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Final report of 24.03.2023

Distributed Micro Intelligent Storage (MSID)

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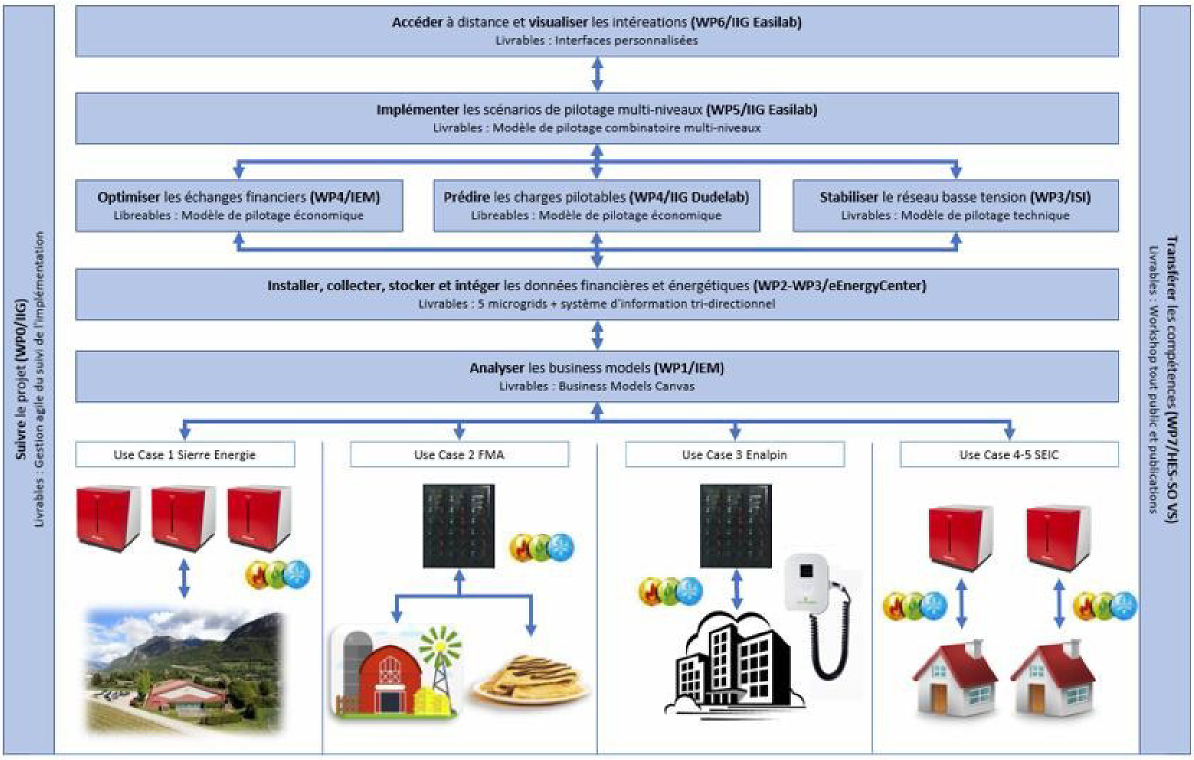

MSID

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Summary

In the context of a potential electricity shortage in the spring of 2023, the remote control of intelligent micro-distributed storage (MSID) is of increasing interest to distribution system operators (DSOs).

The SFOE MSID project brought together academic actors (HES-SO Valais-Wallis and Icare) and industrial actors (ElectrInfo, Enalpin, FMA, OIKEN, Seic-Télédis, Studer-Innotec) with the aim of solving two major problems caused by the injection of photovoltaic (PV) energy, which are the optimisation of self-consumption and the management of the grid voltage. Indeed, two DSOs are facing the first issue with different use-cases. As far as SEIC-Télédis is concerned, the issue of self-consumption is present at two sites - two private houses wanting to make use of local storage. Visp and Enalpin also have this problem, but for the station building where their premises are located.

Regarding the second issue addressed by the project, two sites of two different DSOs were used to carry out the demonstrations. In the case of FMA, it is an end-of-line farm located in Gryon in the canton of Vaud. The replacement of the diesel generator by PV needs to control the storage to stabilise the voltage. Finally, the last site is located in Sierre at the Pont-Chalais tennis court. The high production of the solar panels in the tennis hall causes voltage problems on the grid.

The OFEN MSID project has made it possible to respond to the various problems with the implementation of a Virtual Power Plant (VPP) platform and a control box. This device controls the various inverters (Xtender Next3, from Studer-Innotec, Victron, from Victron Energy, or IMEON, from IMEON Energy) in place on the various sites and collects as much useful data as possible generated by the devices in place (inverter, battery, heat pump, DHW, etc.). A VPP visualisation platform is made available to the DSOs and end customers in order to observe historical and actual data updated every 15 minutes. The VPP platform developed within the framework of the SFOE MSID project also offers the possibility of creating control algorithms. These algorithms are built with the help of the data collected but are also generated. The photovoltaic production prediction algorithms as well as the financial algorithms linked to the OFEN GBFlex market place are available and can be used in the creation of the control algorithm. These combinatorial strategies have allowed the optimisation of the intelligent control and thus allow a better management of the PV production and energy consumers on the sites.

The demonstrations presented in this final SFOE MSID report prove the efficiency of the system. On the self-consumption side, we tested the system in real conditions at our OFF-GRID development site before deploying it at partner sites. On the grid voltage stabilisation side, we demonstrated that in the event of a voltage surge, the system was ready to react in order to reduce the problem as much as possible by driving the batteries available in the project. All the tested and validated combinatorial strategies can be found in chapter 5 of this report.
In conclusion, this project has allowed us to aggregate and remotely control several sites with very different use cases but with common problems. With the demonstrators in place, we are able to prove the usefulness of setting up an intelligent system to control distributed micro-storage. Within the framework of the SFOE MSID project, six implementation sites have been created. The system is scalable and we estimate between 500 and 1000 sites in the current version of developments. The algorithm creation system already provides for actions in the event of a planned shortage to ensure maximum availability of storage before a period of 4 hours in autarkic mode for example.

Résumé

Le projet OFEN MSID a réuni des acteurs académiques (HES-SO Valais-Wallis et Icare) et les acteurs industriels (ElectrInfo, Enalpin, FMA, OIKEN, Seic-Télédis, Studer-Innotec) dans un but de résoudre deux problématiques majeures dues à l'injection de photovoltaïque (PV) qui sont l'optimisation de l'autoconsommation et la gestion de la tension réseau. En effet, deux GRDs font face à la première problématique avec des use-case différents. En ce qui concerne la SEIC-Télédis, la problématique d'autoconsommation est présente sur deux sites, deux maisons privées voulant valoriser le stockage local. Du côté de Viège, Enalpin a également cette problématique à gérer mais pour le bâtiment de la gare où se trouve leurs locaux.
Concernant la seconde problématique traitée par le projet, deux sites de deux GRDs différents ont permis de réaliser les démonstrations. Dans le cas de FMA, il s'agit d'une ferme en bout de ligne situé à Gryon dans le canton de Vaud. Le remplacement de la génératrice diesel par du PV nécessite de piloter le stockage pour stabiliser la tension. Pour terminer, le dernier site se situe à Sierre au tennis de Pont-Chalais. La production élevée des panneaux solaires de la halle de tennis pose des problèmes de tension sur le réseau.

Le projet OFEN MSID a permis de répondre aux différentes problématiques avec la mise en place d'une plateforme Virtual Power Plant (VPP) et d'un boitier de pilotage. Cet appareil pilote les différents onduleurs (Xtender Next3, de Studer-Innotec, Victron, de Victron Energy, ou IMEON, de IMEON Energy) en place sur les différents sites et récolte le plus de données utiles possibles générées par les appareils en place (onduleur, batterie, PAC, ECS, etc). Une plateforme VPP de visualisation est mise à disposition des GRDs et des clients finaux afin de pouvoir observer les données historiques et réelles mises à jour toutes les 15 minutes. La plateforme VPP développée dans le cadre du projet OFEN MSID offre également la possibilité de créer des algorithmes de pilotage. Ces algorithmes sont construits avec l'aide des données récoltées mais également générées. En effet, les algorithmes de prédiction de production photovoltaïque ainsi que les algorithmes financiers liées à la place de marché OFEN GBFlex sont disponibles et utilisables dans la création de l'algorithme de pilotage. Ces stratégies combinatoires ont permis d'optimiser le pilotage intelligent et permettre ainsi une meilleure gestion de la production PV et des consommateurs énergétiques sur les sites. Les démonstrations présentes dans ce rapport final OFEN MSID prouvent l'efficacité du système. Du côté de la problématique d'autoconsommation, nous avons testé le système en condition réelle sur notre site de développement OFF-GRID avant de le déployer sur les sites des partenaires. Du côté de la stabilisation de la tension réseau, nous avons démontré qu'en cas de surtension, le système était prêt à réagir afin de diminuer le problème autant que possible en pilotant les batteries disponibles dans le projet. Vous retrouvez dans le chapitre 5 de ce présent rapport l'ensemble des stratégies combinatoires testées et validées.

En conclusion, ce projet a permis d'agréger et piloter à distance plusieurs sites avec des cas d'usage très différents mais avec des problématiques communes. Dans le cadre du projet OFEN MSID, six sites d'implémentation ont vu le jour. Le système est scalable et nous estimons entre 500 et 1000 sites dans la version actuelle des développements. Avec les démonstrateurs en place, nous sommes en mesure de prouver l'utilité de la mise en place de système intelligent pilotant les micro-stockages distribués. Le système de création d'algorithme prévoit d'ores et déjà des actions en cas de pénurie planifiée permettant d'assurer la disponibilité maximale du stockage avant une période de 4 heures en mode autarcique par exemple.

Dans le contexte de potentielle pénurie d'électricité du printemps 2023, le pilotage de micro-stockages intelligents distribuées (MSID) à distance intéresse de plus en plus les gestionnaires de réseaux de distribution (GRDs).

Zusammenfassung

Das BFE-Projekt MSID hat die akademischen Partner HES-SO Valais-Wallis und Icare und zusammen mit den industriellen Partnern ElectrInfo, Enalpin, FMA, OIKEN, Seic-Télédis, und Studer-Innotec zusammengebracht, um zwei Hauptprobleme zu lösen, die durch die Einspeisung von Photovoltaik (PV) entstehen: die Optimierung des Eigenverbrauchs und die Steuerung der Netzspannung. In der Tat stehen zwei Verteilnetzbetreiber (VNB) der ersten Problematik mit unterschiedlichen Fallstudien gegenüber. Bei der SEIC-Télédis ist die Problematik des Eigenverbrauchs an zwei Standorten präsent, da zwei Privathäuser die lokale Speicherung verbessern wollen. In Visp hat Enalpin ebenfalls diese Problematik zu bewältigen, jedoch für das Bahnhofsgebäude, in dem sich ihre Räumlichkeiten befinden. In Bezug auf die zweite vom Projekt behandelte Problematik wurden die Demonstrationen an zwei Standorten von zwei verschiedenen VNB durchgeführt. Im Fall von FMA handelte es sich um einen End-of-Line-Bauernhof in Gryon im Kanton Waadt. Der Ersatz des Dieselgenerators durch PV erfordert die Steuerung von Speichern, um die Spannung zu stabilisieren. Der letzte Standort befindet sich in Sierre beim Tennisplatz Pont-Chalais. Die hohe Produktion der Solarpaneele in der Tennishalle führt zu Spannungsproblemen im Netz.

Im Rahmen des BFE-Projekts MSID konnten die verschiedenen Probleme mit der Einrichtung einer Virtual Power Plant (VPP)-Plattform und eines Steuergeräts gelöst werden. Dieses Gerät steuert die verschiedenen Wechselrichter, Xtender Next3 von Studer-Innotec, Victron von Victron Energy oder IMEON von IMEON Energy, die an den verschiedenen Standorten installiert sind, und sammelt so viele nützliche Daten wie möglich, die von den installierten Geräten (Wechselrichter, Batterie, WP, ECS, etc.) erzeugt werden. Eine VPP-Plattform zur Visualisierung wird den VNB und den Endkunden zur Verfügung gestellt, um die historischen und tatsächlichen Daten, die alle 15 Minuten aktualisiert werden, beobachten zu können. Die im Rahmen des BFE-Projekts MSID entwickelte VPP-Plattform bietet auch die Möglichkeit, Steuerungsalgorithmen zu erstellen. Diese Algorithmen werden mit Hilfe der gesammelten, aber auch der generierten Daten aufgebaut. Tatsächlich sind die Algorithmen zur Vorhersage der Photovoltaikproduktion sowie die Finanzalgorithmen im Zusammenhang mit dem BFE-Marktplatz GBFlex verfügbar und können bei der Erstellung des Steuerungsalgorithmus verwendet werden. Diese kombinatorischen Strategien haben es ermöglicht, die intelligente Steuerung zu optimieren und so ein besseres Management der PV-Produktion und der Energieverbraucher an den Standorten zu ermöglichen. Die Demonstrationen in diesem Abschlussbericht BFE MSID belegen die Effizienz des Systems. Auf der Seite der Problematik des Eigenverbrauchs haben wir das System unter realen Bedingungen an unserem OFF-GRID-Entwicklungsstandort getestet, bevor es an den Standorten der Partner eingesetzt wurde. In Bezug auf die Stabilisierung der Netzspannung haben wir gezeigt, dass das System im Falle einer Überspannung bereit ist, zu reagieren, um das Problem so weit wie möglich zu verringern, indem es die im Projekt verfügbaren Batterien benützt. In Kapitel 5 dieses Berichts finden Sie alle getesteten und validierten kombinatorischen Strategien.

Zusammenfassend lässt sich sagen, dass dieses Projekt die Aggregation und Fernsteuerung mehrerer Standorte mit sehr unterschiedlichen Anwendungsfällen, aber mit gemeinsamen Problemen ermöglicht hat. Im Rahmen des BFE-Projekts MSID sind sechs Implementierungsstandorte entstanden. Das System ist skalierbar und wir schätzen, dass unsere VPP-Plattform 500 bis 1000 Standorte in der aktuellen Version der Entwicklungen steuern könnte. Mit den vorhandenen Demonstratoren sind wir in der Lage, die Nützlichkeit der Einführung eines intelligenten Systems zur Steuerung von verteilten Mikrospeichern zu beweisen. Das System zur Erstellung von Algorithmen sieht bereits Aktionen im Falle einer geplanten Knappheit vor, die es ermöglichen, die maximale Verfügbarkeit des Speichers vor einem Zeitraum von beispielsweise 4 Stunden im autarken Modus zu gewährleisten.

Vor dem Hintergrund der potenziellen Stromknappheit im Frühjahr 2023 ist die Fernsteuerung von verteilten intelligenten Mikrospeichern (MSIDs) für Verteilnetzbetreiber (VNBs) zunehmend interessant.

