertaken on the evolution of the retail tariff. The expected decrease in PV system investment cost is also expected to increase the PV adoption rate and in the same way, the retail tariff. This fast increase of the PV penetration could lead to over-voltage and line or transformer over-loading. [120]

The design of the system is given by the abovementioned design and operation optimization already introduced. If the investment is not only profitable but has an Internal Rate of Return (IRR) higher than a given threshold, the prosumer invests in the computed optimal system design. The IRR depends not only on the electricity consumption, PV potential but also on the evolution of both battery and PV investment costs.

The presented methodology is applied to a selected LV grid in Rolle, composed of 71 buildings with 41 grid connections. [121]

Results show a path to high PV hosting in a low-voltage network, ensuring at the same time a safe grid operation without reinforcement, high profitability for the prosumers, and constant revenues for the grid maintenance. This path from 2020 to 2050 relies on a 30% increase of the retail tariff, incrementing from 21.02 to 27.81 cts/kWh, and a severe operation regulation with a GU constraint ending to 0.2 in 2041. In the current framework, line overloading or over-voltages could become the new grid bottleneck. This could be avoided by upgrading the transformer at the right time. One improvement, toward a more optimal path, would be to allow an update of the system designs by either installing more PV modules, or more battery capacity. [122]

Related deliverable

4e2. Deployment recommendation for large penetration of PV and distributed storage

4.4.4.2. Models for the optimization of grid penetration of smart controllable batteries in different grid topologies (the case of EVs)

This activity aims at developing a methodology that allows for the design of a plausible distribution network and to populate it with plausible loads. This tool allows for inter-building connections, consideration of geographical obstacles, and clustering of the loads. On this synthetic network, it is then possible to test different penetration scenarios of PV generation, electric heating via heat pumps, and electric mobility. All of this is integrated into a simulation environment that allows performing a power flow study on the synthetic grid and testing the effect of DSM control algorithms for grid optimization. The DSM-tested algorithms are based on MPC techniques and rely on realistic predictions of load and production curves on the network and could therefore be used in the real world. This methodology is applied to the study of the effect of vehicle to grid (V2G) for energy management. This is done for both winter when the power required by EVs is added to that already required by for instance heaters and in summer, when the PV injects a lot of energy around noon and causes the power flow to reverse. The results showed that in both cases the EVs are able to reduce the power excursions at the transformer. Since the control is based on realistic (but not perfect) forecast and the time granularity is 5-min, the risk of exceeding the operating limits of the transformer is not fully mitigated. The installation of a BESS could address this issue. The simulation tool was effectively used to select where these stationary batteries could be located so that both “local” voltage and ”global” power constraints are respected.[123]

Related deliverable

3d4. Models for the optimization of grid penetration of smart controllable batteries in different grid topologies

4.4.4.3. Definition of optimal control of DHW for self-consumption strategies

The aim of this activity is to develop an algorithm for the optimal control of the Heat pumps coupled with a PV installation to heat and maintain the occupants’ comfort while maximising the use of the renewable energy, leading to the minimum possible operating cost. Therefore, a linear thermal model was proposed to obtain the heat pump’s (HP) optimal control trajectory by solving the MILP. A novel heuristic control algorithm (HCA) was presented to control an HP and its ancillary electrical heater (EH) in the framework of a PV system in a self-consumption scheme[124]. The algorithm optimizes an indicator comparing the variation of the operating cost and the generated heat. It is versatile and agnostic of the building modeling complexity. The algorithm’s primary objective is to keep the temperature state variable in the imposed bounds. This ensures comfort in the building and the appropriate service temperature for the domestic hot water (DHW). The first step is to evaluate the system’s behavior and target time windows when temperatures are below the target temperatures and heating is needed. Then, for these time windows, the algorithm evaluates the value of the indicator and chooses the best set of actions that minimize this indicator.[125]

The HCA is straightforward and an effective control algorithm suitable for implementation in any micro-controller without the need for advanced computing technology. The system behavior model is versatile, allowing to catch any non-linearities related to the HP behavior under part load or detailed coefficient of performance (COP) calculations. A linear formulation of the problem was used with the operating cost as the objective function to benchmark this algorithm and solve it using a MILP solver[126].

A set of 15 building models was built to have a representative case study. This is based on the cantonal buildings' registry of the canton of Vaud from which all buildings of the Rolle demonstrator and surroundings are extracted. The considered buildings, although anonymized, are real buildings from which their properties are extracted using the Swiss society of engineer and architects (SIA) norm. Four typical periods of one week were used to simulate the HCA's behavior and compare it with the MILP. Under the assumption of a perfect forecast, the HCA's performance is close to the linear problem one.
The differences in operating costs are negligible. The temperature deviations can sometimes be significant but stay in the same range as the MILP. The HCA, because it includes the HP's running and switching costs, uses the HP more carefully, hence having lower running time and switching than the MILP. This should increase the lifetime of the HP in a real application. Despite the HCA's computing time being much larger than the MILP, the HCA has a low computing burden when considering that we simulated one week of operation at 15 min time resolution. Therefore, the HCA is suitable for a real deployment in a HP and solar controller.[127]
Related deliverable
5c. Definition of optimal control of DHW for self-consumption strategies

4.4.5 Socio-economic methods and business tools

This set of activities consists of two interrelated elements, (a) the development of a platform for the evaluation of the flexibility-related business models and (b) the establishment and operation of the Energy Community of Rolle. The latter provides the model used in the former one with information on the social acceptability of the local community to flexibility-related solutions. However, it goes further by investigating in practice the real willingness of the general public to get actively involved in the energy transition in Switzerland and their readiness to invest in new technologies for providing the grid with services.

4.4.5.1. Development of a platform for business models evaluation

The aim of this activity is to develop a platform for the evaluation of flexibility-related business model while considering socio-economic and technological aspects. For this purpose, the existing TREES simulation model[128] that originally focused on simulating the diffusion of self-consumption concepts in energy systems was expanded with three different business models for decentral flexibility. The approach undertaken involves the following steps:
(a) Representation of the supply area of RE, considering likely future diffusion of renewable energies and self-consumption from PV (kWh) over time. For this purpose, a workshop was organised with Romande Energie to familiarise the company with the model used[129], and receive initial inputs on a case study of the business case "battery swarm" while defining model boundaries and characteristics.[130]
(b) Estimation of the residual load over time in the supply areas of RE with trend to self-consumption. This involves the valorisation of the work of other project partners working on the techno-economic aspects in the Rolle demo area (See 4.4.2).
(c) Assessment of flexibility potential based on home batteries in the area of RE based on inputs of other project partners (see 4.4.3, and 4.4.4)
(d) Definition of the number of customers adopting the investigated flexibility business models of RE[131]. For this purpose, an Energy community was put in place in collaboration with the local authorities consisting of habitants of the Rolle demo site.[132]
(e) Quantification of the flexibility volume accessible by RE with the business models (BM) for the cases of battery swarm, district battery (300 kWh large-scale battery with battery renting model)[133] and multi-energy flexibility
(f) Cash-flow / profit analysis for RE of flexibility business models,
(g) Evaluation and comparison of three flexibility business models for the implementation by RE, and
(h) Uncertainty analysis of business strategy.[134]
(i) Validation of the replicability of the proposed method by comparing it with the implementation in another site in Arbon.
(j) Development of a user interface for the simulation model[135]

The analysis provides evidence that the battery swarm BM can be profitable for Romande Energy SA. The district battery case can be profitable in various scenarios: (1) Providing ancillary services is attractive, but also sensitive to changes in the merit order curve. (2) The renting model can contribute (strongly) to recovering the costs of the district battery.[136] However, the comparison between Rolle and Arbon demonstrated that the competitive battery rent reacts very sensitively to external factors, notably battery size capacity of storage prosumers (resp. Investment volume), electricity price, grid tariff, autarky degree and PV feed-in tariff.[137]
Furthermore, the viability of flexibility aggregation business models relies on the combination of different revenue streams. This can unleash the deployment of PV (and storage) installations and valorisation of the flexibility[138]. However, current regulation, notably unbundling and grid tariff setting one, prevent prosumers from using their batteries for purposes other than self-consumption. Indeed, the development of decentralized, daily and seasonal storage is hampered by the limited liberalisation of the energy market that does not allow the most customers to acquire part of their supply from a neighbouring producer. A drastic change in tariffs for network usage and acquisition of the grid injected PV power as well as a proper remuneration of group flexibility would allow the creation of local communities. This would make possible many business models favouring the development and valorization of flexibility and the appearance of new actors. Furthermore, to improve the market access for flexibility aggregators, regulators can adjust the bidding structures on national balancing-power markets, by reducing the minimum bidding capacity and the bidding period. This reduces the critical mass of prosumers a flexibility aggregator needs to have in the swarm to start off, but also reduces the steps until further bids can be made.[139]
<u>Related deliverables</u>
5e1.(New) Workshop's minutes on business cases
5e2.(New) Workshop's minutes on Dynamic business case development and Strategy experiments
5e3.(New) Documentation of the user interface for the simulation model

4.4.5.2. Energy Community of Rolle

For the definition of the willingness of the final customers to get actively involved in the energy transition as well as the incentives to achieve that, Romande Energie in collaboration with the local authorities of Rolle and Mont-sur-Rolle established the Energy Community of Rolle. The approach undertaken includes (a) organization of an introduction session together with the local authorities and the research community for familiarisation of the general public with the energy transition terminology through gamification, (b) launching of a survey together with the Cantonal authorities of Vaud related to the energy aspects, namely DIREN-VD, (c) organization of a workshop for the presentation of the DSM technological solution and raise awareness of the final customer on the impact of their behavior on energy needs and the emissions associated with it, (d) definition of the most appropriate DSM technology, in terms of technical feasibility and economic viability, to be installed at the premises of seven final users and recruitment of the volunteers to participate to this experiment, and (e) organization of a workshop with an enlarged focus on the carbon footprint of the residential energy consumption and provision of tailored carbon coaching.[140]
The activity demonstrated that final customers do not understand the added value of the DSM solution, and why it is not the Smart Meter that provides this service. Also, the grid stability is something that they consider as a given, and responsibility of the DSO, and they are not willing to pay for this as an extra service. The flexible resource capacity of Rolle neighborhoods equipped with smart meters has been assessed but remains low. Despite the presence of heat pumps in some recent residential neighborhoods, their potential for flexibility is low in relation to the consumption and power of the neighborhood substations. Electric heaters and boilers in multi-family buildings are difficult to access and contribute little to the integration of PV. Despite the installation of 700 smart meters in six urban and residential networks, technical (SAP) and legal reasons (secure identification of the beneficiary) make it impossible to provide load curves via the Romande Energie customer portal. These are major practical, legal, and social barriers to the valorization of local flexibility. For the project, this resulted in the moving of the DSM activities to the Chapelle demo site, where an early adopter was already involved in the project, and the consideration of stationary batteries for the experiment. It is important to note that Rolle is among the communities with the highest acceptance rate of the federal law on energy[141] which give an even more importance on these findings.[142]

Related deliverable
5f. (New)-Energy community activities at the Rolle demo site

4.4.6 Guidelines and recommendations for various stakeholders.

The aim of this activity is to provide decision-makers with tools, guidelines and recommendation for the acceleration of renewable energy integration. By building on outcomes of the other activities undertaken on this demo site, it summarizes findings to avoid conflicting messages. It can be split in two parts (a) one on the guidelines related to planning methods, e.g., KPIs, long-term planning methods, and (b) another one related to the technological solutions themselves that should be implemented to achieve the energy transition in Switzerland on a viable way.