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API	Application Programming Interface
DSO	Distribution System Operator
ECS	WH (hot sanitary water)
EASILab	Energy Application and System Integration lab
ESR	Energie Sion Region
FMA	Force Motrice de l'Avançon
HES-SO	Haute Ecole Spécialisée - Suisse Occidentale
HVAC	Heating, Ventilation and Air-Conditioning
IEE	Institute Energy and Environment
IEM	Institut Entrepreneuriat & Management
IIG	Institut Informatique de Gestion
ISI	Industrial Systems InstituteMLMachine Learning
MSID	Micro Intelligent Distributed Storage
NEM	Network Energy Manager
OIKEN	ESR and SIESA merger
SFTP	Secure File Transfer Protocol
SIESA	Sierre Energie
SOC	State of charge (Percentage of battery)
US	User story (Functionality)

1 Introduction

1.1 Context

The idea of a microgrid consists of creating a sub-grid in which a connection is created between energy production sources and energy consumption sinks in order to balance production and consumption peaks at the level of this sub-grid (Genoud Dominique, 2012) (Sutter, 2005). In Europe, we can mention the IssyGrid or Nice Grid project (see Fig. 1) (Nice Grid energy storage, 2014). The architecture of the storage systems is broken down into 3 levels for a total capacity of 1.5 MW. A 1.1 MW battery links the RTE (Réseaux et transport d'électricité) and EDF (Electricité de France) network, three 33 kW batteries are installed on the low voltage network of the district and 4.6 kW batteries at the residential customers' single phase. These batteries are controlled by an aggregator (Network Battery Aggregator) which collects the status parameters of each battery, proposes flexibility offers to the NEM (Network Energy Manager) and optimally distributes the NEM's decision. The whole system allows the remote control of flexibility sources (storage and postponement of consumption) from an optimisation centre taking into account the state of the network at local and regional level as well as consumption and production forecasts.

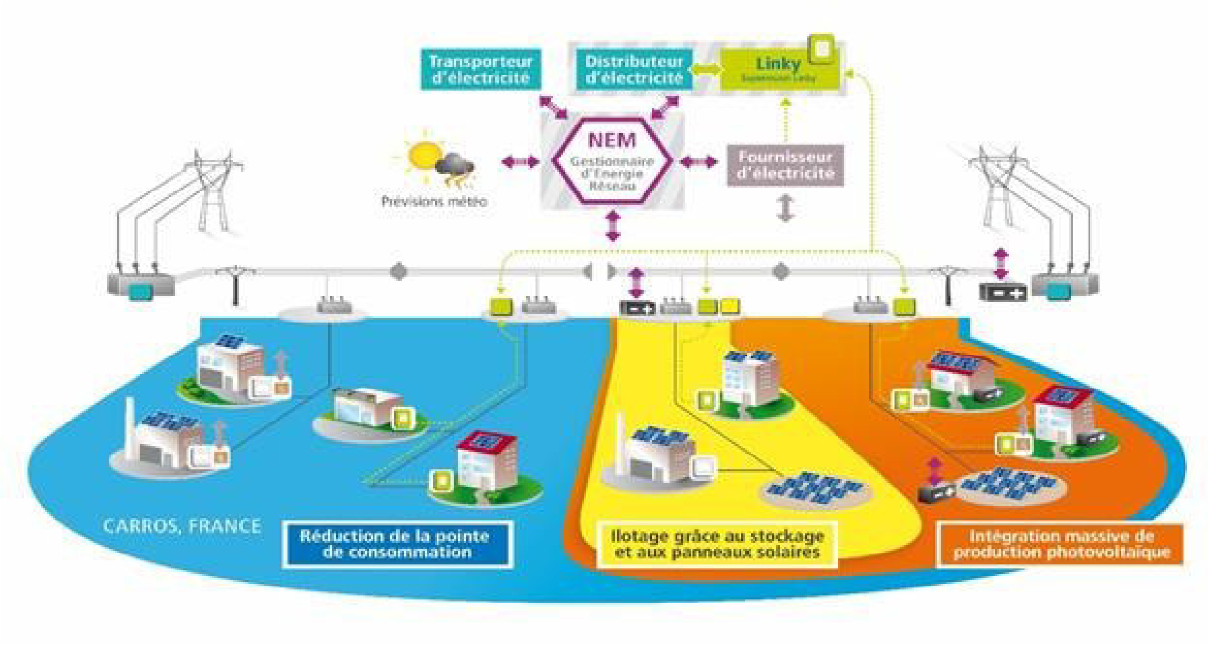

Figure 1: Representation of the NiceGrid microgrid with the different levels of control, [NIC-2015].

In Switzerland, a large battery on the electricity grid was inaugurated in 2018 in Dieketon in the canton of Zurich. The maximum power of this mega-battery is 18 MW with a storage capacity of 7.5 MWh. The device allows renewable power plants to be operated without voltage drop issues or overvoltage (Noel Graber, 2017). At the EPFL (Ecole Polytechnique Fédérale de Lausanne) in Switzerland, work is being done on the simulation of Microgrids using predefined scenarios for control as well as electronic components capable of simulating the operation of a SmartGrid in real time. We can also mention the Microgrid of the HES-SO at the Techno-Pôle de Sierre which has both a solar production installation, second-hand measurements of consumption and production and a new 25 kWh battery technology from the company Leclanché which makes it possible to smooth out the power peaks (IBATS, 2013)

We also have the SolarGrid project (ENEA, 2021) which aims to optimise grid costs and improve the quality of electricity supply. Several simulations have been validated to support the integration of electric mobility and decentralised photo-voltaic systems into the grid under realistic conditions. In addition we can mention the ProsumerLab at the BFHS, which is working on the intelligent building that generates electricity, stores it and only uses it again when needed. With increasing digitalisation in the building sector, falling prices for photo-voltaic systems and electricity storage, more and more buildings will produce and consume electricity. There is an emerging consensus that decentralised electricity generation and supply will be central to the energy systems of the future. Finally, the European Horizon2020 project domOS analysed the effect of "smart technologies" on the improvement of energy efficiency and flexibility of existing buildings. About 200 buildings in Sion as well as 10 electric vehicle charging stations were used as case studies (European project domOS, 2022).

New economic development opportunities

We are currently facing various global issues such as the electricity shortage with an increased need for energy independence which could be partly met by storing photo-voltaic production or/and other combined systems.

Virtual Power Plant : The problem of the optimal integration of these diffuse productions has given rise to the notion of VPP (Virtual Power Plant), the aim of which is to aggregate small energy sources and optimise their use through an information system that can be remotely controlled by the energy suppliers. These energy sources can combine the production of renewable electricity as well as heat. This concept has been the subject of several European projects. Examples of such projects are FENIX, IssyGrid or GRID4EU (gridinnovation, 2015). The potential market for these VPPs in Switzerland is quite large as they can operate on the secondary and tertiary frequency management markets, balance groups, the SPOT market and the Tunel contract. For an order of magnitude, the market in Switzerland has been estimated at CHF 100 million per year (Abrell, 2017). New products on the market today offer a range of energy-related services such as Tiko power or Tiko Sun. With Tiko power, it is possible to take control of the heating system: you can see when your equipment is working and how much it consumes. You can also compare your consumption with the average of other members in order to help you improve your energy efficiency.

We can also mention Tesla and its Powerall battery: These batteries allow peak consumption to be smoothed out, peak consumption to be shifted to more favourable times, to have a back-up reserve and to manage the energy demand from the house or from Tesla's vehicle charging. However, it does not come with a three-phase inverter, despite having a higher power rating of 3.6 kVA. These systems are often too technical and are not easily understood by everyone, nor are they suitable for the trade.

Steps in this direction are being taken with the V2X Switzerland consortium (V2X Suisse, 2023) in which electric car manufacturer Honda is partnering to demonstrate bi-directional charging technology [1] .

These products and their functionalities can be used as inspiration for the interface proposed to the customers as well as the possible services in this project. However, we will go further to provide a customised tool that will be based on a personalised and comprehensive multi-criteria (economic, technical and environmental) management system.

Development of energy cooperatives

[1]https://www.just-auto.com/news/honda-and-v2x-suisse-consortium-plan-vehicle-to-grid-charging-tech

In Switzerland, based on this desire for energy independence, and following the new law (LENE), this became possible on the 1st of January 2018. This is an opportunity for DSOs to offer new services to customers such as the management of microgrids of cooperatives, billing, etc.

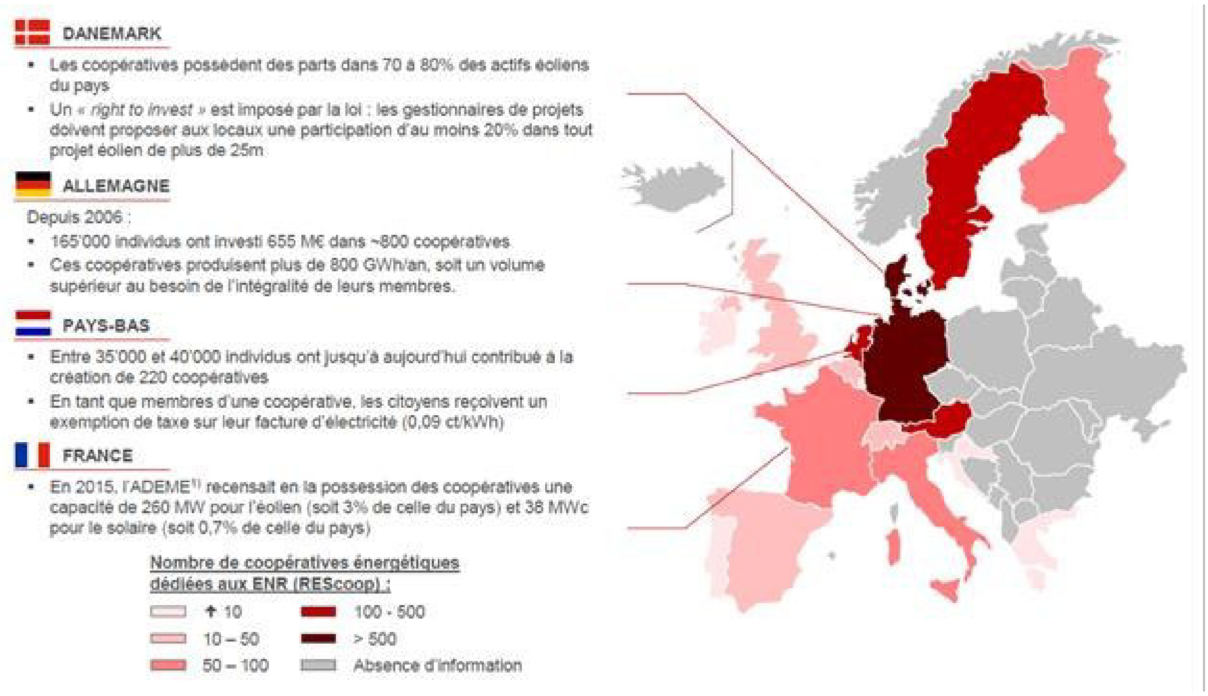

Figure 2: Number of energy cooperatives in Europe

However, the law has certain limitations which, as we shall see later, do not allow the connection of even close neighbours if an unused plot of land separates them. Improvements are to be made to the law under discussion.

This is related to the need for Swiss DSOs to also become energy service providers. The assessment of the potential market is still to be defined, but the evolution in Europe shows us that energy cooperatives are in full development, in particular in Germany and Denmark (cf. Fig.2). For example, the island of Samsø in Denmark has become the first island to be self-sufficient in renewable energy thanks to the involvement of its inhabitants in the form of an energy cooperative.

1.2 Benefits of the SFOE-MSID project

Energy potential

Our objective is to promote the development of renewable energies, especially in isolated areas, by integrating more flexible loads and self-consumption, working on the existing grid and allowing more added value to be created. All this with user friendly applications.

A diesel generator consuming 3,500kWh per year was used to produce electricity at the first high altitude demonstration site (FMA DSO pilot site). This generator could be replaced by 36 kW of solar generation, a 15kWh battery connected to a 15kW inverter and the connection to the low voltage grid end (without grid reinforcement). From the point of view of the electricity grid, it is necessary at all times to ensure a balance between production and demand. These renewable sources of electricity are, for the most part, intermittent generation.

Moreover, the predictions linked to these renewable productions are totally dependent on meteorological data and generate significant errors. Faced with the different variations in demand and production of renewable energies, the means of energy production do not have the same reactivity to ensure the balance of the electrical network in order to compensate for sudden variations in consumption and production of renewable energy. Batteries allow rapid charge and discharge cycles, 100% in 1 hour, as required for this project. A second typology (pilot site of the GRD OIKEN) with 3 single-phase inverters avoided the grid reinforcement necessary for photovoltaic and limited the use of peak-shaving.

We also want to increase the self-consumption of electricity generated by photovoltaics in buildings by 20 to 30% compared to today. Storage in electric vehicles has been evaluated for the use-case of the Visp railway station (pilot site of the Enalpin DSO)

Economic added value

- Bringing together 4 DSOs with 4 different visions
- Analysis of potential data server pooling architectures (datahub)
- Assessment of the profitability potential for the sites
- Maximising potential market gain through price prediction and flexible loads
- Develop new business models based on flexible energy loads while maximising self-consumption of microgrids

We have defined the impact of the benefit of heterogeneous microgrids with the steering according to the economic criterion. On this standard case we have established the associated business model canvas (BMC) on the basis of interviews and literature research. For the use-cases, we will highlight the potential profitability and the conditions that each technology (battery, demand management...) can bring to the network manager, the district manager, the building owners and the final consumers.

In addition, the electricity price forecast has been studied in this report and is an important decision-making information for energy-related investment choices, whether in the short term (day-ahead), medium term (1-3 months) or long term (3 years). The day before for the next day, a network operator will be able to make a trade-off between buying on the market and using capacity to balance the network. An automatic SMS notification system for electric vehicle owners will encourage charging at the right time.

Societal value added

- Integrate different actors such as traders or installers
- Include economic partners in the decision-making process
- Provide a customised tool based on a classification of users and their feedback

We provide a customised product where the customer is at the centre of the decision making process and where the different functionalities of the application have been designed according to the customer and the segmentation carried out beforehand. We have created an application that can be adapted to the practical case and to the billing system (subject to peak power, > 100 MWh/year). Consumption is detailed in the customer's bill.

Environmental added value

- Promotion of renewable energy in remote areas
- Promote self-consumption by integrating it into the combinatorial control model
- Promoting the recharging of electric vehicles with solar energy
- Increasing energy efficiency through feedback to customers

Technical added value

- Simplification of network sizing (connection study)
- Rational modification of the network (material, implementation costs)
- A new tool contributing to the stability of the grid and thus improving the quality of electricity supply
- The eventual replacement of the centralized remote control
- Creation of predictive learning models based on prices and energy flows

For DSOs, the sizing of distribution networks has become very difficult to determine between technical and economic interests. A 'worst case' sizing (full production, minimum consumption) will not be a feasible alternative in terms of cost and time. It is obvious that a resizing of the network at each request for a production connection would not be manageable. Intelligent and distributed technology is therefore one of the possible solutions for achieving the energy transition.

Scientific added value

Predictions based on market prices and local PV production prediction using artificial intelligence algorithms.
Financial optimisation of microgrids under the strong constraint of grid sizing and self-consumption desired by the end customers. A PhD student was trained and bachelor and master projects were proposed.