4.4.6.1. Best investment strategies when prosumer capacities are increased in the grid

This activity aims to take a closer look at the economic, environmental, technical and security impact of the development of decentralized energy systems. Therefore, it focuses on the development of tools and guidelines for decision makers to identify the best investment strategies when prosumer capacities and renewable energy are increased in the grid. For this purpose, the following approach is undertaken:
(a) The significance and behavior of the different KPIs to evaluate centralized and decentralized investments strategies[143] is demonstrated at one LV grid of the Rolle demo site. Results show the importance of appropriate system boundaries, the need of hourly resolution of emissions values related to the grid, and the increasing attention which needs to be devoted to the grey energy connected to modern energy systems. Correlation of different key performance indicators are revealed to ease the process of decision making.[144]
(b) A long-term planning method is demonstrated at the same LV grid of Rolle. The energy integration of new centralized and decentralized equipment is evaluated, based on the defined KPIs, on a monthly basis over four periods until the year 2035[145]. The results show that, among the four investment scenarios identified, the base option consists of the integration of a very low temperature district heating with decentralized heat pumps to satisfy the heat requirements below 75°C, as well as heat recovery systems and the refurbishment of about 33% of the building stock. This option allows to decrease the final energy consumption of around 36%, cut the CO_2 emissions by a half, multiply the renewable energy share by a factor 3.5 while reducing the annual total cost by 24%.[146]
(c) The study, applied in Rolle, confirms the relevant influence of PV panels' azimuth and tilt on the performance of building energy system[147]. Whereas south-orientation remains the most preferred choice, west oriented panels better match the demand when compared with east-oriented panels. Apart from the benefits for individual buildings, an appropriate choice of orientation was shown to benefit the grid: rotating the panels 20º westwards can, together with an appropriate scheduling of the BES, reduce the peak power of the exchange with the power grid by 50% while increasing total cost by only 8.3%.
(d) A new taxonomic framework was developed starting from a general analysis of the emerging solutions, identifying intersectoral synergies and limitations with respect to the 'smart energy system' concept. From the scenario portrayed, a set of issues involving engineering, regulation, security, and social frameworks have been derived in a theoretical fashion. The findings suggest the urgent need for multidisciplinary cooperation to address engineering and ontological challenges gravitating around investments in the smart grid concept.[148]
Related deliverable
5a Best investment strategies when prosumer capacities are increased in the grid

4.4.6.2. Performance of the implemented solutions with guidelines for subsequent implementation

This activity aims at investigating the potential of the implemented solution in the residential district to increase their sustainability, even achieving climate neutrality and self-sufficiency, by using a combination of PV power generation, batteries, heat pumps, and individual thermal storage.
The problem was addressed as a multi-objective, mixed integer-linear programming problem, with the operating expenditures (OPEX) and capital expenditures (CAPEX) of the system as competing objectives, and the installed sizes and operating load of the different energy conversion units (including PV panels and

batteries) as optimization variables. The proposed approach was applied to a reference residential district of the RE demonstration site.

The results of the application of the proposed method to the case study allowed drawing the following conclusions for the study are[149]:

- It is relatively cost-efficient to achieve carbon neutrality, but this is only possible if PV panels are also installed on facades. The installation of PV panels on facades has the potential of increasing the total energy generated by approximately 80%. However, PV panels should be prioritized on roofs (first horizontal, then South-East-West-North) and only then on facades (South, East/West, North). Further additions of PV panels and batteries allow for reducing operating costs but have little effect in further reducing the total Global warming potential (GWP) potential of the energy system. Electricity prices have a significant impact on the maximum PV surface that can be covered while still being economically viable. Current tariffs would allow up to 80% of the total available surface to be covered.
- For achieving self-sufficiency for the district, approx. 40% to 100% of the available surface should be covered with PV while the round-trip efficiency of the storage unit decreases from 100% to 50%. Storage has an important role to play in the energy transition but currently, this is not a viable solution. Even when assuming a 100% round trip efficiency for the storage, very large storage capacities are required. The revenue generated by the difference between power retail (acquired from the grid) and PV power acquisition prices is not sufficient to pay for the storage that is required to make the district self-sufficient. This is true already at relatively low installed PV capacity when storage starts to be required for seasonal instead of daily storage, thus increasing dramatically the required capacity and storage time.
- Building renovation, with its important effect on energy demand reduction, was identified as the most promising in synergy with PV generation. This is because building renovation allows reducing both the required installed PV and storage capacity to achieve self-sufficiency by half.
- The development of a more efficient 4G or 5G district heating system will allow reducing by more than 15% the size of the storage while reducing by about 15% the PV area. Moreover, the foreseen deployment of a 5G district heating and cooling network is expected to realize sector coupling by introducing power to gas (P2G) and electro-thermal energy storage (ETES) capacity in the decentralized district energy system.

<u>Related deliverable</u>

5Overall. Performance of the implemented solutions with guidelines for subsequent implementation

5 Conclusions

There were several conclusions drawn from this project. These include both market and technology perspectives. The former are reflecting mainly the views of the DSO, through the eyes of Romande Energie, and the latter ones are presented by demo site and activity below.

5.1 Market aspects – Overall

5.1.1 Preliminary remark

The aspects reported below reflect the key conclusion that Romande Energie withdrew from the project as a result of its interaction with the various project stakeholders. These interactions include (a) the project manager's experiences while providing demonstration sites and infrastructures required for the implementation of the research partners' activities, (b) the Romande Energie's Smart Lab team observations during interactions with the public (deliverable 5f), (c) the results reported in the numerous project deliverables and (d) the analysis of knowledge and technology transfer to the daily operations of Romande Energie carried out jointly by the project manager, as representative of DSO's regulated activities, and the business developers of the various open-market activities. These findings represent a purely internal point of view and should not be considered the result of an academic approach.

5.1.2 General context

With the increasing decentralization of production and storage, along with the electrification of heating/cooling and mobility, the DSO must develop the **observability of local networks** and its ability to anticipate highly fluctuating local operating conditions. While monitoring sensors are lacking at the local networks, they are widely present at the HV networks along with real-time monitoring and control approaches. However, the direct transposition of these solutions from the latter network to the former ones is not feasible since the number of assets increases by roughly a factor of 10^5 while moving from the HV to the assets behind the meter. Therefore, new approaches should be developed to assess the decentralization impact on the lower network and take actions on them.

The term "**smart grid**" is an overall concept that links the public network, and all the private equipment connected to it. The public network is essentially composed of passive elements, such as cables, district transformers, and safety elements, while active elements, such as power production or storage equipment, appear mainly on the customers' side and are not network assets. It is in the interaction between the network and its users where intelligence can be created. The REeL project has notably contributed to demonstrating that the necessary technologies to operate this system in an efficient and intelligent way are available.

However, the deployment of these **technologies faces several obstacles**. For instance, the flexible resource management solutions tested on the demonstration sites of Aigle (use case: network battery on an MV feeder, *see* deliverable 2c and section 2.4.2.3) and Chapelle-sur-Moudon (use case: private community battery, district battery in the LV network, *see* section 3.4.5.2), are not feasible under current framework conditions. This is because, on the one hand, the DSO should invest in the data collection infrastructure (PMU class sensors, means of communication, IT architecture) essential for these solutions to function. On the other hand, house owners and other market actors should invest simultaneously to create and manage the flexible resources (including daily and seasonal storage in particular) necessary to reduce the impact of renewable energies on the power infrastructure.

However, to date, there is no appropriate **market framework** for these private investments to occur. Indeed, there would be several energy actors that would benefit from the predictability of power consumption derived from the withdrawing of entire network sections. Energy actors such as DSOs, energy suppliers, balance group managers, and the TSO. would have an interest in decreasing the costs of the impact of renewables' stochasticity on their business models. While they might be ready to pay for that, there is currently no flexibility marketplace. The only existing related marketplace is that of providing system services, which is limited to certain categories of resources complying with specific rules. Moreover, the flexibility available to ancillary services may not contribute to limiting operating problems in local networks or energy supply portfolio management. Without an adequate price signal, the flexibility value chain[150] cannot be fully valorized.

It is reasonable to think that only the **diversification of income sources** can provide the long-term horizon required for private investors and service providers. The more flexible resources appear in a decentralized way, the more they are likely to create value for different actors. While large centralized flexible resources, such as turbine-pumping plants or inertia reserves, play a key role in the security of supply and the stability of the power system, the multitude of resources distributed in local networks is expected to play an equally important complementary role. On the one hand, implicitly for the active consumers themselves, by reducing their exposure to energy and network costs, and on the other hand, explicitly via an aggregator which can valorize the potential flexibility of a large number of resources by responding to the demand of actors seeking to acquire it.