1.3 Project objectives

Within the framework of the SFOE MSID project, 8 workpackages have been defined, each with its own objectives. Below you will find a brief summary of these work packages with their main objective and their leader:

- WP0 Project Management
  - Main objective: Steering the project in order to achieve all the objectives of each work package as well as adapting the project according to the findings and evolutions according to the Scrum agile methodology
  - Head: HES-SO Valais-Wallis Institute of Computer Science (IIG) David Wannier

- WP1 Developing new business models
  - Main objective: Definition of the flexibility potential per load and the associated gains for the different actors of our system
  - Head: HES-SO Valais-Wallis Institute of Entrepreneurship and Management (IEM) Stéphane Genoud

- WP2 Creation of microgrids
  - Main objective: Installation and stabilisation of the low voltage network for the sites
  - Head: HES-SO Valais-Wallis Institute of Industrial Systems (ISI) Nicolas Jordan

- WP3 From microgrid to co-generation using Big Data
  - Main objective: Creation of an information system that allows for the reactive collection and management of flexible loads for buildings in an aggregated manner
  - Person in charge: Institut Icare Valentin Decaillet

- WP4 Optimising financial trade by predicting prices and local PV production
    - Main objective: To have reliable information to maximise financial gains between the different actors in the system
    - Head: HES-SO Valais-Wallis Institute of Computer Science (IIG) Dominique Genoud

- WP5 Implementing combinatorial strategies
    - Main objective: To make compatible on the one hand the maximisation of self-consumption and on the other hand the valorisation of flexible loads in different configurations/under different constraints
    - Head: HES-SO Valais-Wallis Institute of Computer Science (IIG) David Wannier

- WP6 Digitalisation of information
    - Main objective: To provide interactive and personalised visualisation and control systems for each of our sites and for all the actors identified by the DSOs
    - Head: HES-SO Valais-Wallis Institute of Computer Science (IIG) David Wannier

- WP7 Dissemination and feedback
    - Main objective: To explain our results based on our 5 sites in scientific and public presentations
    - Head: HES-SO Valais-Wallis Institute of Computer Science (IIG) David Wannier

1.4 Scope of application

In this SFOE report, the content is divided into four parts. In the first part, we detail the different project sites. In the second part, we develop the issue of self-consumption with the sites of the distribution operators SEIC-Teledis and Enalpin. In the third part, we present the second issue of grid voltage stabilisation. Finally, we demonstrate the combinatorial strategies used in the implementation. A conclusion containing the perspectives of our results, the national and international cooperation as well as the publications can be found at the end of this report.

2 Description of the facilities

Within the framework of this SFOE project, 5 sites are distributed among 4 DSOs. They are as follows:

Site 1, FMA, Gryon
Site 2, SEIC-Télédis, Saillon
Site 3, SEIC-Télédis, Nendaz
Site 4, OIKEN (formerly Sierre Energie), Sierre
Site 5, EnAlpin, Visp

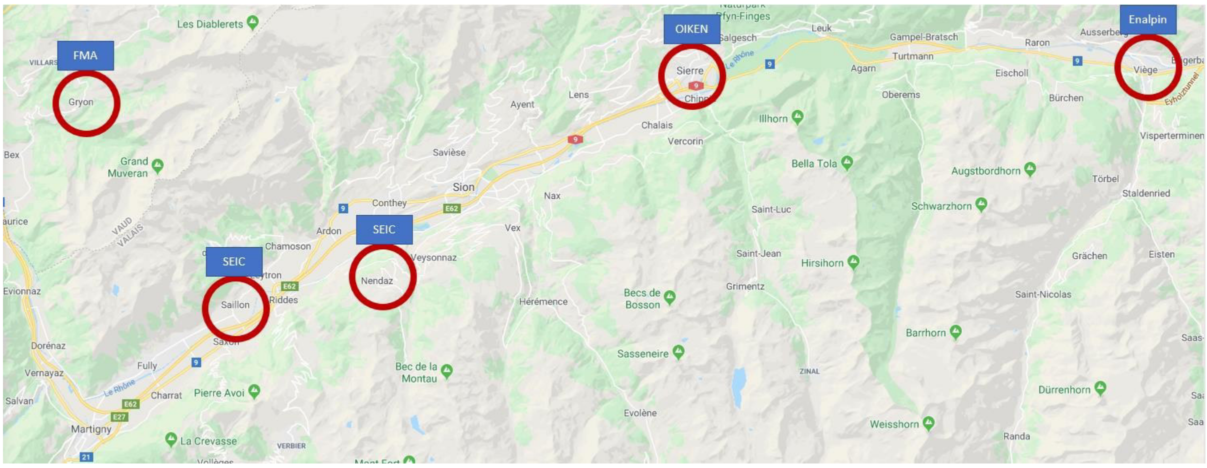

Figure 3: Map of pilot sites

2.1 SITE 1 - FMA

Site 1 FMA is located in Gryon near the resort of Villars (1300m) in the canton of Vaud. It is a farm and a mountain bar. Solar panels have been installed (30kW on the farm). The primary objective is to replace the farm's (diesel) generator (D1) and guarantee a stable energy supply according to local consumption and the weather (while maximising solar production). The low voltage grid is there to supplement this. FMA was also asked to design a scalable system that would allow the connection of other consumers in the area.

Figure 4: Site 1 - FMA

FarmFigure 5: Site 1 - FMA Café

Our partner FMA installed the fibre so that the system could be connected to the internet and the data could be sent to the FMA database instance. The installation of a measurement system allowed to size the optimal storage and inverter power to allow the addition of new consumers.

The necessary system consists of the new Studer-Innotec Next3 inverter and three lithium batteries with a total of 16 kWh. The system was installed on site. The data collection and control box developed by the HES-SO Valais-Wallis was also installed on site, as well as a local weather station to calibrate our prediction system based on artificial intelligence algorithms.

Figure 6: Next3 inverter at the FMA site in Gryon

2.2 SITE 2 and SITE 3 - Virtual Power Plant (VPP) - SEIC-Teledis

The DSO has two sites for this project. Site 2 is in Saillon and site 3 in Nendaz, in Valais. These are private customers of SEIC-Télédis who have agreed to participate in this project. Both houses are installed with an Imeon inverter and a Leclanché Apollion Cube battery as well as the data collection and control module developed by the HES-SO Valais-Wallis. They also each have a photo-voltaic production (8kW for Saillon and 7kW for Nendaz) and flexible loads.

The aim is to control the battery according to the photovoltaic production (which was not compatible with micro-inverters). An optimisation of the battery charging and discharging set point according to the photovoltaic production prediction data of the next hour has been implemented on the VPP battery aggregation platform.

The value of small batteries has been demonstrated by making this capacity available to the sub-balance group through the GB-Flex market place (SFOE project no. SI/501952)

Figure 7: Site 2 - SEIC-Télédis *SaillonFigure 8: Site 3 - SEIC-Télédis Nendaz*

2.3 SITE 4 - OIKEN (formerly Sierre Energie)

At the end of 2019, ESR (Energie Sion Région) and Sierre Energie merged to become "OIKEN". OIKEN provides site 4 which is located at the tennis court in Pont-Chalais near the town of Sierre. The site has solar panels (PV surface of 867 m^2) on the roof with a capacity of 138 kW. The installation of three single-phase inverters with three Apollion Cube Leclanché batteries was carried out by OIKEN. It should be noted that some of the batteries did not withstand the winter period and had to be replaced. The data collection and control module developed by the HES-SO Valais-Wallis was installed on site.

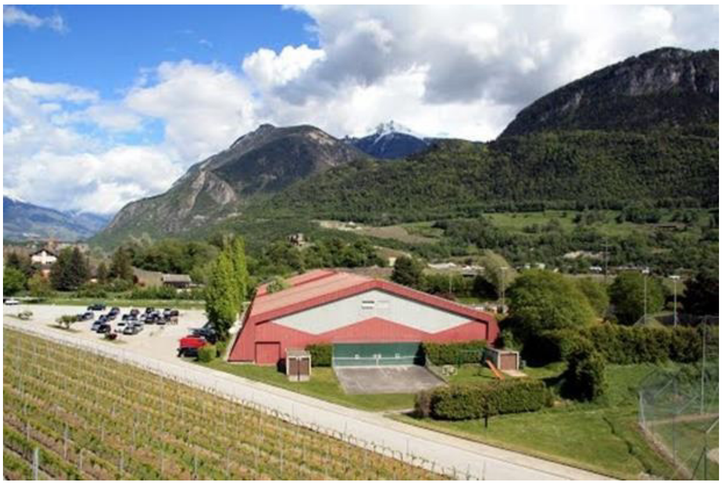

Figure 9: Site 4 - OIKEN Tennis

Their objective is to evaluate the contribution of local micro-storage to reduce or avoid peak shaving. We have created a tool for sizing the storage capacity according to the desired voltage quality (15 kWh allow to avoid peak shaving with a voltage quality of 1.7t p.u).

Figure 10: Site 4 - OIKEN Box containing the solarlog and the control box that allows data recovery

In terms of cybersecurity, since the existing Solarlog Base 100 does not allow production data to be sent securely (only the FTP protocol is available), we had to add an FTP server in our control box located in the local network and convert it to a secure SFTP protocol for sending to the aggregation server (VPP platform).

2.4 SITE 5 - EnAlpin

Site 5 (EnAlpin) is located at the Visp train station. It includes the premises of the Enalpin company, the various shops in this building, 6 electric cars, their charging stations and the solar panels on the roof of the building with an output of 80 kW.

Figure 11: Site 5 - EnAlpin

PVFigure 12: Site 5 - EnAlpin - Charging stations

Their objectives are to optimise their self-consumption and to study new business models related to EV recharging. The economic study allows the battery to be sized according to the optimised scenarios. The cost of energy in 2019 did not allow the additional cost of a battery for local storage of photovoltaics to be profitable. The choice was made to study storage in electric vehicles and the potential of V2G instead of the investment in the local battery imagined at the time the project was submitted. An automatic SMS notification function for electric vehicle owners has been integrated into the VPP platform.

2.5 SITE 6 - Off-grid development and testing site

In order to carry out the tests in a dedicated environment and thus validate all the new features before deploying them to our partners, an additional site had to be added.

Figure 13: Off-grid development site

We have at our disposal an off-grid site used as a development and test environment. This site consists of a 4.5kW PV installation and a VPP with 2 Weco batteries of 5kWh each, and a Victron battery of 5kWh. Below is a diagram of the installation and the links between each energy flow (blue) and the control (green) of the flexible loads (boiler, domestic hot water, generator).

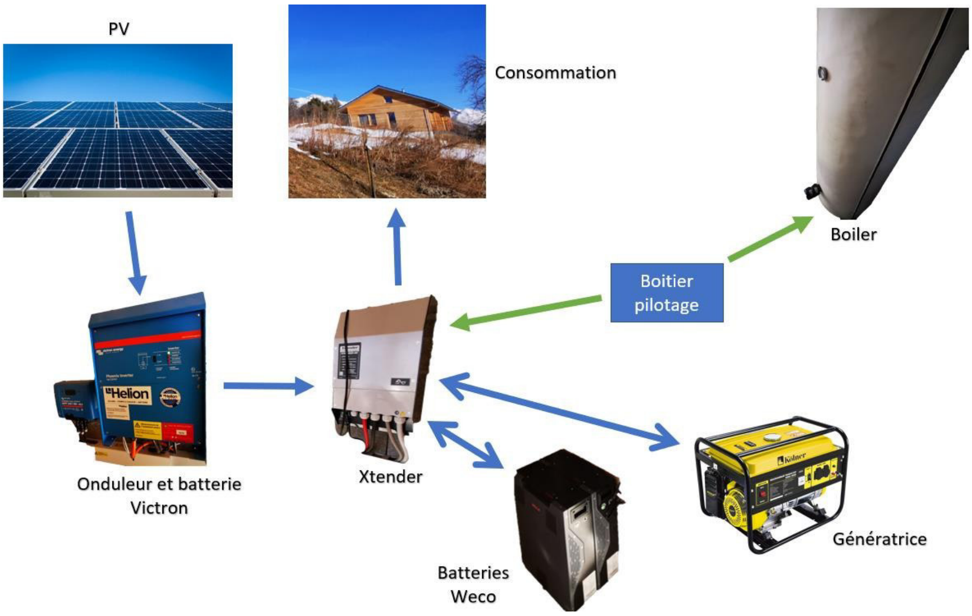

Figure 14: Site 6 - Off-grid development site

3 Optimisation of self-consumption

3.1 Introduction

The first issue addressed in this SFOE MSID project is that of self-consumption. From the moment a renewable energy source is introduced into a building via the distribution network, we are confronted with the issue of self-consumption (Stephant, 2021). In this situation, several questions arise: Is it better to store the energy? To send it to the grid? At what price?

Three project sites, belonging to the DSOs SEIC-Teledis and Enalpin, experience this problem on a daily basis. As introduced in the previous chapter, the two individual houses of SEIC-Teledis have solar panels with a capacity of 8.25 kWp and a battery with a capacity of 6kW for 6kWh of energy. Enalpin's building is more imposing, as it is the railway station in Visp. This building has a large amount of photovoltaic production (80 kW) and several consumers such as charging stations for electric vehicles or offices. The annual electricity consumption of site 5 is 113'506 kWh. Quarter-hourly measurements for the entire year 2018 are used.

In this chapter, we discuss the steps that allowed us to propose optimisations and analyses related to the physical demonstrator of our two partners.

3.2 Competencies

In order to optimise the self-consumption of the sites, we need to call on several different skills.

First of all, it is essential to be able to retrieve as much useful data as possible from all the sites. To this end, a control box developed by the HES-SO Valais-Wallis was developed. In addition to being wired to the inverter in order to control it, this control box also manages the secure transmission of data to the aggregation server consisting of a TimeSeries InfluxDB database. Every minute all possible data is collected before being sent every 15 minutes to the database. In order to get as much information as possible from the site, the control box will not only retrieve data from the inverter but also from the photovoltaic micro-inverters, Shelly smart-meters, DHW temperature sensors, or local weather data.

The second competence is the control of the Leclanché Apollion Cube battery by the UPS. On the two SEIC-Télédis sites, the inverters are IMEON 9.12. Our control box is capable of controlling this type of inverter via Modbus RTU communication. This communication allows us to retrieve the value of the various Modbus registers and to send them back. By using data from multiple sources, we were able to control the battery.

Battery control can in some cases (compatible systems from one manufacturer) be done directly from the inverter. The OFEN MSID project is distinguished by the ability of the developed box to make decisions at the local level and at the remote aggregate level, taking into account a larger number of parameters. In the case of SEIC-Teledis, for example, the IMEON inverter does not have access to the data from the solar (micro-inverters), which means that its control requires a box that has access to data from several heterogeneous systems that are not compatible.

The collection of meteorological data allows a complementary competence to enter the scene. This is the competence of artificial intelligence. In order to be able to anticipate the photovoltaic production and thus charge/discharge the battery in advance, the prediction of the sun-related data is vital. A prediction algorithm based on machine learning (ML) has been developed in the SFOE MSID project to anticipate the production of solar panels, thus making it possible to control the battery by knowing the predicted production one hour in advance.