A second obstacle is linked to the principle of **attributability to network costs**. Only what is useful to the network is attributable to the grid tariffs. Therefore, the DSO should justify the added value of the roll-out of expensive monitoring systems in its networks. However, this would be difficult for networks without flexibility valorization solutions. Indeed, developing observability without the possibility of controlling flexible assets does not prevent the DSO from reinforcing its networks to avoid congestion and voltage issues. Furthermore, only part of the costs of these monitoring systems would be imputable since the network only partially benefits from these technologies. The same applies to the district or network batteries for which the DSO cannot transfer all of the cost to the grid tariffs.

The technologies deployment can also face an additional obstacle, namely the **interoperability of the various solutions**. For instance, in the two above-mentioned use cases, the deployed technology is the same both on the public network and on the side of the flexible resources. While, in both cases, the effectiveness of decentralized intelligence has been demonstrated, these ideal conditions are not necessarily replicable in real life. Indeed, various energy management systems are in the market and can be deployed and not all of them are set up to interact with DSOs' systems. The DSO can certainly set technical requirements in its special connection conditions, but when it comes to costs borne by the end user, it cannot impose one market product over another.

Furthermore, **grid monitoring systems** exist, but the challenge lies in the selection of the right one by balancing cost and benefits. An alternative low-tech approach is to develop the observability of local LV networks from smart meters data (deliverable 3c) which seems to result in acceptable accuracy at low cost. However, when dealing with sensitive data, the DSO must develop data science skills and put in place a strict data protection policy to ensure that confidentiality is maintained within its own organization. These reflections carried out with the partners have enabled Romande Energie to initiate in-depth work on the use of metering data and its data protection practices. Using this approach, an estimation of the grid state was obtained based on the past (the day before) operating conditions due to the daily reading of the meters. The use of machine learning or artificial intelligence would still be necessary to obtain a forecast vision useful for operation. This approach gives the DSO the possibility of estimating its flexibility needs (volume, area, duration) to interact with other actors.

Making more **use of the metering infrastructure (SMI)** deployed within the framework of the legal obligation of the DSOs, without further investment in the network is a cost-efficient way to increase the security and efficiency of network operations. Although this information is not in real-time, better visibility of the state of the network is thus possible while enabling the provision of relevant energy data in open access to other energy stakeholders.

While the DSO does not have access to **metering data in real-time**, the customer has an interface available for this purpose. This data can then be leveraged by its energy service provider or aggregator in various grid or market service business models. For this, the contribution of digital economy technologies will be decisive, notably in the creation of a marketplace for flexibility. More and more new actors, such as Virtual Global Trading, Exnaton, Hive Power, Equigy, and EPEX-Spot Local Energy Market (Centrica), are offering the use of these technologies in the energy sector through digital platforms regulating exchanges and contractual aspects.

5.1.3 The real paradigm shift

The **network management** should be adapted to the decentralization of production, where active customers move from the periphery of the energy system to the center. An ecosystem emerges where its management and control are no longer centralized, where intelligence, data, analytics are distributed, where local conditions rule the emergence or not of different technologies, where the financial flows of business models are distributed between several actors and finally where the services dematerialize the notion of monitoring and control systems.

As mentioned at the beginning, transposing into a distributed system the approaches that have so far made it possible to supervise and control HV networks would not be the most efficient.

5.1.4 The four main lessons of the project

- Low residential flexibility today, tomorrow and for a long time to come
- The importance of the district in the efficiency of the overall energy system
- The importance of grid usage and feed-in tariffs
- The importance of governance in the energy transition

5.1.4.1. Residential flexibility

The work of the academic partners shows that there is no significant potential for **behavioral flexibility** on the residential side, neither today nor tomorrow. Of the 24% of the load that is today in principle movable/flexible, only 6-7% would be easily movable, considering the characteristics of the households and the needs of their activities. Consumption patterns are and will continue to be largely conditioned by daily family routines rather than financial incentives (deliverables 4e1, 5d2). This raises the question of how residential flexibility will evolve with the increasing electrification of heating/cooling and mobility.

As mentioned in §4.4.4.3, the efficient use of **heat pumps**, from an energy and economic point of view over their entire life cycle, seems to favor an implicit flexibility model (i.e., for the benefit of the owner, similar to self-consumption). This is achieved by a local regulator optimizing the operating costs of the heat pump according to the electricity tariffs and the energy performance of the building (deliverable 5c). There would therefore be little interest in an explicit flexibility model (i.e., for the benefit of external actors).

The flexibility potential of **individual mobility** has only been addressed from a theoretical point of view (see §4.4.4.2, deliverable 3d4) as to its contribution to relieving local networks in a “vehicle-to-grid" (V2G) model. However, doubts remain about the feasibility of this model. Discussions with academic partners and internal analysis indicate a tendency for public charging stations to integrate more easily in the medium-term "grid-to-vehicle" models (load reduction) than V2G models. This is aligned with the experiments conducted in Europe by Jedlix (see USEF - Practical deployment of electric vehicle flexibility 2020). Therefore, private charging stations favor implicit flexibility, thus optimizing the owners' energy systems.

Section 4.4.4.1 (deliverable 4e2) formulates recommendations for the **large-scale deployment of PV and decentralized storage**, while § 4.4.6.2 (deliverable 5) addresses the **performance of the deployed technologies** and highlights the need for storage development to increase the district’s self-consumption. The former recommends reducing the injection of PV into the local grid, and the latter highlights the need for storage in the district (downstream of the district transformer). Then the necessary capacity should be distributed to the producers "behind the meter". Indeed, only the deferred exchange of energy at a lower power level allows the district to both self-consume and not overload the local LV network lines. The concept of a district can be likened to that of a local energy community that uses the public grid.

As noted in the findings of Deliverable 5, there is a **lack of revenue in current business models** to fund the necessary storage. An alternative approach to the public funding or subsidy would be to pay these district communities for the service they provide to the grid by helping to limit congestion and to other stakeholders by adopting a predictable power consumption profile.

5.1.4.2. The importance of the district

The work in Deliverables 5, 5b, and 5d1 highlights the value of **strategic multi-energy system planning at the district level**. Indeed, the district represents the minimum functional size of the energy system that needs to be managed for a coherent decarbonization policy. The importance of reconciling data on existing distribution networks, not only electricity but also gas and water, with local data, such as available renewable resources, land use plans or building data, is shown. While this data is available today, it is rarely accessible or discoverable due to regulations and its dispersion in numerous databases of public administrations or public service companies. This data is notably essential to the work of the engineering offices that establish energy and climate plans on behalf of the municipalities as required by the implementation of the cantonal policies. The time required and the results’ quality of these plans would be greatly improved by giving access to data sets prepared for this purpose via a platform. The technologies that guarantee access rights, confidentiality, and purpose without moving all this data to one place already exist. For instance, VIA Science Somerville (MA) with its Trusted Analytic Chain (TAC) is one of them.

The "building to district and district to grid" approach adopted in this work allows for more efficient planning of network convergence and even for the creation of new networks such as for hydrogen or CO_2. The exploitation of these energy potentials at the district level will require **subsidy programs** that promote technologies based on the local conditions in terms of available resources, infrastructure, and other energy installations too. Indeed, subsidies that promote, for instance, HPs in buildings accessible by a distant heating system might be inefficient.

5.1.4.3. The importance of tariffs

The aspect of tariffs has been addressed and discussed with the academic partners in several activities. In particular, deliverable 5d3 highlights **tariffs' influence on PV and batteries' penetration rate**, as well as on the payback time of these installations and the grid use rate (both import and export). A doctoral thesis based on these activities[151], highlights in §4.4 that the same is true for heat pumps and domestic hot water production. Romande Energie extended this work demonstrating that it is possible to optimize all these metrics while maintaining an adequate income for the grid operation. Variable tariff structures for grid usage and for feed-in tariffs were discussed too[152].

Furthermore, in this work, it was shown that **grid tariffs based on power or "block rates"** clearly allow to limit or postpone the grid reinforcement investments, by optimizing the use of the existing infrastructure. The tariffs are therefore to be considered as an alternative to the direct control of the devices at the customers' premises by the DSO. This approach is more efficient than any technology because it is immediately effective without requiring a roll-out.

Work that continues beyond the end of the REeL project includes the assessment of the impact of dynamic grid usage and feed-in tariffs on the abovementioned metrics. It is already evident that a poorly structured tariff can work against energy transition goals, for example by providing an incentive to install the minimum amount of PV needed.

5.1.4.4. The importance of governance

Matthias Finger, former Elcom member and political scientist, was arguing already in 2005[153] on the need for **coherence between technical and institutional coordination** to ensure infrastructure efficiency. As this final report and the deliverables of this project show, the technologies that are needed to integrate renewable energy into our energy system can be summarized as a system of systems whose overall efficiency depends on the coherence with which it is created.

This need for coherent coordination can be illustrated by the above-mentioned example on the importance of the district. The choice of the energy technology's deployment depends on location-related data, while subsidy programs' supports are mostly location agnostic. Without a common coordination mechanism based on the most relevant data, decisions are not backed by evidence, and each stakeholder's choices are exposed to biases. This results in inefficient energy systems including technologies deployed and ultimately underused. the same kind of WEB3 technologies as mentioned here above would also allow common data-based governance

5.2 Technology perspective - Aigle demo site

5.2.1 PMU-based situation awareness for MV networks

<u>Outcomes</u>
In this activity, the state estimation functionality of the PMU-based grid monitoring system of Zaphiro was validation. The system was able to monitor accurately and in real-time the grid state (voltage and energy flows), by using only current sensors placed in 20-50%of the nodes (no voltage sensor is needed, which are difficult to install).
<u>Innovation</u>
Combining the fast and accurately time-synchronized PMU measurements with powerful algorithms that extract unique information from this data (such as state estimation and fault location), SynchroGuard is the first smart grid solution able to:

- Generate 200x data than conventional solutions.

- Provide full grid visibility, but with 3x fewer devices.
- Support the control utility-scale batteries to integrate more renewables and EVs.
- Guarantee the fastest and simplest installation on the market.

Impact of innovation

A grid monitoring and automation system based on PMU technology, like SynchroGuard, can be considered as the ideal solution that electrical utilities are looking for to enable the Energy Transition. It is an all-in-one solution addressing the main challenges of distribution grid management, namely providing visibility of the grid state, reducing the impact of blackouts thanks to faults identification and location, and enabling the integration of more renewables and EVs. In addition, it is rapidly scalable thanks to a very simple installation. To render the solution more accessible for the DSO, Zaphiro develops partnerships with manufacturers of the grid protection systems in order to equip them with their algorithms.

5.2.2 Forecasting of PV generation

Outcomes

We developed and evaluated the performance of four algorithms that can disaggregate PV generation from the aggregated active power measurements of a group of prosumers with high accuracy while they are only slightly affected by the level of PV penetration in the prosumption mix.
Furthermore, we developed and evaluated the performance of a specific method to compute prediction intervals (PIs) of the GHI and the power generation of PV based on the use of an all-sky camera. Results show that the all-sky camera-based GHI estimations outperform the classical estimations provided by the Heliosat-2. Furthermore, when used for GHI point forecast, the proposed method has a better performance than a simple persistent method for forecast horizons larger than 1 min.

Innovation

Since solar irradiance is highly dependent on the cloud coverage, image-based solar cloud forecast has been largely studied by the recent literature[154]. Particularly, the use of all-sky cameras for irradiance estimation has recently come to prominence. We have developed a new machine-learning method to forecast the prediction intervals of the GHI for different time horizons. The method relies on the integrated use of GHI time-series and all-sky camera images. As a side result, we have proposed a method to estimate the GHI from images delivered by an all-sky camera. The method extracts first a number of features from historical all-sky images and from a clear-sky model. Then, it performs a feature selection to determine the most relevant features by applying principal component analysis (PCA).

Impact of innovation

Given the major role that stochastic renewables resources play in the modern and future electrical infrastructure, the predictive assessment of PV power production variability, and the associated uncertainty, in a probabilistic way is essential. The tools developed and validated in the frame of this activity are enabling solutions that should feed into activities related to grid control, notably those associated with Demand Site Management and operation of BESSs. Final users of this solution are PV operators, energy communities' managers, and DSOs.

5.2.3 Real-time control strategies for heterogeneous resources at MV

5.2.3.1. *OPF-based control*

Outcomes

The main outcomes of this activity are: (a) development of a robust day-ahead OPF-based dispatch process that considers the forecasts of loads and distributed generation; (b) development of a computationally efficient intra-day OPF-based real-time control of the controllable resources to track the dispatch plan; (c) validation of the proposed methodologies in a full-scale real environment via the REel demonstrator site in Aigle.

Innovation

The innovation of the proposed solutions lies on the definition of exact and computationally- efficient algorithms for the optimal operation of active distribution networks. This is achieved via deep knowledge, prediction, the available resources, along with a thorough experimental field validation. Specifically, the main innovation is the development of a strategy for the fulfilment of the day-ahead dispatch plan thanks both to the very accurate forecasts carried out the day before as well as to the real-time BESS control to compensate for the real-time small fluctuations that would make the actual grid.

Impact of innovation

The potential user of the proposed innovation is ultimately the local DSO or an aggregator that has the knowledge of the grid state, which can exploit the proposed tools for the distribution grid optimal management. On the one hand, this approach can augment the exploitation of the distributes renewable-based generation by increasing the renewables host capacity of their network and deferring grid reinforcements. On the other hand, it will prevent DSOs to face market-related penalties due to non-fulfilment of the dispatch plan and reduce the overall bulk system reserve due to the high fidelity in the computation and tracking of the day-ahead dispatch plan.

5.2.3.2. COMMELEC-based control

Outcomes

The outcomes of the activity were the development of the COMMELEC software agents and their successful deployment on the REel demonstrator at Aigle for the tracking of a day-ahead dispatch plan. COMMELEC was able to track the dispatch plan in real-time within the desired accuracy, while also maintaining the grid in a safe state.

Innovation

Compared to past experiments with COMMELEC, a new method was used to compute the weights of the various objectives of the grid agent. This method translates the weights into physical quantities that can be chosen intuitively, such as maximum voltage violation and maximum deviation from the dispatch plan.

Impact of innovation

The proposed method can be adapted to other real-time control systems with similar objectives and reduces the time and effort needed to tune the parameters of the system, until acceptable performance is achieved.

5.2.3.3. Distributed control strategies

Outcomes

New algorithms for distributed control of BESS have been developed and characterised by the following features:

- No parametric model of the grid is required for the controller design. Only the spectral data acquired after small perturbations are used.
- The hierarchical droop-based primary and secondary control approach is replaced by a distributed control system structure.
- Faster frequency recovery time and less frequency NADIR are achieved with respect to the classical approaches.
- Controller parameters are computed by convex optimization algorithms and are adapted online to different operating conditions.
- Dynamic stability for low-inertia grids with communication delay is guaranteed.
- Hardware-In-the-Loop validation of real power grids.

Innovation

The use of data, instead of a parametric model, and convex optimization techniques for tuning the controller parameters are the main innovations of this project. All transient and steady-state performance specifications are converted to convex constraints and objectives. A passivity-based approach for the safe integration of distributed generation and storage units into the grid with plug-and-play capability has been developed in the same framework. The deep learning methods are used for voltage and frequency control and power sharing in islanded microgrids.

Impact of innovation

The developed algorithms can be used by the manufacturers of BESS for the control of their power electronic interfaces. In a higher level, the energy distribution companies that use BESS for voltage and frequency control in their power grids can also implement the proposed strategy.

5.2.4 Coordination between DSO and TSO (provision of ancillary services)

Outcomes
A methodology based on linear programming was developed to characterize the capability of distribution systems for the provision of both active and reactive power reserves to the upper-layer grids at their PCC. The performance of the proposed method has been tested at the demo site in Aigle.
Innovation
The approach studied here is novel since: (a) is using renewable energy sources for the provision of ancillary services and (b) introduces the concept of prioritizing renewable providers.
Impact of innovation
The impact of sourcing ancillary services from distributed generators is twofold: firstly, the transmission system operator can access the alarge amount of new generation capacity that is added to the system also for operational needs and, second, the final consumer who is installing small solar PV systems will have an additional possible revenue by participating to the ancillary services market.

5.3 Technology perspective - Chapelle-sur-Moudon demo site

5.3.1 Monitoring of the grid

Outcomes
A model-less approach for the estimation of sensitivity coefficients was developed and validated. It gives very promising results by achieving an average 4.6% difference compared to the average value of the reference method.
Innovation
There are various methods for the calculation of the sensitivity coefficients for an electrical power grid, such as Jacobian, Gauss-Seidel. The model-less approach is an alternative for determining the sensitivity coefficients, specifically in distribution grids where an accurate and up-to-date information of grid model is not always available. The inaccuracy of the grid model can be due to imperfect knowledge of the grid topology (e.g., frequent changes of topology) and/or inaccurate grid parameters (e.g., ageing/damage of infrastructure, neglecting impedance of fuses/joints/connections). The novelty of the proposed method is that it overpasses these challenges by determining the sensitivity coefficients based on only measurement data and without requiring the grid parameters.
Impact of innovation
Often, DSOs do not possess an accurate and up-to-date model of their grid. However, this information is required by most common methods to estimate the sensitivity coefficients. This model-less approach addresses this challenge enabling the DSOs to undertake power system-related analysis and control approaches. This outcome is of great interest but since the related technology must be spread on both grid and customer side, the transfer into daily operations will face legal, financial, and technical hurdles.

5.3.2 Forecasting

5.3.2.1. Weather forecasting

Outcomes
A weather forecasting method was developed and successfully validated which is using low-quality sensors data, notably Netatmo stations, already deployed in order to increase the 24-hours ahead NWP-based forecast accuracy of electric power demand.
Innovation

The novelty of the proposed method relies on the use of the Netatmo stations[155], which are already deployed, to correct the spatially coarse prediction of a widely used weather forecasting methodology such as NWP. This is done on a computational efficient way allowing its wide applicability.

Impact of innovation

The proposed technique can be used by DSOs, energy retailers, balance responsible parties to increase the accuracy of the forecasted consumption of a group of end users. The technique, which relies on the use of low-quality sensors, highlights the possibility of using incomplete and corrupted data to achieve lower forecasting errors for energy demand.

5.3.2.2. Consumption forecasting

Outcome

By comparing various forecasters in terms of performance in predicting 24 hours ahead power consumption and production, a forecaster was identified that is embeddable in a smart meter, due to the low computation time, and has an acceptable level of accuracy. Furthermore, a model was identified that has a high level of accuracy when predicting aggregated power profiles. A distributed algorithm is proposed to perform hierarchical reconciliation of power forecasts, which can be used to preserve the users' privacy while obtaining sum-consistent forecasts.

Innovation

Much research in the past decades focuses on the reduction of MPC computational time, mainly due to the need of performing real-time control on embedded platforms. The explicit MPC formulation, which relies on multiparametric programming, has gained a lot of popularity for real-time control. However, this method can become infeasible for a high number of states and control horizons.[156] The novelty of the proposed solution lies in the investigation of the possibility of reducing the computational burden by means of considering non-uniform step-size control problems, in which disturbances (the predicted power production/generation) are mediated over increasingly large timesteps.

Impact of innovation

The proposed method allows the integration of electrical consumption/production forecast in distributed agents facilitating the implementation of distributed control techniques. This ensures inexpensive, timely, secure, and efficient control of power network assets and grid operation.

5.3.3 BESS Control of the grid for self-consumption and grid purposes

5.3.3.1. *Forecast- and communication-based control algorithms*

Outcomes

The role of the power generation and consumption forecasting methods on the financial performance of the energy communities was demonstrated. Also, the performance of forecasting-based control algorithms was evaluated in Chapelle and the financial benefits compared with the grid refurbishment.

Innovation

Accuracy of forecasters is not usually compared in closed-loop control, but rather in open-loop through KPIs on the prediction accuracy. In this deliverable, we performed a closed-loop comparison through different coordination and remuneration schemes. Forecasters were selected among different parametric and non-parametric models which already proved to deliver good results in the energy demand and production prediction tasks.

Impact of innovation

Financial performance is the main go/no-go criteria for the deployment of EC and more general DSM. The proposed solution facilitates such deployment by increasing the financial performance of those solutions. Currently, such solution can be applied at pilot projects since the legal framework does not allow yet the implementation of these ECs.