3.3 Realization

Data collection and storage

In order to collect the data on site, we installed a control box as mentioned above to create the link between the battery and the Timeseries InfluxDB aggregation server. Below is an example of the modbus addresses and values of the Imeon inverters that can be retrieved.

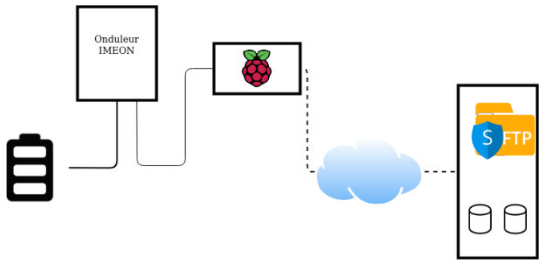

Figure 15: Representation of the architecture with the Imeon inverter and the Leclanché battery

The data is read via the modbus protocol every minute and saved in a local JSON file on the control unit. The data is then transcribed into a CSV file for processing by the aggregation server and adding the data to the TimeSeries InfluxDB database.

The CSV file exchange is based on a secure SFTP protocol. This file contains the daily data of the values retrieved from the inverter and battery as well as from the solar panels. This data is aggregated to the minute and the CSV file is sent every 15 minutes over the centralised SFTP. It is then imported into the database of the aggregation server.

Register address	Function word	Function	Response/Query Format	Command Type
2.4 AC OUTPUT				
0x0200	1	AC output voltage L1	"short" encoded on 2 Bytes, the value has a resolution of 0.1V Ex: 234.6V 0x09 0x2A (2346)	R
0x0201*	1	AC output voltage L2	"short" encoded on 2 Bytes, the value has a resolution of 0.1V	R
0x0202*	1	AC output voltage L3	"short" encoded on 2 Bytes, the value has a resolution of 0.1V	R
0x0203	2	AC output power L1 (From AC output connector of inverter)	"int" encoded on 4 Bytes, the value has a resolution of 1W Ex: 967W 0x00 0x00 0x03 0xC7 (967)	R
0x0205*	2	AC output power L2 (From AC output connector of inverter)	"int" encoded on 4 Bytes, the value has a resolution of 1W	R
0x0207*	2	AC output power L3 (From AC output connector of inverter)	"int" encoded on 4 Bytes, the value has a resolution of 1W	R
0x0209*	2	AC output power(total) (From AC output connector of inverter)	"int" encoded on 4 Bytes, the value has a resolution of 1W	R

Figure 17: Modbus Imeon


```
"Time": "2020-01-16 09:44:00",
"pv_api": {
    "power": {
        "current": 161,
        "today": 332,
        "lifetime": 45537838
    }
}


"Battery": {
    "Voltage": 55.1,
    "StateOfCharge": 16,
    "Current": {
        "Charge": 11.9,
        "Discharge": 0
    }
```


Figure 16: Example JSON file generated by the collection of data from the control box

Here is an extract of the file sent with the measurements of the photovoltaic and the battery:

Once the data has arrived on the SFTP, it is automatically integrated. DSOs or data scientists can then consult them on the Grafana visualisation tool.

Figure 18: Visualisation of cleaned SEIC-Teledis data in Saillon and Nendaz

Photovoltaic power prediction

First, we dealt with the missing values, of which there were many. Indeed, several time ranges were lost during technical failures, and sometimes missing values were created by the sensors. For example, the IMEON inverter regularly returns outliers during modbus calls. We decided to restrict our datasets to the longest time range available without missing values in the case of Saillon, i.e. the data from mid-May 2020 to October 2020. We then added to the dataset the theoretical maximum photovoltaic production curve (European PVGIS data) for each site. This represents the maximum radiation on each day of the year, calculated on the values from 2005 to 2020. In order to generate this curve, we need different information for each site:

- GPS position of the solar panels
- Installed PV power
- Panel tilt
- Azimuth of the panels

With this information we generate a PV production curve for each hour between 2005 and 2020.

$$\text{Let } prodPV_{site} = PVGIS(positionGPS_{site}, powerPV_{site}, inclinationPV_{site}, azimutPV_{site})$$

From these hourly measurements between 2005 and 2020, we generate the theoretical maximum PV production curve for each site, as follows:

$$PVmax_{site} = \max_{heure}(prodPV_{site})$$

For example, the maximum PV production for the Saillon site on 30 March at 13:00 is estimated by taking the maximum of the PV production curve (given by PVGIS) of all available 30 March at 13:00 between 2005 and 2020. The same for each hour of each day of the year.

Here are the two PV_max curves generated for Saillon and Nendaz:

- Saillon (position (46.173, 7.196), installed capacity 8kWp, inclination 17°, azimuth 32°)

Inclination: 0° = South

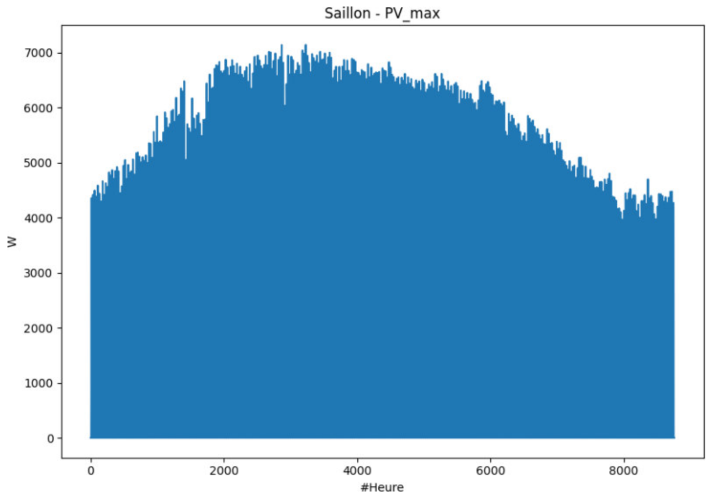

Figure 19: PV_max Saillon

Nendaz (position (46.195, 7.310), installed capacity 7kWp, inclination 22°, azimuth -15°)

Inclination: 0° = South

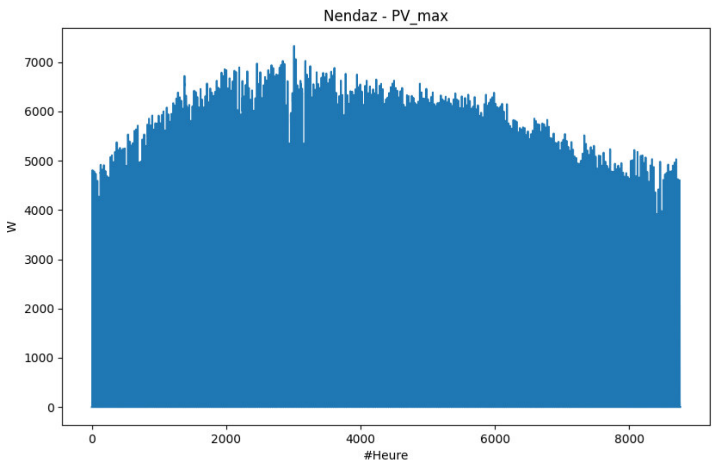

Figure 20: PV_max Nendaz

Then, for each date, location and characteristic of the installation, station, the prediction date of the value = date_data - lead_time is calculated. A new column is added corresponding to the date for which the prediction is made (= original date)

Finally, our dataset will therefore consist of : [t0 (prediction date), station, feature[2], variable, t0 + delta_T (date for which the prediction is made)]

We generate the features for each line according to the time we want to make our prediction (t+15min, t+1h, t+24h). For this, each line of the dataset will select the last prediction made by the COSMO models (midnight, 3h, 6h, ...).

Then, if for example the prediction is made at 4:00 for 4:15, we want to keep, for each feature and each station, the prediction for a maximum of 4 hours (in our case, for 4 hours). If the prediction is made at 4:15 for 4:30, we will also keep the prediction for 4 hours (because we always predict for each hour).

Finally, the dataset used, for each site, is as follows:

The prediction is made at time t

- Measurements (up to time t) from meteoswiss stations around the site
- Weather predictions at t+1h from meteosuisse stations around the site
- PV_max value at t+1h
- PV value to be predicted at t+1h

In order to improve our results, we first wanted to integrate weather data directly from the location. For this purpose, we are able to retrieve simulation data as well as weather predictions from meteoblue.

For each site, we therefore propose a method to know if we should charge the battery:

- Generation of the PV_max curve (as explained above, with the variables latitude, longitude, power, azimuth, orientation)
- Retrieval of meteoblue simulation data
- Retrieval of meteoblue prediction data
- Generation of the target variable of our models (t+1h, and 24 steps of the following day) based on the meteoblue simulation data
- Training of models with meteoblue prediction data
- Incorporation of the models into an API for PV prediction and battery charge/discharge decision display

We are therefore able to estimate whether we need to charge/discharge the battery and compare with the reality for the Saillon and Nendaz sites.

- Generation of the PV_max curve

The method used is the same as mentioned earlier in this document.

- Retrieval of meteoblue simulation data

We are able to retrieve simulation data at time t from meteoblue. This data is not accessible live, and is therefore only used to generate our new target variable. The data retrieval is done on the meteoblue interface, in order to retrieve simulation data. These can be imported as csv for the sites of Nendaz, Saillon and Gryon. We retrieve sunshine, direct and diffuse radiation, and cloud cover data.

- Retrieval of meteoblue prediction data

[2] A feature is a dataset value such as "solar radiation", "cloud cover", etc.

We are able to retrieve t+n hour prediction data from meteoblue at time t. Indeed, the meteoblue models predict weather variables every day at noon, for the whole next day (one prediction per hour).

We get the prediction data from meteoblue directly from their API. We retrieve these through a query generator on the meteoblue interface. We have implemented this on our API, in order to access live data when predicting our model.

- Generation of the target variable of our models based on the meteoblue simulation data

We retrieve from the meteoblue data, a variable named Cloud Cover Total (between 0 and 1, 0 being no clouds, 1 being a completely covered sky). We calculate our new target as follows:

$$PV_{target}(t) = PVmax(t) * (1 - 0.75 * Cloud\ Cover\ Total(t))$$

The idea is to have a realistic simulation of what the PV production of a given site is. If we have 0% clouds, we produce PVmax. If we have 100% clouds, we produce 25%*PVmax. Between these two limits, we consider that the evolution of the production is linear.

- Training of models based on meteoblue prediction data

We have two types of models (which will turn out to be the same). The first is to make a prediction at t+1h. For this, we use the simulation data available at t, t-1, and t-2, and the prediction data at t+1. Finally, we use PVmax at t+1. For both sites, we calculated the **Root Mean Squared Error** and **Mean Absolute Error** metrics. This calculation is done on the day only**:**

Table 1: Root Mean Squared Error (RMSE), Mean Absolute Error (MAE) and Mean Average Percentage Error (MAPE) for Saillon and Nendaz sites (PV prediction)

Metric/Site	**Saillon**	**Nendaz**
RMSE (daytime only) [Wh]	**470.4**	**820.9**
EAW (daytime only) [Wh]	**217.1**	**473.1**
MAPE (daytime only) [%]	**13.2**	**29.9**

Our models were trained at each site using 84530 hourly weather data between 1 January 2008 and 22 August 2017 and validated using 41635 hourly weather data between 23 August 2017 and 23 May 2022. Over one day, the average error is therefore 217.2 for Saillon and 473.1 for Nendaz. These figures show that on a production day, the average error in Wh does not exceed one third of the production. For Saillon, these figures are encouraging, and demonstrate a low model error.

These figures show our calculated target, model predictions and actual PV measurements for sunny days:

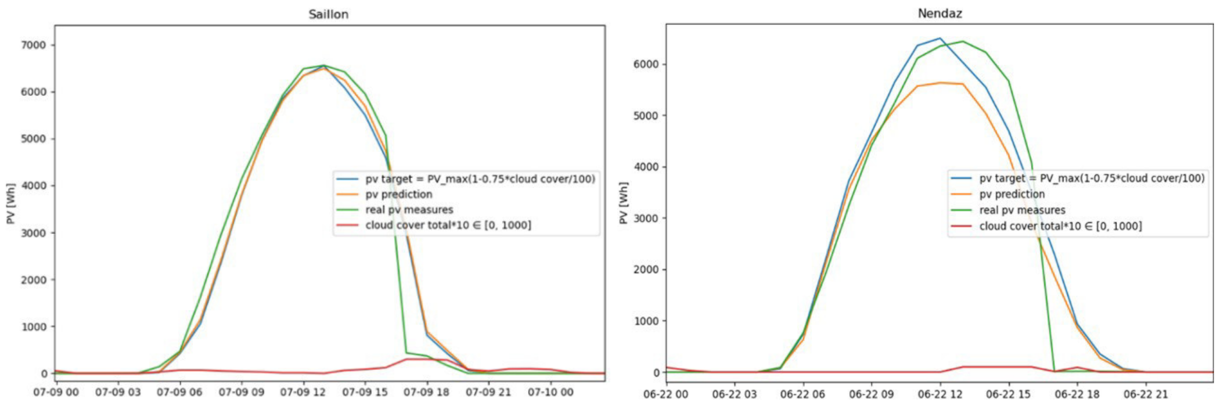

Figure 21: Targets calculated for sunny days

Our target corresponds perfectly to the actual PV measurements for sunny days: The average sunny day of the target is 3235.6, and the MAE between the target and the measurement is 409.9 for Saillon.

The average sunny day of the target is 3154.9, and the MAE between the target and the measurement is 798.7 for Nendaz.

These figures show our calculated target, model predictions and actual PV measurements for cloudy days:

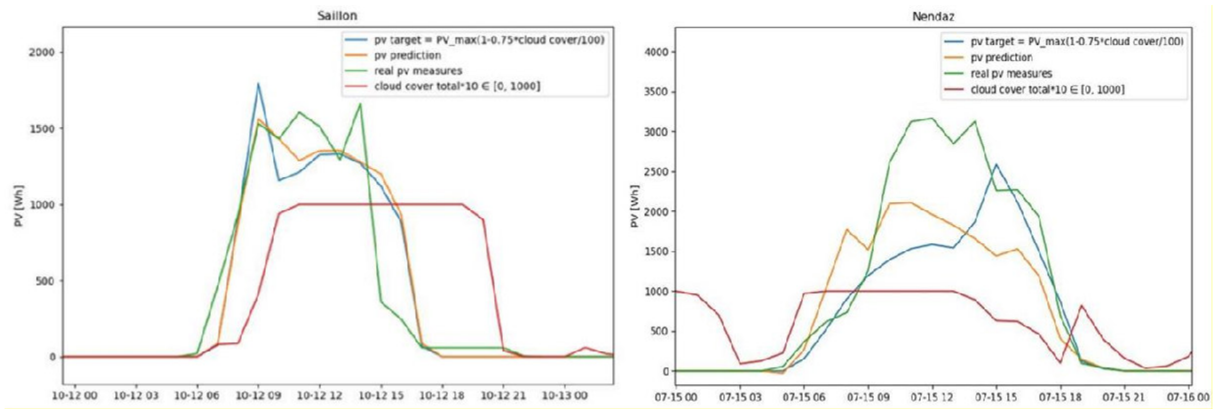

Figure 22: Targets calculated for cloudy days

Similarly, our target calculation is also validated for cloudy days. The average target for a cloudy day is 1008.4, and the MAE between target and measurement is 306.8 for Saillon.