5.3.3.2. Grid measurements- based LV grid control using flexibilities of grid and home batteries and PV inverters (without weather forecasting)

Outcomes
This activity resulted to the development and validation of a real-time control algorithm which is based on grid-measurements to forecast the loads and generations.
Innovation
The novelty of the proposed solution is the utilization of the grid-measurements for the forecasting instead of weather forecasting which is normally used.
Impact of innovation
This approach enables the utilization of one infrastructure, namely the grid monitoring one, for various purposes from forecasting of loads and generations to the evaluation of the voltages and power flows, and determination of the optimal set-points of the flexible resources. Such a grid monitoring system can be integrated into the SCADA of the DSO to streamline the process.

5.3.3.3. Ageing-aware BESS control framework

Outcomes
The key outcome of this activity is the demonstration of the advantages of considering ageing factors on the BESS control algorithm.
Innovation
The novelty of the proposed method relies on the utilization of an algorithm that takes into consideration various ageing factors of the BESS. Also, the proposed solution achieved good performance in controlling the BESS without the need of grid measurements or weather forecasting.
Impact of innovation
The proposed method enables the deployment of a BESS without any additional cost associated to a further need for observability of the grid and facilitates the increase of the BESS profitability by providing multiple services simultaneously. This approach has already been integrated in the regular businesses of Romande Energie.

5.3.3.4. COMMELEC-based BESS control (EPFL-LCA2)

Outcome
The main outcome of this activity is the validation of the COMMELEC framework in the control of the BESS in Chapelle. The shadow agents were able to correctly forecast the interval in which the next measurements would fall while using limited CPU and memory.
Novelty
The algorithm predicts well for this time interval and has a very low-performance overhead in terms of CPU and memory usage. The proposed solution is better than most state-of-the-art methods and a publication is under-way.
Impact of innovation
The COMMELEC framework enables the control of network assets while exchanging a limited amount of information with the central server. This enables the safe operation of the grid in a timely and inexpensive manner.

5.3.4 BESS applications

Outcomes
The key outcomes of this set of activities include (a) the identification of the BESS ageing factors to be included in the BESS control models, (b) the validation of these factors by comparing an ageing-aware control with a “standard” control, (c) the validation of two different BESS control strategies, based on the timeframe during the day of self-consumption maximisation, and (d) the demonstration of the advantages of coordinating two BESS in VPPs for the provision of multiple services. It was demonstrated that in short terms the no consideration of ageing factors may support self-consumption but an ageing-aware BESS control pays-off in the long term by increasing the lifespan of the BESS. Also, the control strategy of postponing of the self-consumption even after 10 p.m. can increase significantly the CO_2 savings. The coordination of

multiple BESS in a VPP, can have multiple benefits such as increase self-consumption and avoidance of peak rejection.

Innovation

The main novelty of the proposed activities is the integration of ageing factors in the BESS control increasing the profitability of the BESS. It quantifies the losses due to the ageing preservation strategy versus the earnings in terms of a longer BESS utilization as well as the CO_2 footprint of different control strategies.

Impact of Innovation

This work enables BESS owners to properly operate their battery based on their own specific objectives. These can be maximization of self-consumption, revenue, CO2 avoidance and/or life span of their asset. These applications have already been integrated in the regular businesses of Romande Energie.

5.3.5 Protection of electrical infrastructure from cyber-attacks

Outcomes

The key outcome of this activity is the development of recommendations for the improvement of the security in (a) DSM communication (store/retrieve data and send commands) and (b) the entire power system. The former was very specific for the GridEye system implemented in Chapelle while the latter resulted in a method to mitigate targeted attacks by determining their intention, namely introduction of permissions for applications.

Innovation

Current anti-malware systems leverage various methods for malware detection. These include recognizing signatures, behavior analysis, machine learning, and many more. However, they all rely on previously learned and observed data and patterns. Therefore, their protection against new and future attacks is limited as attack signatures can be obfuscated with small changes. The developed solution takes a proactive approach by making actions a software may executes subject to authorization. This enables us to detect new and future attacks

Impact of innovation

Our approach for protecting computers impacts mainly well-managed, standardized IT environments which are mainly found in high secure environments. The approach assists in protecting highly sensitive data and critical resources such as electrical grids from malicious intentions. This is achieved by monitoring application activity and detecting malicious actions on computers using this data. Infected computers can be automatically isolated from the network to avoid malware from spreading further.

5.3.6 Congestion management with the use of SOP

Outcomes

The outcome of this activity involves the development of a SOP with a power of 50 kVA, definition of its control mode, assessment of its impact on the grid and validation its performance in Chapelle. The initial operational evidence is that the SOP can contribute to improving the performance of a low voltage network with distributed generation.

Innovation

The Soft-open point has been described previously as a device that can help to increase a distribution grid's hosting capability for renewable power producers. An initial prototype of 15 kVA has been successfully tested in a laboratory environment. In this activity, the device is brought to the distribution network, which implies two novel challenges which were addressed: (a) the SOP must be fit for continued autonomous operation and have a power of 50 kVA and (b) the SOP must be integrated into the protection of the existing network, provide its own back-up communication and control system and be integrated into the DSO's daily operation.

Impact of innovation

The SOP has great potentials in addressing challenges associated with high penetration of renewable energy sources in the distribution system on a fast and flexible but still solid way, particularly at the MV level.

5.4 Technology perspective - Rolle demo site

5.4.1 Grid monitoring

5.4.1.1. MV monitoring and fault location

Outcomes

A novel fault location method was experimentally validated in a real MV grid enabling the fast detection and location of the earth faults (few seconds) and short-circuits (less than a second). The method was validated in three different cases with always high performance.

Innovation

The main novelties of SynchroGuard approach include (a) a centralized and coordinated method for fault detection, (b) automated computation of fault location, (c) identification of all types of faults, and (d) easy installation of infrastructure based only on current sensors and 1 voltage sensor along the feeder.

Impact of innovation

This fault location method allows DSO operators to repair the fault before it evolves in a more severe short-circuit (in this case it evolved in a phase-to-phase fault of 4 kA), thus preventing an unplanned outage and larger damages to the grid equipment. Also, it decreases the fault location time from 1h07m to a few seconds, thus significantly decreasing the total outage time. It avoids several unsuccessful reclose attempts such as switching maneuvers which are a typical practice used for fault search), which stress all grid components, cause multiple service interruptions for customers and threaten the safety of the operators.

5.4.1.2. Smart meters valorisation for grid purposes, the case of state estimation

Outcomes

The main outcome of this activity is the validation of a method that combines measurements from smart meters and grid monitoring devices, i.e., GridEye, in order to run a 10-minutes state estimation.

Innovation

The typical method of state estimation consists of a non-linear weighted least-square optimization, where a linearization process is necessary. At this linearized point, a Newton-Raphson procedure produces outcomes, which depend on the pre-set convergence criteria. Thus, the iterative procedure is not only computationally costly, but also potentially non-converging. This work presents an alternative method for state estimation, where the outcome is produced linearly, requiring the measurements that are already available.

Impact of innovation

The proposed method enables the valorisation of measurement from smart meters, which are already under deployment in Switzerland, for state estimation of the grid. This increases the visibility of the DSO on their grid without requiring major investments for grid monitoring devices.

5.4.1.3. MV waveform estimation using LV measurement

Outcomes

The main outcomes of this activity are the demonstration of the potential of (a) a digital twin of transformer for the monitoring of the distribution systems at high time granularity, and (b) of the waveform monitoring for the determination of the power quality at MV and LV as well as the system behaviour under fault, since it captures all harmonics content.

Innovation

The novelty of the proposes solution is a combination of two characteristics, namely (a) the use of LV measurement units for the waveform monitoring and (b) the use of a digital twin of the transformer for grid monitoring purposes.

Impact of innovation

The proposed monitoring infrastructure solution is less invasive, requiring the MV network interruption under fewer circumstances, and less costly than a MV infrastructure. This enables a seamless deployment of the solution without affecting the final customers. The use of a digital twin can further lower these interruptions avoiding unnecessary trials. Indeed, the developed digital twin model of transformer enables the technical personnel and system operator to assess immediately any remedial actions to system events. Furthermore, this solution enabled the development of another solution, namely the fault location at the MV-level based on LV measurements.

5.4.2 Current and future grid operational limits and operation bottlenecks

Outcome

The main outcome of this activity is an integrated approach for the elaboration of alternative scenarios for the future grid evolution and assessment of the grid operation bottleneck.

Innovation

The novelty of this methodology lies on the bottom-up approach, considering the optimal design and schedule of every building energy system within the study area, as well as heat cascading and network constraints. Furthermore, once the building energy system has been optimally defined, its impact on the grid is analysed using a state-of-the art power flow algorithm. At the same time, clustering approaches are effectively implemented to minimise the computational burden.

Impact of innovation

The bottom-up approach of the proposed methodology enables decision makers to evaluate the impact of their decision, for instance of promotion of a specific renewable energy technology in a specific area. This function renders the tool valuable for decision making for authorities and utilities.

5.4.3 Load shifting potential and possible ancillary services

Outcome

The main outcome of this activity is a methodological framework to assess the different kind of flexibilities, namely behavior, technical and operational. For the demo site, these results showed that flexibility is difficult to obtain from the households simply by providing financial incentives.

Furthermore, it exposes how advanced grid tariffs can influence the energy system design and operation to decrease stress induced by high PV penetration on the grid.

Innovation

In the frame of this activity, a novel method has been developed to evaluate the potential of photovoltaic (PV) panel considering the roof availability and orientation of the thousands of roofs found at the city scale, non-flat roofs have been clustered according to their orientation. Each roof is associated with a set of PV generation profiles and corresponding cost and footprint.[157] Also, a new metric has been introduced allowing to compare the load shifting potential at the supply side, demand-side, technical level, and operational level. The load shifting potential has been expressed as an equivalent “virtual storage capacity” representing the difference between the initial load and the shifted load.[158]

Furthermore, the novelty of the proposed building to district and district to grid approaches lies in the ability to generate a wide range of optimal energy transition scenarios using multi-objective optimization techniques both at building and district level. The proposed approach differs from previous work by integrating ancillary services by optimizing simultaneously both sizing and operation of the district energy technologies.

Impact of innovation

This activity provides the methodological framework that enables a detailed assessment of the PV potentials and the estimation of the amount of flexibility that can be shifted. This information is required by the authorities and other energy actors to take informed decision while defining incentives for the promotion of renewable energy solutions and valorization of flexibility.

Moreover, the assessment on the impact of advanced electricity tariffs on the energy system design and operation can support DSO to develop dynamic grid tariffs that are correctly structured based on the power. This will allow both DSO and other energy actors to develop new business models that enable a high PV grid penetration.

5.4.4 Optimal deployment of PV and storage systems, EVs and heat pumps

5.4.4.1. Deployment recommendation for large penetration of PV and distributed storage

Outcome

The main outcome of this activity is that even with a high PV penetration, an appropriate operation regulation can be used to ensure a safe grid operation without grid reinforcement. This operation regulation imposes to each system to harvest the flexibility provided by the battery and PV curtailment to limit their feed-in power below a given level. This flexibility, while beneficial for the grid operator, has a cost for the prosumers, and this cost can be particularly high if the system designs don't consider the introduction of such operation constraint. Furthermore, it was shown that by ensuring a constant revenue for the DSO through a progressive increase of the retail tariff, a path toward high PV penetration in distribution grids is feasible.

Innovation

The proposed solution is original in two folds, (a) it investigates the financial burden of operational constraints that would limit the usage of the grid, (b) the long-term planning highlights how it is possible to reach almost a full PV hosting without having to replace the current transformer and also highlights how the retail electricity price should evolve to maintain the revenue of the DSO.

Impact of innovation

Main user of the solution/results are DSOs as well as public authorities which oversee the development of the energy legal framework. Furthermore, future owners of PV+battery systems could benefit from those outcomes in order to make their investment decision. Following this project, Romande Energie extended the collaboration with the academic partner (EPFL-PVlab) in order to define the evolution of the possible grid tariffs.

5.4.4.2. Models for the optimization of grid penetration of smart controllable batteries in different grid topologies (the case of EVs)

Outcome

This activity results in a simulation tool for the assessment of the impact of different penetration scenarios of PV generation, electric heating via heat pumps, and electric mobility on grid stability.

Innovation

The proposed methodology allows testing the effectiveness of specific DSM solutions (possibly combined with local storage) under various scenarios. Such a procedure can be used to evaluate the effectiveness of a smart DSM with different control algorithms from a techno-economic point of view in multiple situations.

Impact of innovation

Careful planning for the use of technologies such as smart meters, storage, and demand-side management systems has enormous potential to facilitate the transition to an energy system less dependent on non-renewable sources. The proposed solution enables the active management of the electricity distribution grid allowing to minimize the costs generated by the massive introduction of PV production, electrification of heating systems, and the advent of electric mobility.

5.4.4.3. Definition of optimal control of DHW for self-consumption strategies

Outcome

In this work, a novel heuristic control algorithm was presented for HPs. The algorithm optimizes an indicator comparing the variation of the operating cost and the generated heat. It is versatile and agnostic of the building modeling complexity. The benchmark against a mixed-integer linear formulation of the energy management shows that the proposed algorithm performs closely to the optimal solution. The differences in terms of operating costs and temperature deviations are negligible. The simplicity of the algorithm makes it suitable for implementing in a micro-controller as a state machine.

Innovation

The proposed algorithm extends the basic formulation of previous work of the group[159] to encompass the control algorithm around a single indicator. The indicator puts in relation a possible action (like increasing the electricity fed to a HP), the corresponding gain in operating expense, and the heat production gain. The proposed HCA evaluates this indicator as often as needed and chooses the action which minimizes this indicator. Such an approach is novel because it doesn't require any parameters tuning and achieve the close-to-optimal control
trajectory.

Impact of innovation

Starting from the building model formulation and the control problem, this work can very rapidly turn into a real product and be implemented into HP control hardware. The current Swiss market suffers from a lack of such products.

5.4.5 Socio-economic methods and business tools

5.4.5.1. Development of a platform for business models evaluation

Outcome

The key outcome of this activity is a novel simulation approach to assess the dynamics of the long-term value creation of decentral flexibility business models.

Innovation

In contrast to previous research, the simulation platform enables the assessment of different business cases for decentral flexibility, linking multiple aspects of value creation (customer participation in the business model, valorization of flexibility, design, and definition of the compensation for providing flexibility). With its focus on the long-term business dynamics of the flexibility aggregator business models, the TREES model also contributes to advancing the state-of-art in the international academic literature on flexibility aggregator businesses.

Impact of innovation

The flexibility business case analysis helps the energy actors to identify most promising socio-technical configuration for the deployment of decentral flexibilities (house batteries or district batteries), smart grid approaches and storage. Hence it provides the DSOs with decision support on how to design the business model and where to invest in new smart grid and storage technologies. This work complements the activities undertaken by the other project partners on the techno-economic aspects of those solutions (see 4.4.3 and 4.4.4). Furthermore, it provides the policymakers with recommendations on how to unleash the flexibility valorization through regulation adaptation.

5.4.5.2. Energy Community of Rolle

Outcome

The main outcome of this activity is that under current conditions the flexibility can be valorised only with the control of the storage systems. The controllability of other technologies, such as HP, and electric heaters and boilers, present technical or economic barriers. Also, technical and legal reasons enhance the use of smart meter data for any flexibilization purpose.

Innovation

The novelty of the proposed approach lies in the fact that the energy community was operating under real conditions. This means that both technical feasibility and economic viability were considered in the various proposed business models. Indeed, most of the Energy communities studied are based on substitutions and economic support of the devices and therefore are not scalable.

Impact of innovation

This activity enabled Romande Energie to draw some key conclusions for the corporate strategy related to the flexibility valorization.

5.4.6 Guidelines and recommendations for various stakeholders.

5.4.6.1. Best investment strategies when prosumer capacities are increased in the grid (IPESE)

Outcomes

Best investment strategies have been proposed following four different approaches:

- selection of a reduced set of indicators to manage the energy transition and elaborate relevant communication on the strategic investment decisions;
- development of decentralized multi-energy infrastructure leveraging on the presence of on-site big energy prosumers;
- optimisation of the energy flows at district scale with a grid-aware perspective. This typically include coordinated investment in layout of PV panels in roofs and façade of energy autonomous districts;
- investment in the digitalisation of smart grid. This include, for example, the development of energy-backed cryptocurrencies and smart-contract technologies to boost the energy transition with new decentralized energy markets.

Innovation
The proposed solution has three key innovation aspects:
a) The correlation between more than thirty indicators is undertaken, allowing to better understand the trends in the emergence of decentralized urban energy systems (UES).
b) A multi-period MILP formulation is integrated in the proposed method to generate long-term investment planning scenarios.
c) The contribution of PV panels' layout to the investment planning is modeled in more details than existing work, including a more accurate solar irradiation model and the shading effect among panels. Also, the interaction between the PV panels and the remaining units of the BES, including the effects of optimal scheduling is considered.
Impact of innovation
This activity provides energy planers with clear guidelines on what they should take into consideration (and what known) when they undertake the design of an urban energy system. These guidelines are applicable by the authorities when they plan the cantonal or communal energy plan and design incentives as well as the DSO while they plan new business models.

5.4.6.2. Performance of the implemented solutions with guidelines for subsequent implementation

Outcome
This activity provides the decision makers with a tool for evidence-based decisions related to the technological solutions that they should promote to achieve their energy target, whether this is climate neutrality or self-sufficiency.
Innovation
Compared to the existing literature in the field, the proposed approach combines advanced modelling of the energy generation potential from PV panels with a detailed representation of the district energy systems, down to the system of each individual building, thus allowing an accurate representation of the interaction between the energy generation from PV and the rest of the system.
Impact of innovation
The methodology itself is flexible enough to provide tailored made recommendations for any study area, considering that the required input data for the method will be provided. The high level of detailed modeling enables an accurate simulation of the impact of an energy-related decision and adjustment accordingly if needed.

6 Outlook and next steps

The REeL demo project meant building a permanent research platform that will continue existing beyond the end of the project. Indeed, these
At the Rolle demo site, 3 follow-up projects are already in place namely:

- KnowlEDGE – Decentralized, secure, and privacy-protecting AI to improve grid reliability, resilience, and cost performance for DSOs (SFOE R&D Grids, SI/502076, 01.09.2020-31.08.2022): To improve grid reliability, resilience and cost performance, energy companies increasingly rely on AI and other data science techniques to process large amounts of aggregated data. Typically, aggregation means centralizing customer data to train algorithms at significant time and cost while introducing security and privacy risks. KnowlEDGE investigates the advantages of using a distributed (federated) analysis strategy to secure value from industrial, commercial, and residential smart meter data in multiple locations, in particular targeting DSO use cases, and will investigate the feasibility of conducting analysis of data at the grid edge. KnowlEDGE includes the development of federated analytics algorithms, application to smart meter data, and testing on meter infrastructure in the laboratory and in the field. The project will establish that accessing / analysing data in its source locations at the grid edge provides time, cost, security, and privacy benefits using a phased series of proof of grid-edge concept implementations.

- TwinDiGrid: A digital twin grid insight platform for agile digitalization of distribution grids (Innosuisse, 57800.1 IP-EE, 15.01.2022-15.07.2023): In this project, the aim is to design and implement a Grid Insight Platform composed of a data-driven and real-time digital twin of distribution grids linked to an easy-to-develop-and demonstrate environment. It allows to efficiently generate insights and business values from grid federated and trusted data.
- AISOP – AI-assisted grid situational awareness and operational planning (SFOE R&D Grids in the frame of the ERA-Net, SI/502314, 01.11.2021-28.02.2025): AISOP aims to create an AI-assisted decision support system for the electric distribution system operators (DSOs) to drive decarbonisation that is underpinned by advanced digital technology. The decision-support system securely and privately acquires, processes, interprets, and exploits data for the benefit of DSO operational planning. In this context, AISOP expands data-driven techniques for improved operational planning in distribution/local grids with high shares of DERs by integrating AI/ML-based solutions, enhanced situational awareness and market incentives. Within the proposed project we combine (i) data access and ingestion (ii) distribution grid situational awareness, (iii)decision-support for distribution grid management (iv) dynamic tariffs, (v) digital platform integration with exploitation through test and training environments. The developed solutions will be disseminated within EXPERA and validated using the three demo-sites and living labs in CH, DE and DK.