The average cloudy day of the objective is 1569.7, and the MAE between the objective and the measurement is 724.8 for Nendaz.

3.4 Demonstrator/analysis

Finding the optimum battery size for the photovoltaic system at Site 5 - EnAlpin

Prices from Visp Energy (VED) and Services Industriels de Genève (SIG) are used. The reason for choosing SIG is the detailed prices for the purchase of electricity, but also for the reinjection tariffs.
The method is to vary various parameters that define the battery (mainly its capacity and its cost of use, or cost of wear). Then, using a financial site optimisation that describes when the battery charges and discharges, results are calculated.
The main results are the financial gains and the self-consumption rate. If the battery is too expensive, so that the reduction in its life caused by charging/discharging does not compensate for the gains made, it will not be used.

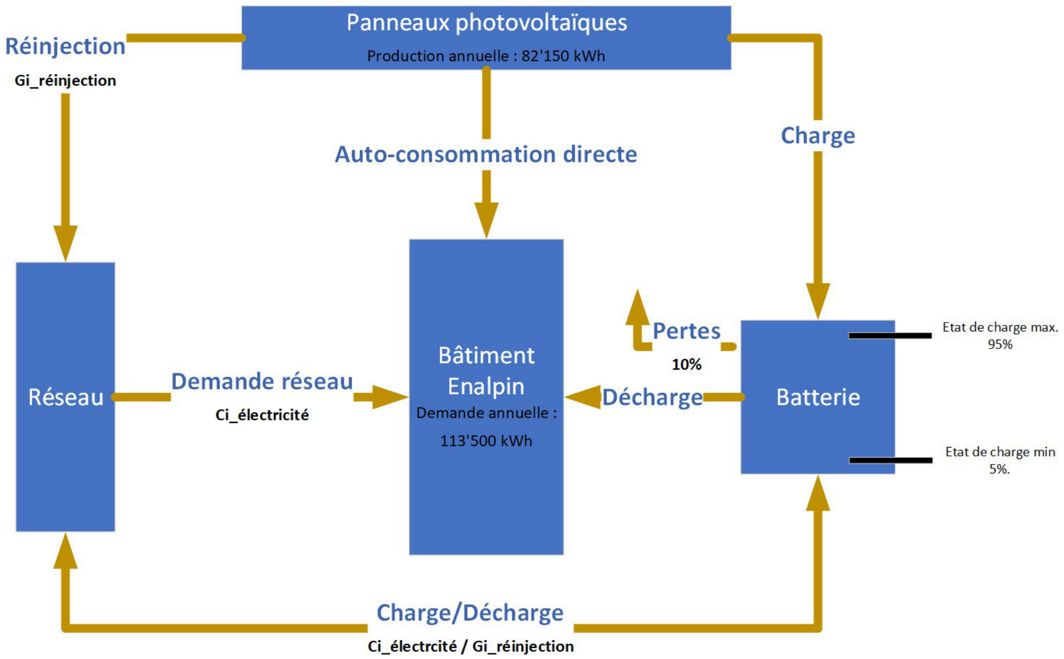

Figure 23: General diagram of the Enalpin site

<u>Optimal battery size in 2019 market conditions</u>
With the 2019 parameters, the cost of energy storage is greater than the price difference between grid demand and power re-injection. The consequence is that the battery does not provide financial savings by increasing the self-consumption of the site. For the battery to be useful, the difference between the prices of grid demand and re-injection must be smaller than the cost of storage. For example, with a storage cost of 13 cts/kWh, it is not worth storing the surplus PV production because the difference between the grid demand price of electricity (Visp Energie, winter, peak hours: 15.59 cts/kWh[1]) and the feed-in price of electricity (same conditions: 7.65 cts/kWh[3]) is less than the storage cost (15.59 - 7.65 = 7.94).

To get a result showing the use of the battery, its cost must be divided by 4.

[3] Purchase and reinjection values as at 30 December 2019

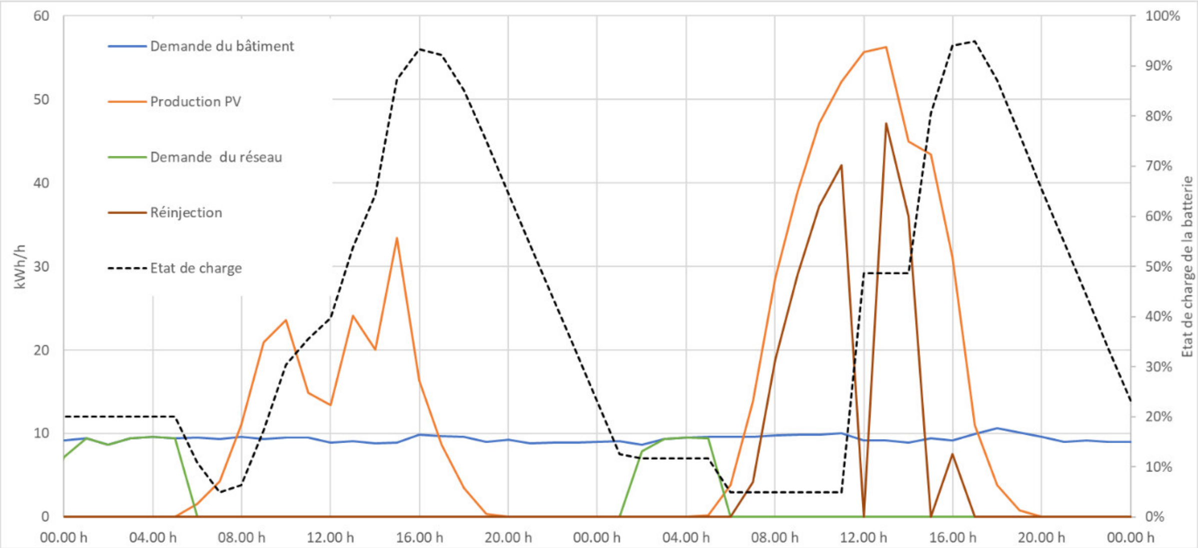

Figure 24: Example of 10-11 May 2018, with a storage cost of 3.3 cents per kWh

<u>Finding the break-even storage cost with 2019 electricity prices</u>

The following graph shows at which storage cost the battery becomes profitable. Two tariffs are used for comparison: VED and SIG: electricity prices in Geneva. The capacity of the battery also plays a role.

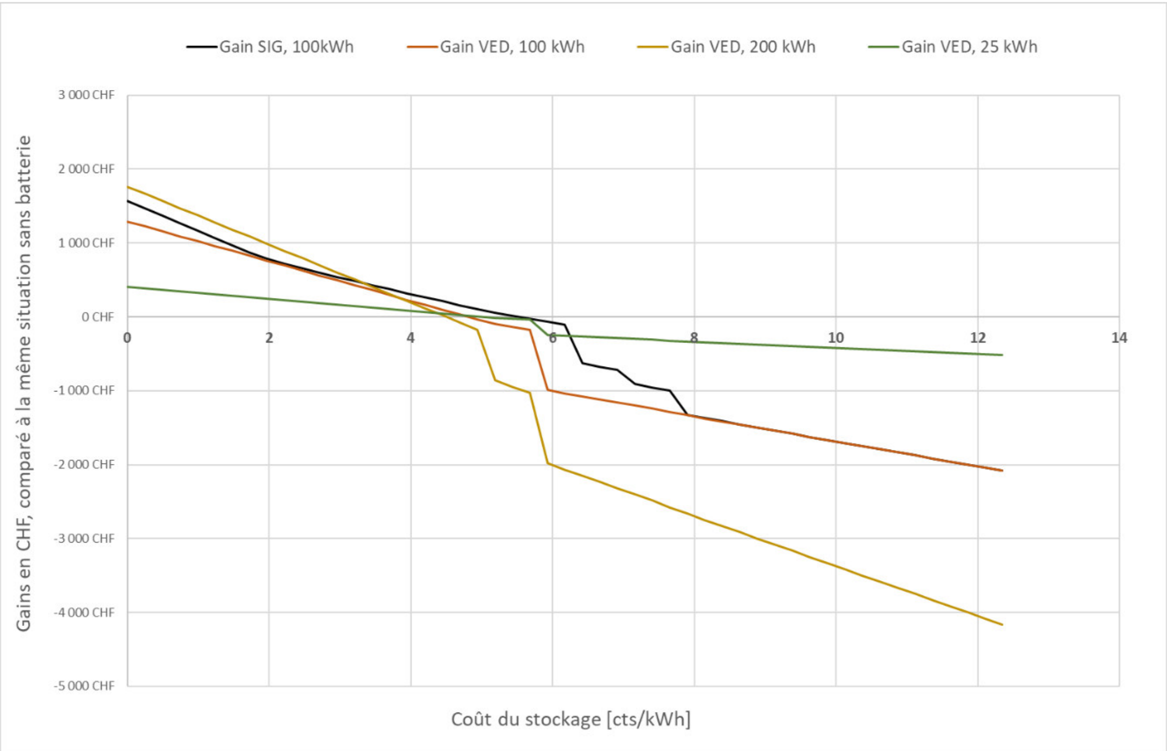

Figure 25: The break-even point is at most 5 cents per kWh

Optimal size for a battery at 75% lower cost

For any battery capacity and for both types of electricity prices, the system is not profitable under 2019 conditions (the storage price being 13.2 cts/kWh). To be profitable, the cost of the battery must be reduced by at least 50% (in the case of the VED tariff and for a 100 kWh battery, the price reduction would have to be 64% to reach the break-even point).

On the market for second-hand batteries from electric cars, the cost per kWh is CHF 400/kWh[4] , which is about 25% lower than the new price, with a 10% reduction in lifetime. We are therefore still far from the 75% target (the storage cost would then be 11.0 cts/kWh). However, from a life cycle assessment point of view, the second life of the battery is really interesting, as it allows the full potential to be used up in static before having to recycle it.

VED: Visp energie prize SIG: Geneva industrial services prize.

The number between 25 and 100 describes the percentage of the battery price (VED_25 indicates the use of Visp Energie prices and that the battery price has been divided by 4).

Electricity prices :

Table 2: Comparison of VED and SIG tariffs

Tariffs 2020 in cts/kWh	VED	GIS
Maximum cost of electricity	15.59	16.65
Minimum cost of electricity	12.54	11.17
Maximum gain of the feedback	7.65	8.44
Minimum feedback gain	5.05	5.08

The following figure shows the VED_25 case in detail:

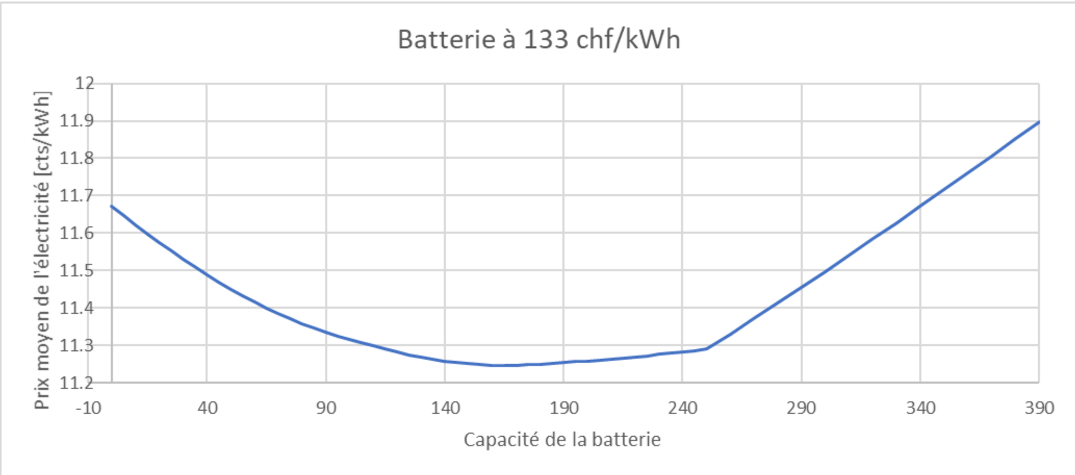

Figure 26: If the storage cost is reduced by 75%, the optimal battery capacity would be 165 kWh

The optimal battery size, for VED tariffs and a 75% reduction in battery price, would be 165 kWh. The average cost of electricity would fall from 11.67 to 11.25 cents per kWh, which would be the same as the average cost of electricity,which is equivalent to a gain of CHF 483 per year, over the 21.4 year service life of the battery.

[4] We received an offer for a 22 kWh battery at CHF 6900 without warranty and for 400 past cycles. With 90% maximum charge and 10% minimum, we arrive at a cost of 392 CHF/kWh

Under current conditions, a 165 kWh battery would have the following impact:

Table 3: Balance of a battery under current conditions at the Enalpin site

Type	Average electricity cost in cts/kWh
Without PV or battery	14.23
With PV without battery	11.67
With PV and battery	14.90

The PV without battery saves CHF 2900 per year, i.e. a total of CHF 87'000 over the lifetime of the PV.
The battery would cost CHF 766 per year, giving a total loss of CHF 11,490 over 15 years.

Explanation of the dynamic resale electricity price allocation system for a PV consumer-generator-battery system

General operation
The aim is to create a dynamic tariff for the resale of power from PV installations that takes into account demand and supply. A battery, providing flexibility in consumption and production, would be valued.

Methodology
The dynamic tariff is calculated by arranging demand and supply in order, without freedom (i.e. without batteries). The electricity prices vary according to these two ranks. The minimum price is the marginal cost of PV production, and the maximum price is the purchase price of electricity minus the stamp and public charges. New arrangements are made several times with new prices and with a battery until a fixed price is reached.