At the Aigle demo site, 2 follow-up project is already in place, namely:

- MESH4U – Optimal integration of electric vehicles fast charging stations into medium voltage power distribution grids (SFOE P&D Grids in the frame of the ERA-NET, SI/502045, 01.12.2020-30.05.2024): The demonstration project relies on a unique field test site to carry-out research in the domain of control and coordination of renewables-fed medium-voltage power distribution grids. The controllability of the available units, i.e., a MW-class battery storage system and two EV fast charging stations of 150kW each connected to a 20kV grid hosting non-controllable multi-MW PV and small hydropower plants, allow for the provision of power system services and therefore is expected to play a central role in the DSO-TSO2 coordination. More specifically, these services refer to dispatchability of the aggregated local resources (with particular reference to the stochastic ones), primary/secondary frequency regulation and reactive power support to the upstream power grid, local grid voltage control and line congestion management. The provision of these services will consider the real-time status of the grid provided by an already-deployed PMU-based state estimator along with the status and the operational constraints of the controllable resources.
- UrbanTwin (ETH Board Join Initiative, 01.01.2023-31.12.2026): UrbanTwin aims at developing and validating an integrated tool to support decision-makers in achieving goals such as the Swiss Energy Strategy 2050 and the vision of climate-adaptive “sponge cities” in Switzerland. This tool involves a detailed model of critical urban infrastructure, such as energy, water, buildings, and mobility, as well as underlying socio-economic and environmental drivers and their inter-dependencies. The aim is to combine, in a holistic fashion, climate change’s underlying drivers and multi-sectoral data acquisition from critical urban infrastructure to create a multi-scale digital twin running on a large-scale IT infrastructure. This digital twin will enable the analysis of data and monitoring of urban systems to probe the effectiveness of potential solutions, head off problems before they even occur, prevent downtime, as well as develop new opportunities and planning strategies for the future. Based on an in-depth exploration of co-design of IT infrastructure to execute efficiently advanced numerical models, and using real-time field data, this new digital twin technology will reveal complex patterns of optimization for the highly complex urban realm.

At the Chapelle demo site, the monitoring and battery control activities will be maintained for an undefined duration and will be self-financed by the involved partners.

7 National and international cooperation

In the frame of the project, several national and international collaborations took place. Given the number of partners, activities, and outcomes of the projects, numerous collaborations were triggered. Some selected collaborations are presented below along with the benefits for the project and the partners.

7.1 National cooperation

The REeL Demo has facilitated collaboration among academics and various power grid stakeholders, including DSO (Romande Energie), TSO (Swissgrid), local authorities (communities of Rolle, Mont-sur-Rolle and Aigle), cantonal authorities (Canton de Vaud), technology providers (Leclanché, EATON, Zaphiro Technologies, DEPsys and GridSteer), and service providers (Aurora's technologies).

Collaborations with the national authorities in Rolle and Mont-sur-Rolle have enabled access to the end-customers. The energy community established during the previous monitoring period continued its activities on engaging the customers to the energy-transition through awareness raising. Concretely, three activities were launched, namely: (a) on the analysis of the carbon footprint; (b) on the community-owned PV plants (jardin solaire); and (c) on the measurement of the power consumption. The activities were supported by events, communication materials, competitions and surveys. These activities are coordinated through the platform https://projetreel.ch/le-projet/. A more detailed description is presented in the Deliverable 5f(New)-Energy community activities at the Rolle demo site.

Collaboration with the industry have multiple benefits for both academic and industrial project partners. During this monitoring period, these collaborations have enabled:

- Knowledge and technology transfer: Companies provide the academic partners with valuable information and get innovation solutions for addressing their needs. During this monitoring period, the close collaboration between Romande Energie and academic partners along with authorities has enable for instance the refining of the models related to the multi-energy grids and increase of their accuracy. Furthermore, information on the accessibility of the DSM solutions has enabled academic partners to focus their research activities to specific flexible loads.
- Access to facilities: The testing in real-conditions is a valuable step of technology evolution towards commercialisation. During this monitoring period, academic partner were able to use the real grid of Romande Energie, and associated expertise of companies technical staff, for the implantation and validation of innovative solutions, such as PMUs, DSM approaches, BESS-based control strategies, all-sky camera based forecasting, Soft open Point devices.
- Data and information: Companies provide data and information to the academic partner that can be used to calibrate and validate their models and provide companies with valuable recommendations. This is the case of Romande Energie and DEPsys that provided academic partners with grid monitoring data in order to advance DSM and multi-energy grid activities as well as BESS sizing and siting and grid planning for PMU installation. Two servers have been finalised during this monitoring period in order to serve this purpose. The central project server located at the Data center of Romande Energie and the Aigle BESS server located in Aigle.
- Commercialization of products: Collaboration among partners can concern the exploitation of a patent or a licence or improvement of a product. This is the case for the start-ups involved in the project, namely Zaphiro Technologies, DEPsys, GridSteer and Aurora's technologies. During this monitoring period, they have finalised the installation of equipment and started providing academic partners with measurements in the case of Zaphiro and DEPsys or implementing their case. This experiment enables them to develop a show-case; and improve the solutions. For instance, the lessons learned from the PMU's installation in Rolle have been already integrated in the solution implemented in Aigle during this monitoring period, in terms of solutions cost, technical characteristics and installation easiness.

Collaboration among academics have been strengthened and trust among partners has been established. During this monitoring period, these collaborations have enabled:

- Data, information and software exchange: Data and information are valuable for the validation of the power grid solutions but not always available or accessible. Raising awareness on the availability of and facilitating exchange of data among partners can contribute to facilitate the implementation of research activities and improve their efficiency. In the frame of REeL demo a common IT infrastructure has been developed where partner can access the data of all the other research groups. Therefore, partners working on real-time monitoring can access grid topologies provided by the DSO; those working on control strategies can access load data from monitoring devices; partners working on the development of the Soft-open-point solutions can access measurement data from PMU, and the DSO can combine building data with its own data for the identification of the most interesting customers for demand side management activities.

- Human resources transfer: Transfer of personnel among groups has been proven as a sustainable mean of knowledge transfer and strengthening links among groups. During the monitoring period year, the expert transferred from EPFL-PWRS to HES-SO VD as advisor for building lab infrastructure received a Professor position enabling the continuation of his activities initiated in the frame of the demo.
- Attractiveness for the industry: The REeL demo is unique of its kind. Therefore, partners have reported that this has enable the attractiveness of both national and international visibility and securing of additional projects.
- Access to companies in other (linguistic) parts of Switzerland: Academics are coming from 3 different linguistic areas of Switzerland in a market where the proximity is a driving force for collaborations, according to the KTT analysis of SCCER-FURIES. Partners have reported the expansion of their activities to other linguistic parts of Switzerland as a benefit of this year too. Indeed, the analysis of the collaborations in the frame of FURIES has pointed out the tendency of industrial partners to collaborate with academic groups that are close to their area. This is the case even though the proximity doesn't always guarantee the most appropriate capabilities for addressing their industrial needs. SCCER-FURIES has enabled to transfer capabilities along the country.

7.2 International cooperation

At the international level, the REeL demo project partners disseminate the project results through their participation in related international project, presentation in international conferences and publication to peer-review international journals.
While publications are mentioned on the following section, the key international cooperation in the frame of projects are mentioned below:

- ERA-NET MESH4U (2020-2023): This international project brings together partners from Italy, Poland, Germany and Switzerland. The swiss part is valorizing the infrastructure developed in the frame of the REeL demo project particularly at the Aigle demo site. It aims to investigate and enhance the grid operation of a renewable-supplied power distribution grid in the presence of MW-class battery storage and electric vehicle (EV) charging stations for multiple objectives by using their controllable power electronics converters.
- ERIgrid Research Infrastructure (Horizon 2020 Research and Innovation Program): Cooperation between Dr. Karimi (EPFL-LA) and SINTEF Energy Research in Trondheim, Norway on the validation of the dynamic grid model for distributed controller strategy. The results are published in the publication Convex Optimization-based Control Design for Parallel Grid-Connected Inverters, C. Kammer, S. D'Arco, A. G. Endegnanew and A. Karimi, in IEEE Transactions on Power Electronics, 34(7): 6048–6061, July 2019. Furthermore the results were presented at the IEEE Conference in Decision and Control, Nice, France, 2019 under the title Data-Driven Distributed Reactive Power Sharing in Microgrids, S. S. Madani and A. Karimi, IEEE 58th Conference on Decision and Control (CDC), Nice, France, 2019, pp. 7512-7517, , https://doi.org/10.1109/CDC40024.2019.9029506, 2019.
- H2020 Osmose: This €28M project aims to develop flexibilities required to enable the Energy transition to high share of Renewable Energy Sources by capturing synergies across needs and sources of flexibility. Therefore, it brings together 33 partners, notably 6 European TSOs. The activities related to the BESS operations of the REeL demo are validated in the frame of this project too. Knowledge is shared among partners of these two projects. Indeed, the experience achieved on advanced large-scale BESS control capabilities for power grid service provision in occasion of the H2020 EU project Osmose cooperation within its WP3 with the French transmission system operator RSE and the Spanish power

converters manufacturer Ingeteam was extremely beneficial for the outline of the technical requirements and the evaluation of the offers.

Bilateral collaborations were also established between REeL partners and foreign institutes notably:

- EPFL-PWRS and the Norwegian University of Science and Technology (NTNU) on the Aggregator bidding in DSO flexibility markets considering battery degradation in collaboration
- SUPSI and MINES ParisTech on hierarchical forecasting.
- HEIG-VD and Genova University on the SoP.