Results

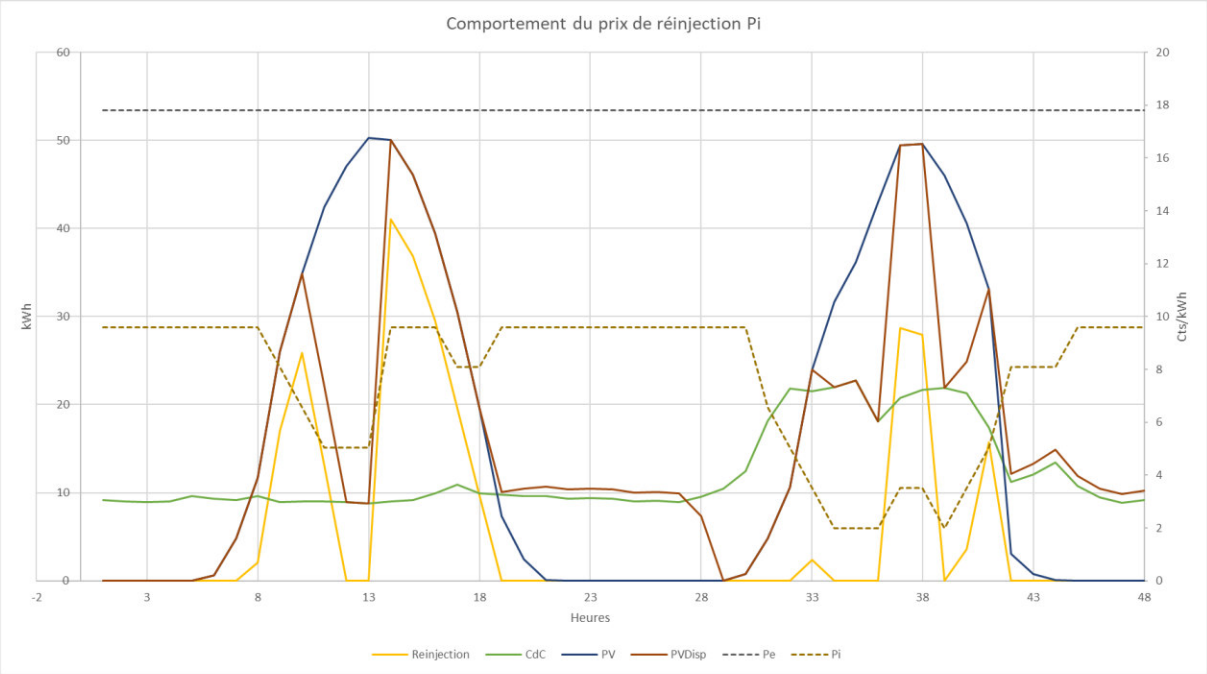

Figure 27: Behaviour of the PI reinjection price

The method does not converge, but alternates. The results of the 6th iteration (which has the maximum daily gain) were chosen. The battery allows the power to be fed back when prices are highest and energy is available. It is the charging of the battery that is prioritised, in order to save the purchase of electricity from the grid. When there is enough overproduction (i.e. PV production - consumption) to fully charge the battery, the surplus is sold back when the price is highest.

Consideration of electric vehicles and charging stations for site 5 - EnAlpin

<u>Methodology</u>

The data used are the measurements of the charging stations for one week in winter and one week in summer of the year 2021.

The selling price per kWh of electricity is 40 cts/kWh. The battery used has a capacity of 100 kWh (with a state of charge between 5 and 95% of its nominal capacity) for a price of 170 CHF/kWh, which corresponds to the price of a Zoe car battery. We divide the battery price by two to simulate a second-hand battery. This gives a storage cost of 4.7 cents per kWh.

The simulation optimises the energy flows over a week, without making a prediction, but with full knowledge. The electricity purchase prices from the grid are Visp Energy prices of 2021. The electricity sales prices at the electric vehicle terminals are given by Enalpin. The feed-in tariffs are calculated via a dynamic price described above.

<u>Results</u>

A battery can significantly increase the self-consumption rate in the 8 scenarios described: Summer/Winter scenario, with/without electric vehicle and with/without battery. The cost of storage of about 5 cents per kWh is the limit of profitability of the battery.

In the summer, the cost of recharging electric vehicles is close to financial neutrality, at CHF 20 per week. In winter, on the other hand, the costs are around CHF 300 per week.
Finally, in 2021 conditions, a second-hand battery has little impact on profitability. When the demand for electric vehicles is higher and batteries are cheaper, the break-even point will be reached.

	Hiver				Eté				
Demande électrique du bâtiment	1984				1925				kWh
Production PV	233				2392				kWh
	Véhicule él.		Pas de V. él.		Véhicule él.		Pas de V. él.		
Demande électrique des bornes VE	90		-		179		-		kWh
(VE : véhicule électrique)	Batterie	Sans batt.	Batterie	Sans batt.	Batterie	Sans batt.	Batterie	Sans batt.	
Taux d'autoconsommation	100%	79%	100%	79%	56%	45%	52%	40%	
Demande réseau	1851	1890	1753	1800	800	1025	720	952	kWh
Réinjection sur le réseau	1,1	49,85	1,1	49,85	1063	1340	1160	1446	kWh
Demande réseau	320	327	303	311	122	157	109	146	CHF
Gain réinjection CHF	0,1	1,8	0,1	1,8	54	63	56	66	CHF
Coût de la batterie	4,3	-	4,3	-	24,6	-	25,4	-	CHF
Gain de la vente aux VE	36	36	-	-	72	72	-	-	CHF
Bilan sur la semaine	**-288**	**-289**	-307	-309	**-20**	**-23**	-79	-79	CHF
Charge de la batterie	48,75	-	48,75	-	277,1	-	285,85	-	kWh
Prix vente max	17,62	17,62	17,62	17,62	15,73	15,73	15,73	15,73	cts/kWh
Prix vente min	16,38	16,38	16,38	16,38	14,98	14,98	14,98	14,98	cts/kWh
Prix revente max	9,41	9,41	9,41	9,41	7,52	7,52	7,52	7,52	cts/kWh
Prix revente min	2	2	2	2	2	2	2	2	cts/kWh
Prix vente min VEL	40	40	-	-	40	40	-	-	cts/kWh
Prix vente max VEL	40	40	-	-	40	40	-	-	cts/kWh
Différence batterie / sans batt.	5,3		6,6		27,1		26,1		CHF

Figure 28: Comparison of different scenarios

3.5 On-site measurements between September-November 2022

Within the framework of the OFEN MSID project, we have measured the self-consumption part in two specific cases. Firstly, we are interested in our off-grid development site (site 6) where we can control two batteries (Weco and Victron) through their respective inverters (Studer-Innotec Xtender and Victron) as well as the owner's hot water. A complete algorithm has been set up and has been running continuously since its commissioning on 3 November 2022. In a second step, we look at the sites of our partner SEIC-Télédis in Nendaz. As mentioned above, the Nendaz site contains a Leclanché Apollion cube battery that can be driven by an Imeon three-phase inverter.

<u>Off-grid development site</u>

At our off-grid development site, we have been thinking about how to best optimise the electricity produced by the photovoltaic panels. We have created an algorithm with several cases including

- Inverters and a Victron battery (5kWh) with a state of charge (SOC) greater than 50% or not
- Studer-Innotec Xtender inverters and two stacked Weco batteries (2x 5kWh) with SOC above 20% or not
- PV above consumption or not

Note that the algorithm only controls the Studer-Innotec Xtender inverter and the hot water relays.

As the current law does not allow for the reconstruction of an own consumption pool (OCP) with the neighbour because a small plot of land separates them, the owner has installed a generator in order to protect itself in case of bad weather over several days. Before the algorithm was implemented, its Victron battery was overused as we can see from the graph below:

Figure 29: SOC Studer XTender and Victron evolution on the Off-grid development site (before algorithm implementation)

The battery would often drop to 0 which is not recommended for the latter. In addition, the owner had to manually switch on the hot water in his house. You will find in annex 1 a pdf file containing the visual of the implemented algorithm. On the MSID platform, we can see below its implementation:

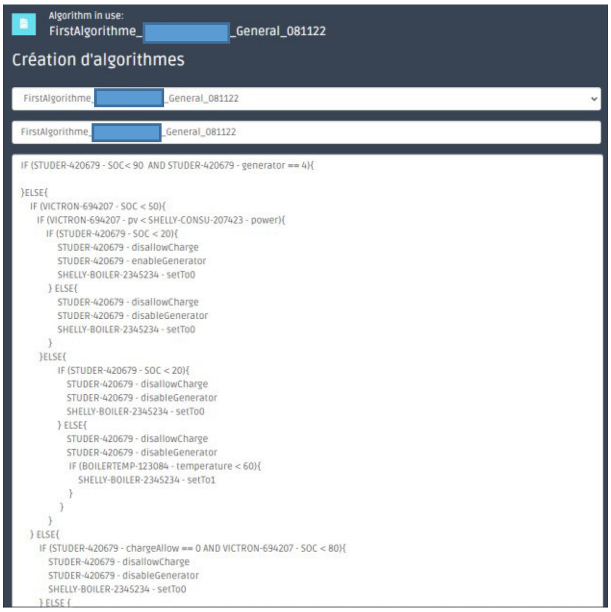

Figure 30: Creating the algorithm from the vlhmsid platform

In order to measure the efficiency of the algorithm created, we let it work for several weeks. This allowed us to validate its operation in sunny and bad weather. We can see for example on the graphs below the reaction of the algorithm in prolonged bad weather or in good weather.

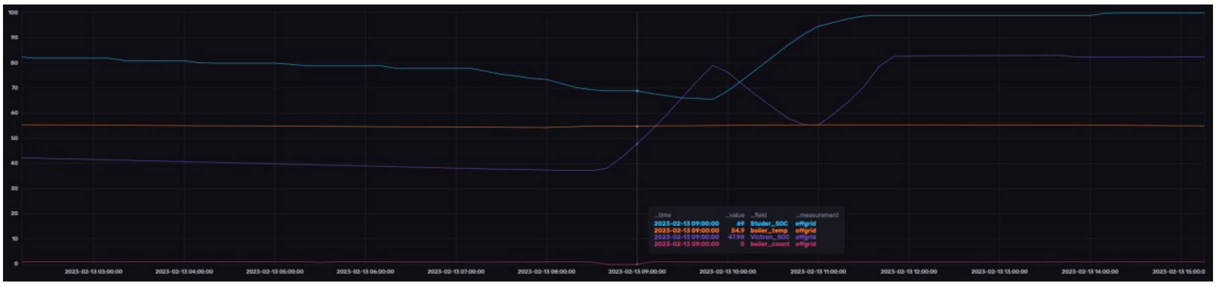

Figure 31: SOC measurement of the two batteries at the offgrid development site (bad weather)

As we can see in the figure above, the algorithm closed the hot water relay (pink) when charging the Victron battery (purple) allowing for a faster recharge. Once the 80% SOC of the Victron battery was reached, the algorithm reopened the relay.

In this last graph, we can see that the algorithm started and cut off the charging of the Weco batteries by the Victron in an automated way when the Victron battery reached 50%. When the Victron battery reached 80%, the system opened the relay again, allowing the Weco batteries to charge through the Victron battery.

With the help of the algorithm, we are able to allow the house owner to last 2 full days using only his batteries in case of bad weather. Previously, he was unable to self-consume during a day without sunshine. In addition, the automation of the water heating provides additional comfort. Depending on the energy available, the relay is automatically activated to heat the water.

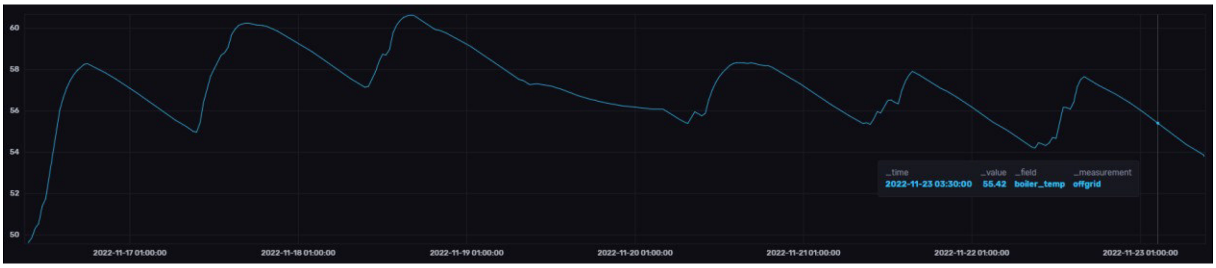

Figure 32: Hot water temperature measurement of the off-grid development site

<u>SEIC-Télédis Nendaz production site</u>

Once tested, on our development environment, we planned a test of three algorithms on September 21, 2022 at the SEIC-Télédis site in Nendaz. We noticed that our orders were working, however the IMEON inverter seemed to modify the registers in an uncontrolled way. Indeed, the basic inverter control system was activated in parallel. Once the IMEON control system was disabled, we started testing during the day on 22 September 2022.

For the first algorithm tested, we validated the action related to a potential electricity shortage. In the code below, we have defined a shortage period (12:12 on September 22, 2022). One hour before the announced shortage, i.e. from 11:12, the battery is charged to 100%.

IF (Penurie - start < NOW) {

IMEON - Charge

}

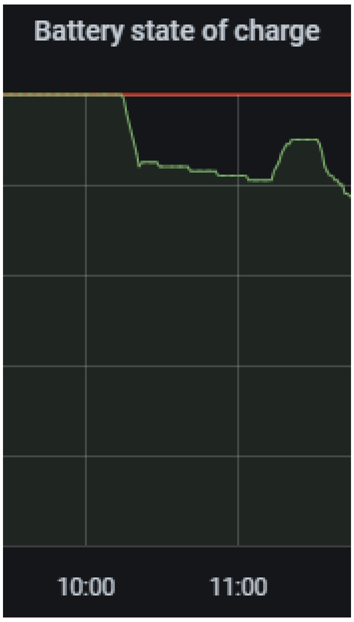

Figure 33: Data from the first test (shortage) of the algorithm at the Nendaz site

As we can see from the graph below, it did indeed work, the battery did start charging at 11:12.

IF (Prediction Production > 3000) {

IMEON - Charge

} ELSE {

IMEON - Neutral

}

In the second algorithm, we check the value of the photovoltaic production prediction created in workpackage 4. If it is greater than 3kW (3'000W), we charge the battery. If it is not, we do not trigger the charge. We can see this in the figure below:

Figure 34: Data from the second test of the algorithm at the Nendaz site

The battery was in neutral (the small discharge is due to the resources needed to maintain the battery). Then the prediction mentioned that there would be more than 3kW of power in the next hour which triggered the charging of the battery from 11:59.

We tested a third, more complete algorithm to see if the system met the needs of the field. You can find below the code of this last tested algorithm:

```
IF (Prediction production > 3000) {
    IF (IMEON - SOC > 95) {
        IMEON - Neutral
    } ELSE {
        IMEON - Load
    }
} ELSE {
    IF (IMEON - SOC < 20) {
        IMEON - Neutral
    } ELSE {
        IMEON - Discharge
    }
}
```

In this third algorithm, we integrate a data retrieved directly from the IMEON modbus such as the SOC of the battery. If the photovoltaic prediction is sufficient for the next hour, we check if the battery is not already full and if not, we put it on charge. In case the PV prediction is low, we check if the battery is not too discharged and in this case we discharge it according to the consumption.

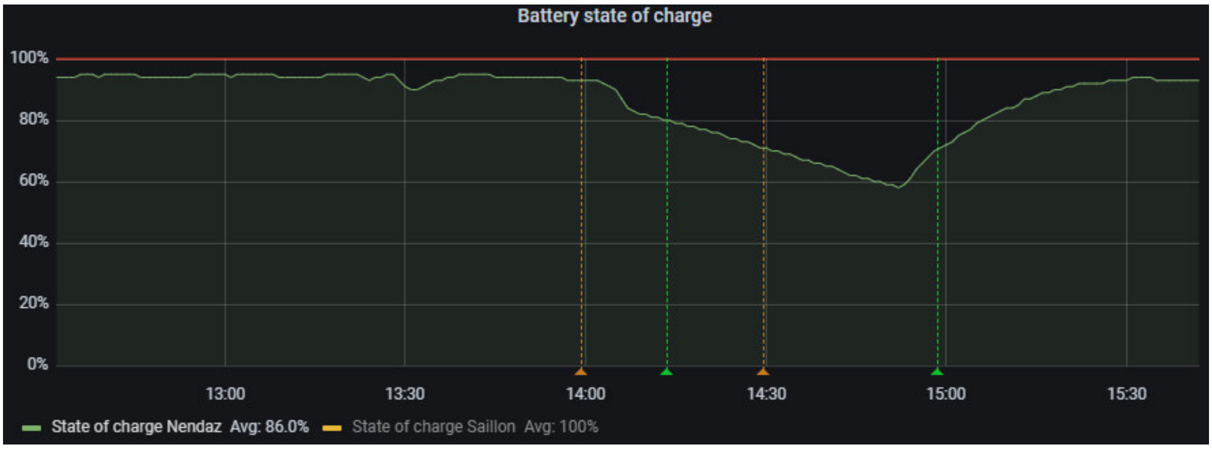

Figure 35: Data from the third test of the algorithm at the Nendaz site

As we can see in this third graph, the battery remained at 95% from 12:00 to 14:00 because the prediction tells us that the panels would produce more than 3kW. Then in the afternoon (between 2pm and 3pm), the prediction was not so good, so the algorithm discharged the battery in order to meet the needs of the inhabitants of the house. Then from 3pm onwards, the 3kW mark was exceeded again allowing the battery to be charged up to 95%.

4 Network voltage problems

4.1 Introduction

The Swiss electricity grid is over 250,000 kilometres long and exists on 7 different levels. The very high voltage level 7 of 380kV or 220kV is used to transport large amounts of electricity over long distances, as is the case for imports or production. The electricity then passes through transformer levels, high voltage (between 36kV and 150kV) and medium voltage (between 1kV and 36kV) before arriving on the low voltage level 7 (≤ 1kV) used in household sockets.

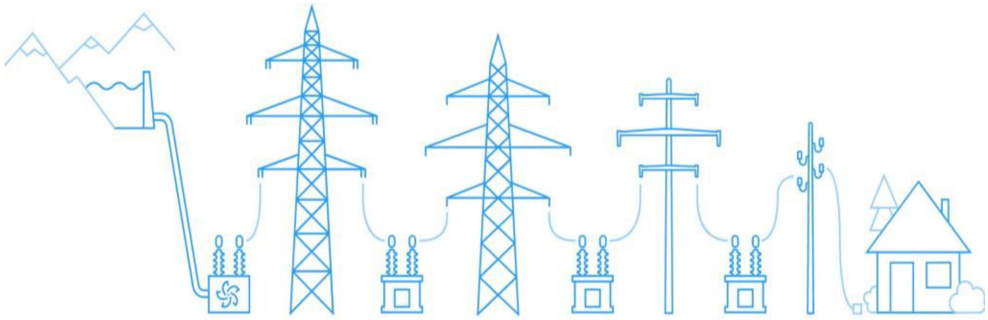

Figure 36 Voltage levels of the Swiss electricity network

With the deregulation of the electricity markets, which is leading to the gradual privatisation of the electricity production and distribution sectors, we are now witnessing a decentralisation of energy production in the electricity networks.

The current structure of the electricity distribution network needs to be rethought to accommodate the increasing number of renewable energy generators in low voltage networks. Indeed, the insertion of a large number of generators leads to overvoltage problems in these networks which, depending on the state of load of the network, can lead to non-compliance with the voltage values authorised by the electrical standard (BOUAKRA, 2016)

In order not to exceed the maximum allowed voltage, intelligent power management systems must be introduced into the grids. These systems manage the charging cycles of the batteries in order to reduce the amount of load introduced into the grid during a period of high generation.

MARI (Manually Activated Reserves Initiative) is a platform for the cross-border exchange of control energy. The MARI platform enables the auctioning, billing and monitoring of fast tertiary control energy within the European internal electricity market (activation time of 12.5 minutes and delivery time of 15 minutes).

4.2 Competence

To address the above-mentioned voltage management issues, several competencies were brought together in this project.

As for self-consumption, it is essential for the management of grid voltages to be able to control the battery via the inverter. The control box installed by HES-SO is able to control and read the registers of the Studer-Innotec Xtender XTH inverters (OIKEN installation in Pont-Chalais) through a Modbus RTU communication and the Studer Next3 inverter (FMA installation in Cergnement) through a Modbus TCP communication.

The second necessary skill is the collection of meteorological data and the prediction of the production of the photovoltaic installation, which allow to anticipate possible overvoltages of the network and thus trigger a charge of the batteries. Conversely, if consumption causes a drop in voltage, the battery can be discharged.

An additional skill to correct the low-voltage grid problem is the analysis of the maximum voltages during several photovoltaic production curtailment scenarios. These studies make it possible to define the possible voltage thresholds in an installation in order to dimension the battery capacity according to the desired voltage quality.

4.3 Realization

When creating the microgrids, we established a methodology for the optimal sizing and control of the energy storage systems, which takes into account the voltage constraints of the low voltage distribution network (LV). We applied the methodology to the cases of FMA - Site 1 (Cergnement farm) and OIKEN - Site 4 (Sierre tennis). Both sites have a photovoltaic installation which reveals the problem of voltage rise (reaching critical voltages) during the injection of the surplus solar production. We will detail the methodology to solve the problem in five points:

Analysis of the initial situation of site 1 - FMA and site 4 - OIKEN

In this first section we study the characteristics of the LV networks of the respective sites, as well as the measurements of the physical parameters related to the energy consumption of the site and the LV network. This procedure will allow us to target the problems and define the best solution strategy.

The information gathered from the FMA network and the measurements is summarised in the figure below. They allow the location of the end of line site as well as the measurement points. The measurement data available are from January 2019 to August 2020.

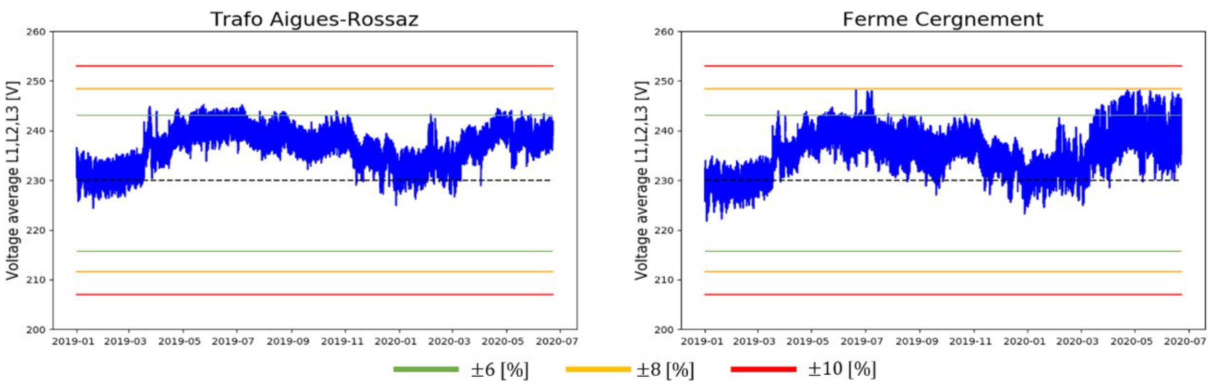

Figure 37 Voltage measured at the transformers and at the farm (15 minute timestamp)

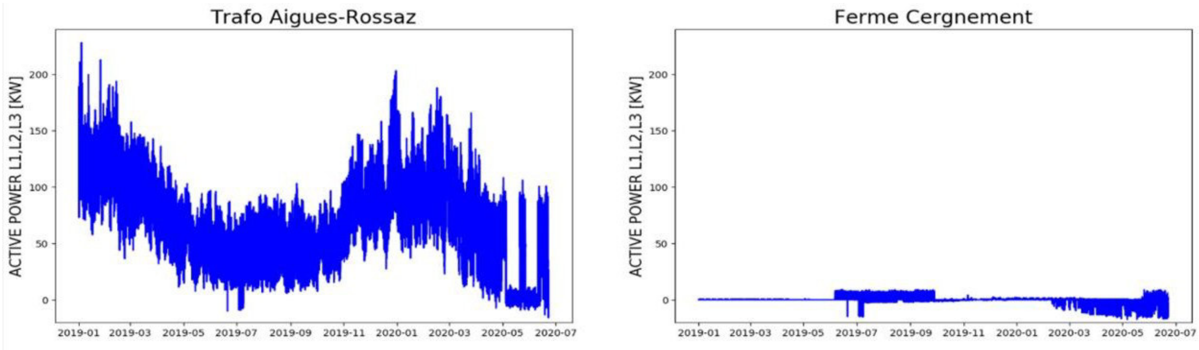

Figure 38 Active power measured at the transformers and at the farm (15 minute timestamp)

The analysis of the voltage and active power measurements at the farm reveals that the injection of surplus solar production becomes critical in spring/summer. The decrease of consumption in the whole grid in these periods and the increase of injection causes the voltage level at the farm to rise to about 1.08 pu (~248*V*) at full production.

As far as the OIKEN installation is concerned, the information gathered from the network and the measurements is summarised in the figure below. The main characteristics of the network were able to be retrieved.

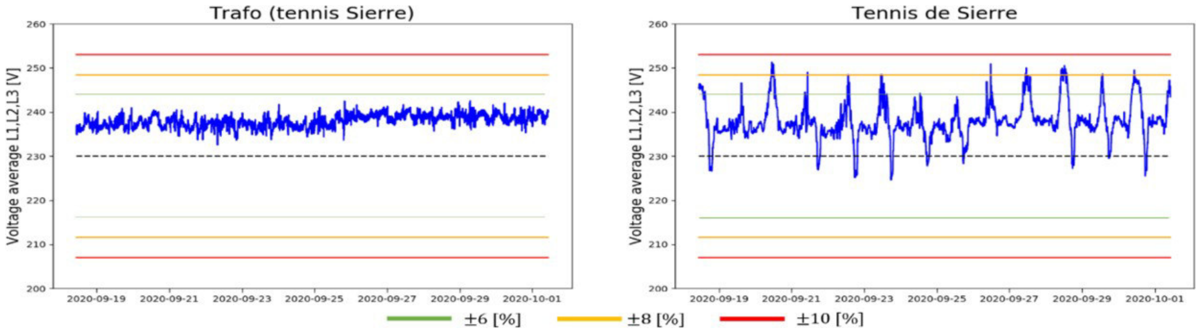

Figure 39 Voltage measured at transformers and tennis courts (1 minute sampling)

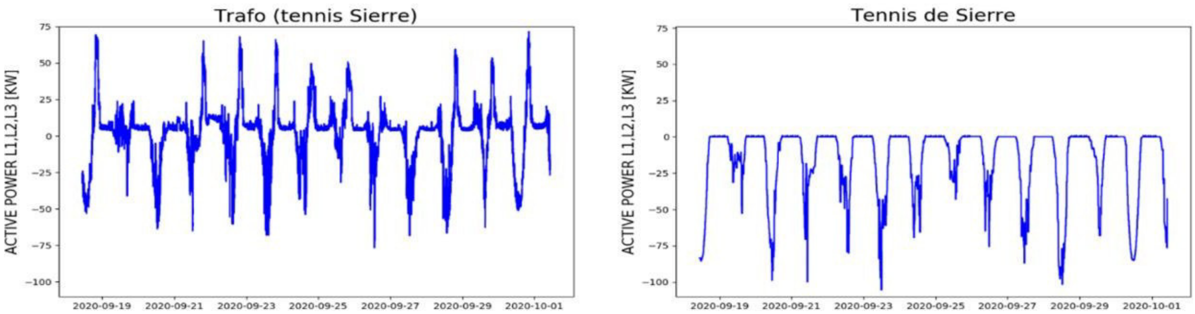

Figure 40 Active power measured at transformers and tennis courts (1 minute sampling)

We placed a measuring device at the transformer because no measurements were taken there. We only had historical measurements available at the tennis court. The high resolution measurement data (1 second sampling) is collected from 19 September 2020 to 1 October 2020 (2 weeks), using a Chauvin Arnoux PEL103.

The analysis of the voltage and active power measurements at the tennis court reveals that the injection of the surplus solar production is critical. The low consumption in the whole network and the increase of the injection causes the voltage level at the tennis court to rise to approximately 1.085 pu (~249.5V) in full production. We also note high voltage volatility due to large variations in power flow ±75kW within minutes.

Methodology for modeling and simulation of electrical networks

The modelling methodology consists in reconstructing the structure and physical elements of the network to be studied with the help of a tool. For this purpose, we used the *Python* programming language and the reference library for physical modelling and simulation of electrical networks, *pandapower* (Institute, 2022).

With the elements collected from the power networks, we can proceed with the modelling. Then, for the simulations, we inject the load measurements (active power) into the model and run the power flow solver iteratively for all measurements. The analyses of the simulation results from the FMA site and OIKEN are described below.

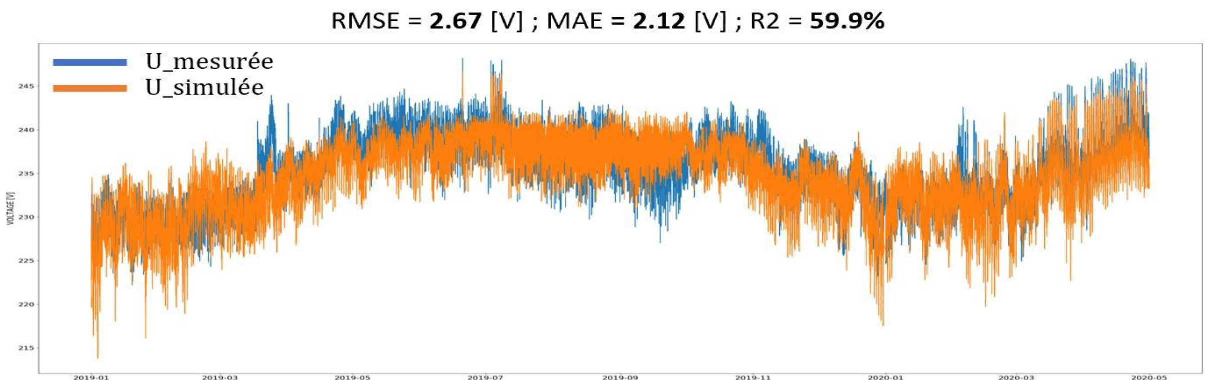

Figure 41 Comparison between measured and simulated voltage (FMA site)

Simulation and results of the physical model site 1 - FMA (Cergnement farm) :

The results of the physical simulations were optimised by varying the voltage level on the medium voltage side of the network to obtain the best results. Ideally, the simulated voltages are the same as the measured ones. This would mean that the model perfectly represents reality. Thus, the average error obtained is 2.7 [V] over 1.5 years of simulation (10 minutes sampling).