Regarding the events where REeL results were presented, the most important are the following:

- SCCER-FURIES special session at the 21st European Conference on Power Electronics and Applications (EPE'19 ECCE Europe): In the frame of this session hold in Genova between 3 and 6 September 2019, SOP related activities were presented to the international community in a well-attended session.
- SCCER-FURIES special session at the International Symposium on Power Electronics, Electrical Drives, Automation and Motion (SPEEDAM): In the frame of this session hold virtually between 24 and 26 of June 2020, SOP related activities were presented to the international community.
- Power Systems Computation Conference (PSCC) : The PSCC is one of the most outstanding events in the power systems area. Between 29 of June and 3 of July 2020, 8 presentations have been presented with results related to the REeL demo namely.
- SWISS - INDIA Smart Grid Roundtable at India smart utility week 2020: Prof. Dr. P. Favre-Perrod gave an invited speech to this event that took place between 3 and 7 of March 2020 in New Delhi. He presented among others results from the demonstration activities in the REEL project, notably on smart metering and the soft open point.
- CIRED workshop 2020: The GridEye measurements and distribution grid model in REeL demo project are used in the context of the project of a Marie Curie Individual Fellowship hosted at DEPsys. The results of the work are accepted to be presented in CIRED workshop 2020 in Berlin under the title of "Grid monitoring for efficient flexibility provision in distribution grids".

The main benefits of the partners from such collaborations are the following:

- Knowledge and technology transfer: While the REeL project is mainly focusing on the challenges rising from the Swiss energy transition, the scientific relevance of the developed solutions requires a global consideration of the state-of-art. Collaborations with international partners enable to access capabilities that are not always available in the country.
- Validation of results: Collaboration with international partners enables access to new infrastructures and data for valorization and ensures replicability of innovative solutions. This allows the control of the replicability of the results of the REeL project and benchmarking of the performance of the developed solutions. During this monitoring period, this was the case for an international project that partners were involved to such as the H2020 Osmose.
- Visibility: International collaborations enable impactful dissemination of the REeL's results too. This has been enabled through participation in SCCER-FURIES special sessions and high-impact events.

8 Communication

The communication activities undertaken in the frame of the project were mainly related to the Aigle and Rolle demo site.

Communication activities in Aigle were mostly passive, aiming at raising awareness of the local community on the innovative activities undertaken on site. Those activities were organized together with the local authorities. An information panel was installed on the top of the BESS with key information about the project, as well as logos of the involved partners and the funding agent.

In Rolle, communication activities were more active aiming at engaging the local community to the project. Indeed, inputs of the residents of the demo area were required to assess the willing of the general public to be actively involved in the energy transition. Communication activities include the development of branding for the energy community, development and maintenance of a new website (https://projetreel.ch/le-projet/), organization of workshops and development of communication materials. The activities are described in the Deliverable 5f(New)-Energy community activities at the Rolle demo site.

9 Publications

9.1 Aigle demo site

9.1.1 PMU-based situation awareness for MV networks

A. Derviskadic, P. Romano, M. Pignati and M. Paolone. Architecture and Experimental Validation of a Low-Latency Phasor Data Concentrator, in IEEE Transactions on Smart Grids, vol. -, num. -, p. 1-10, 2017.

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A. Derviskadic, P. Romano and M. Paolone. Iterative-interpolated DFT for Synchrophasor Estimation in M-class Compliant PMUs. 2017 IEEE PES PowerTech, Manchester, UK, June 18-22, 2017.

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F. Mahmood, L. Vanfretti , M. Pignati , H. Hooshyar , F.Sossan and M. Paolone (2018) Experimental Validation of a Steady State Model Synthesis Method for a Three-Phase Unbalanced Active Distribution Network Feeder[in] IEEE Access, 6, pp. 4042-4053.

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G. Frigo, A. Derviskadic, Y. Zuo and M. Paolone. (2019) PMU-Based ROCOF Measurements: Uncertainty Limits and Metrological Significance in Power System Applications, in IEEE Transactions on Instrumentation and Measurement, p. 1-13, 2019-03-27.

G. Frigo, A. Derviskadic, D. Colangelo, J.-P. Braun and M. Paolone. (2019) Characterization of Uncertainty Contributions in a High-Accuracy PMU Validation System, in Measurement, 2019-06-18.

A. Derviškadić, G. Frigo and M. Paolone. (2018) Impact of Time Dissemination Technologies on Synchrophasor Estimation Accuracy. IEEE International Conference on Smart Grid Synchronized Measurements and Analytics – SGSMA, Texas A&M University, College Station, Texas, USA, 2018.

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9.3.4.1. Best investment strategies when prosumer capacities are increased in the grid (IPESE)

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10 List of deliverables

10.1 Aigle demo site

Involved partners**	Title	Delivery date
EPFL-DESL	4a1-Study of targeted feeders' operational limits	12.2017
	4a2-Sizing and siting of a utility scale and distributed battery energy storage system	12.2017

	4c-Tools for multi time horizon PV point forecasting and prediction intervals	04.2020
	4a3-Operation of the battery storage systems for grid control, feeder dispatching-	03.2021
	2c-Simulation and experimental validation of linearized and exact convex optimal power flow methods using the feeder data (with the use of PMUs)	05.2022
	4d-Validation of an advanced control algorithms based on short-term forecasting of PV generation	05.2022
EPFL-DESL/ SUPSI	1d-Development of models for prosumers behaviour identification	06.2018
EPFL-DESL/ EPFL-LCA2	2b2-Successful response of the entire feeder with the use of COMMELEC agents	03.2021
	2b3-Successful deployment and impact measurement of COMMELEC-based control on MV	03.2021
	2overall-Compilation of real-time control strategies for heterogeneous resources at MV and LV	03.2021
EPFL-DESL/ EPFL-PWRS/ Swissgrid	4f1-Definition of Schemes and Needed Coordination for the Provision of Ancillary Services from Small Distributed Resources	11.2018
	4f2-System-wide modelling and optimization of ancillary services provision and system impact	02.2020
EPFL-PWRS/ Swissgrid	4f3-Validation of the Model On the Demonstrator- Optimal Scheduling and Control of Active Distribution Networks for Power Flexibility Provision at TSO-DSO Interface	09.2020
EPFL-LA	2a1-Experimental validation of voltage control of inverter interfaced grids in grid connected mode (with the use of BESS)	11.2018
	2a2-Identification and Validation of dynamic grid model for distributed controller strategy	03.2021
	2a3-Experimental validation of frequency and voltage control of inverter interfaced grids in islanded mode (with the use of BESS)	03.2021

10.2 Chapelle demo site

Involved partners	**Title**	**Delivery date**
DEPSys	1c-Validation of Model-Less Approach for Estimation of Sensitivity Coefficients	11.2019
	Extra_Final depsys report for REeL demo project	05.2022
EPFL-DESL / EPFL-LCA2	2b1-Successful communication and control of one DSM device with the use of Commelec agent in 1 feeder	11.2018
FHNW	3a2-First results of control of DSM Units by GridEye	12.2019
	3a4-Protection of infrastructure from cyberattacks	08.2020
SUPSI-ISAAC	3d1-Algorithms and models for the prediction of the day ahead energy demand of households and the distribution grid (24hours)	01.2019
	3d2-Improvement of numerical weather prediction at local scale using aggregated low-quality sensor data	06.2019
	3d3-Design and test of distributed DSM algorithms that use communication and new forecasting models	09.2020
	3Overall-Cross-site Comparison of the performance of different DSM strategies. Investigation of the possible conflicts (LIC and Chapelle-sur-Moudon) and sub-optimality issues	03.2021
	3b-Assessment of the performance of the decentralized battery control strategies, based on 1 year data	03.2022

	3f-Assessment of investment costs of controllable batteries and comparison with grid refurbishment	03.2022
Aurora's grid*	4b-Ageing Analysis of a BESS	01.2019
	4b3-First Industrial Validation of Energy Management for Multiple Applications EMMA 2.0	04.2021
	4b2-Life cycle management of the BESS	05.2021
	NEW-Green energy credits and virtual power plant battery connection	08.2022
HES-SO-VD/FR	6a1_Preliminary study for soft-open point deployment into REEL Demo	12.2017
	6a2_Design principle of soft-open point	12.2017
	6b-Laboratory test of Soft Open Point Prototype	06.2019
	6c1-Report on soft-open point deployment	09.2020
	6c2-Field test verification	03.2021

10.3 Rolle demo site

Involved partners	Title	Delivery date
Zaphiro Technologies *	1a-Asset monitoring study (topology, voltages, currents and flows) at 50 fps	02.2020
	1b-Experimental validation of the FLISR functionality	01.2022
FHNW	3a1-Communication specification GridEye and DSM	07.2018
DEPSys	3c_Validation of the use of voltage and frequency measurements of smart meters for grid control	12.2019
	3d4-Models for the optimization of grid penetration of smart controllable batteries in different grid topologies	03.2021
	Extra_Final depsys report for REeL demo project_Chapelle	05.2022
EPFL-PVLab	4e1-Determination of the flexibilisation potential of the electricity demand)	12.2018
	4e2-Deployment recommendation for large penetration of PV and distributed storage	04.2020
	5c-Definition of optimal control of DWH for self-consumption strategies	12.2020
EPFL-IPESE	5a-Best investment strategies when prosumer capacities are increased in the grid (new users, new PV installations, etc.)	02.2021
	5Overall-Performance of the implemented solutions with guidelines for subsequent implementation	03.2021
EPFL-IPESE EPFL-PVLab	5d1(New)-Development of Future District Scenarios and Definition of Modeling Cases	12.2017
	5b-Design of sizes for buildings energy systems as a function of the grid evolution	06.2018
	5d2(New)-Detailed evaluation of the grid operation bottlenecks and load shifting potential for the reference system	04.2019
	5d3(New)-A list of possible ancillary services for enhanced grid operation and implementation of the most effective ones at the REEL demo site	06.2020
ZHAW/Un. St.Gallen*	5e1(New)-Workshop's minutes on business cases	03.2018
	5e2(New)-Workshop's minutes on Dynamic business case development and Strategy experiments	07.2018
	5e3(New)-Documentation of the user interface for the simulation model	09.2019
Romande Energie	5f(New)-Energy community activities at the Rolle demo site	08.2022
	NEW Outcomes market-perspectives	10.2022

* Contracted by Project management team

** all deliverables were developed in collaboration with Romande Energie

11 References

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