Simulation and results of the physical model of the OIKEN site (tennis of Sierre) :

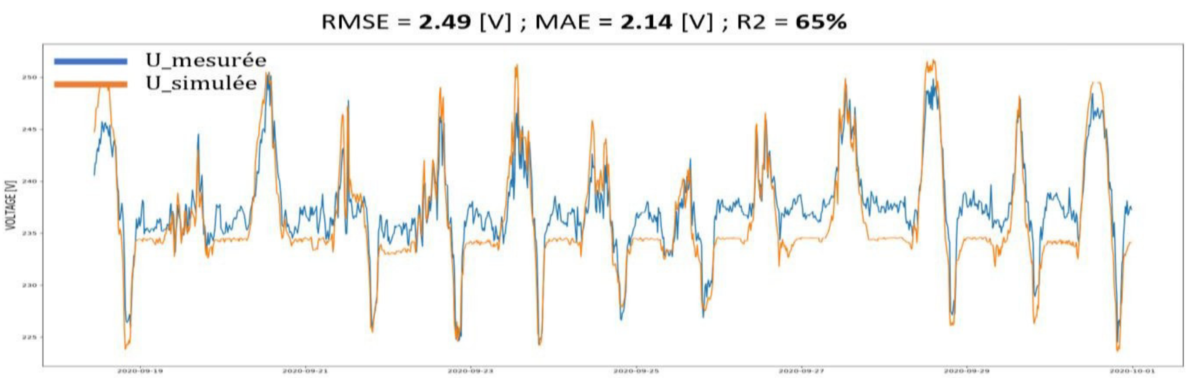

Figure 42 Comparison of measured and simulated voltage (OIKEN site)

The average error obtained over the 2-week simulation is 2.5 [V]. The network is thus relatively poorly represented by the model, especially when there is little or no load or generation at the tennis court.

Analysis of the results of the physical models :

First of all, we note that for both physical models the error is similar, of the order of 2.5 [V] regardless of the simulation horizon (1.5 years vs. 2 weeks). On the other hand, the resolution time of the power flows of these simulations is proportional to the number of time steps to be solved (about 30 minutes for about 52 500 steps). On the other hand, we established that the pandapower library was not sufficiently adapted for the control of energy storage which would be linked to voltage constraints. In order to overcome the inaccuracies and scaling problems of the physical modelling and simulation (pandapower), we developed a new methodology which is described in the next section and was presented at the IEEE CIRED 2021 conference (part 8 publication).

Improved modelling and simulation techniques

The concept developed is to fill in the inaccuracies of the physical model of the power system as much as possible. The process consists of three basic steps. Firstly, the physical model is calibrated, and to do this we use real measurements of the network in question. When we obtain the results for the simulation at a given time step, we compare and try to minimise the error between the simulated and measured voltage. To do this, the calibration parameter used is the voltage level of the medium voltage of the same network. Once the best voltage level (MV) has been calculated, the next step is to generate the power flow boundary dataset at the same time step using the calibrated physical model. The power is varied over a defined interval and all the simulation results obtained are stored. This process is then repeated to build the dataset for training the machine learning model.

Linear optimization for storage system design and control

The sizing and control of the storage in our study is based on a linear optimisation method that characterises the power flow model. The process and model used and completed is taken from the diploma thesis "Development of a tool for pre-sizing renewable energy systems." (Weibel Amine, 2019).

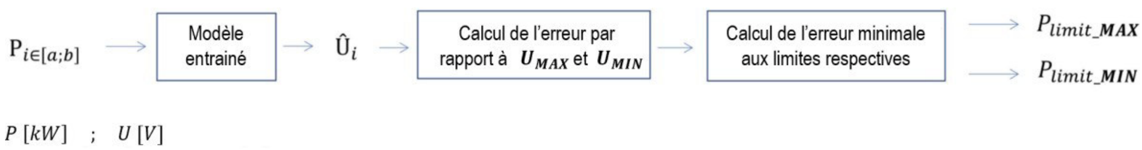

Figure 43 Power flow limit extraction process associated with the voltage limit

This involves determining the capacities of physical and temporal variables that meet specific constraints and an objective function. We define the objective function in order to minimise the investment costs of the storage as well as the operational costs that are associated with the purchase of electricity. The constraints of the problem are the technical limits of the technologies installed on site. However, the essential complementary element developed during this study is the implementation of dynamic power flow constraints. Using the improved model, we extract the power limits associated with the desired voltage constraints. This allows us to relax the originally non-linear classical "optimal power flow" optimisation problem. The process of calculating the dynamic power limits is shown below.

First, we use the trained model to predict the voltages in the power limit interval. Note that the voltage constraints are defined with (Umax, Umin). Secondly, the errors of

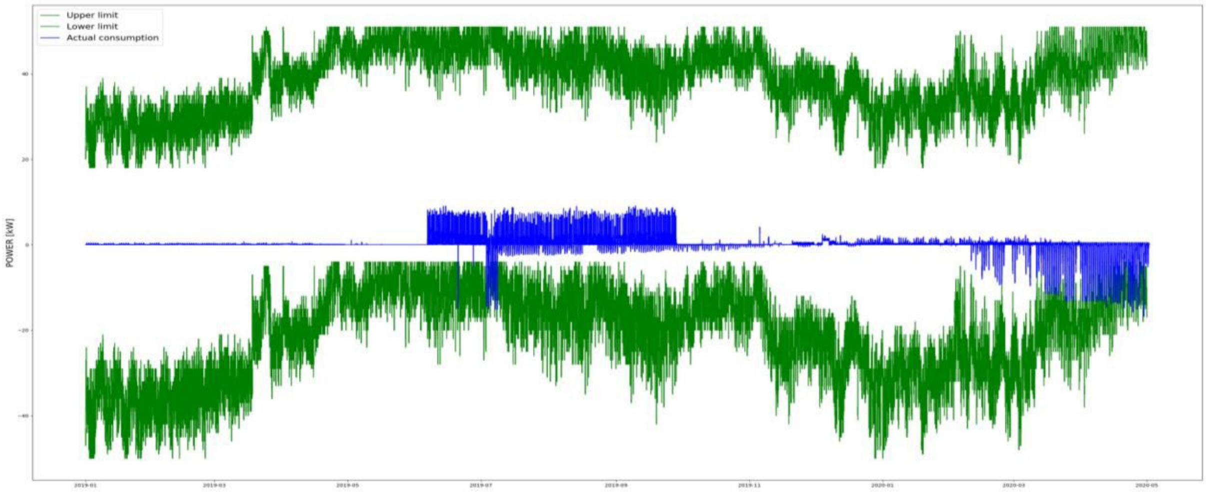

Figure 44 Measured power profile at the farm (blue) and calculated power limits at voltage constraints (±1.06 pu)

the voltage predictions are calculated with respect to Umax and Umin. Finally, we keep the power profiles of the smallest errors, which lie within the range of the defined voltage limits.

Finally, the figure above shows the minimum and maximum power profile to meet the voltage constraints.

Thus, these power limit profiles will allow us to limit the power flows in the optimisation problem formulation and thus satisfy the desired voltage constraints.

Results for the FMA site

In this last section we will present the results obtained from the design and optimal control of the implemented methodologies. We first deal with the case of the Cergnement farm (site 1 - FMA), then with the Sierre tennis court (site 4 - OIKEN).

For the FMA installation the table below summarises the performance results of the different models driven.

Table 4 Improved model performance site 1 - FMA (1.5 years)

Model	*Dataset used (nb. Days)*	*RMSE [V]*	*MAE [V]*	*R2 [-]*
Physic model	None	2.67	2.12	0.60
Model 1	4 (min/max)	0.930	0.590	0.958
Model 2	4 (season)	0.687	0.403	0.974
Model 3	8 (min/max & season)	0.698	0.491	0.975
Model 4	8 (min/max & season)	0.677	0.329	0.977

We select model 4 because it scores the best, with an average error of 0.7 [V]. This model allows us to size the storage according to the desired voltage quality and the required PV clamping.

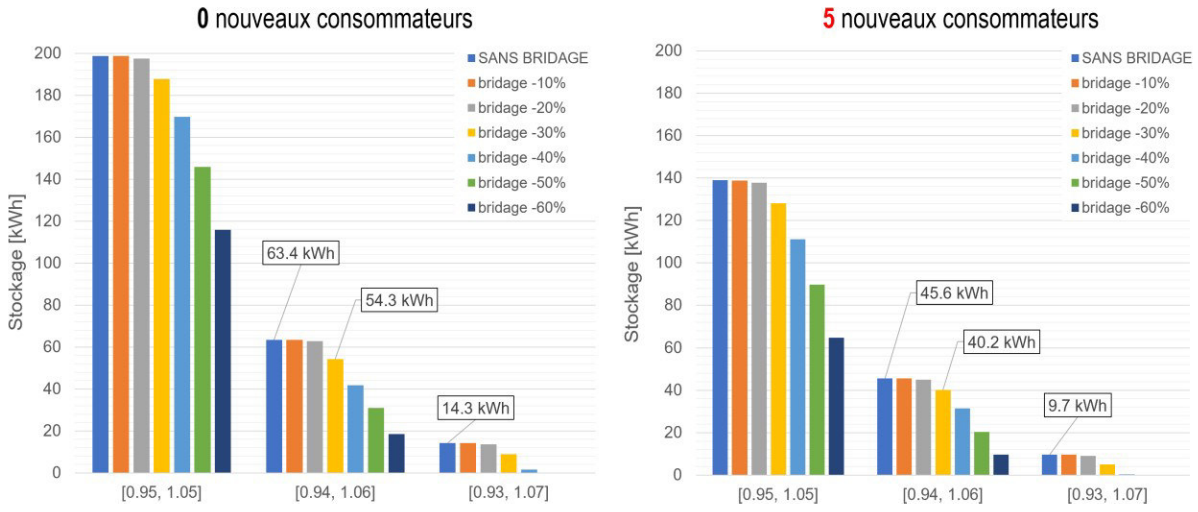

Figure 45 Optimal storage capacities as a function of voltage constraints and solar curtailment, with and without new consumers connected (site 1 - FMA)

We will now calculate the Impact of the bridle on income:

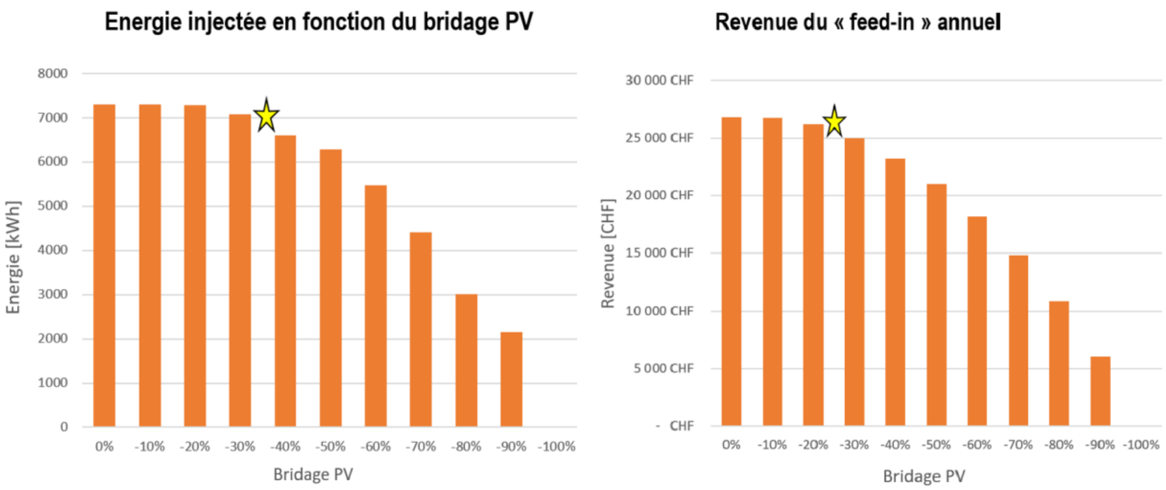

Figure 46 Injected energy and feed-in revenue as a function of PV curtailment (site 1 - FMA)

In addition to respecting the voltage constraints, an estimation of the storage with the addition of new consumers was carried out. To do this, we used the load curve of the transformer normalised to 1.5kW of the maximum peak and multiplied by the number of consumers. The following figure shows the sizing for the two situations.

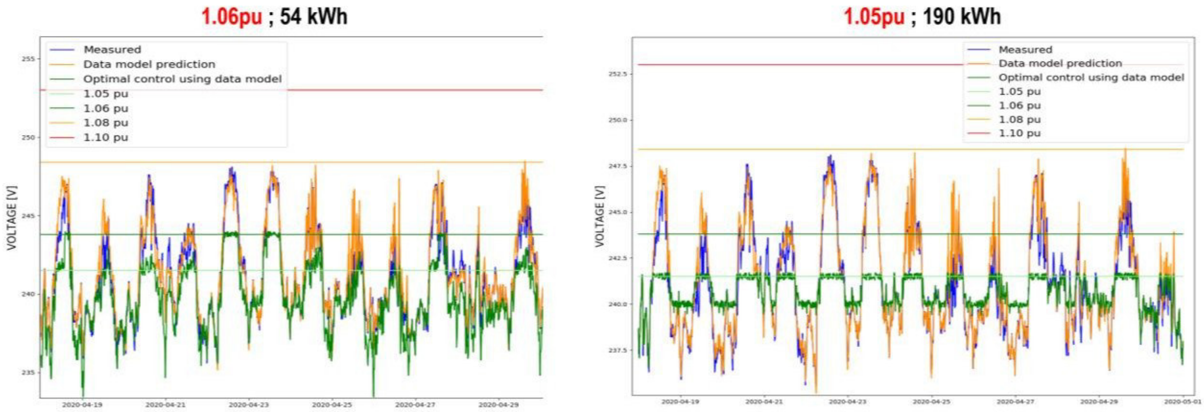

Figure 47 Storage system control for two constraint cases 1.05 and 1.06pu

It can be seen that the implemented control is perfectly effective. Firstly, the voltage limit is respected in both cases. Secondly, the smoothing strategy is particularly expressed in case 1.05pu, we observe a strong stability of the voltage thanks to the battery control.

<u>0 nouveaux consommateurs</u>

Contraintes [p.u]	Stockage [kWh]	P_charge [kW]	P_décharge [kW]	Invest*
[0.94, **1.06**]	64	12	13	~ **56** kCHF
[0.93, **1.07**]	14.5	6	7	~ **20** kCHF

<u>5 nouveaux consommateurs</u>

Contraintes [p.u]	Stockage [kWh]	P_charge [kW]	P_décharge [kW]	Invest*
[0.94, **1.06**]	46	15	7	~ **50** kCHF
[0.93, **1.07**]	10	13	6.5	~ **30** KCHF

**le prix: 500CHF/kWh (stockage) & 900CHF/kW (onduleur)*

Figure 48: Different scenarios (0 new consumers/5 new consumers

Summary: A sizing of 14.5 kWh with a 15kW inverter ensures voltage quality and an extension to 5 new consumers.

Results for the OIKEN site

In the context of the OIKEN installation, the table below summarises the performance results of the different models trained.

Table 5 OIKEN site 4 enhanced model performance (2 weeks)

Model	*Dataset used (nb. Days)*	*RMSE [V]*	*MAE [V]*	*R2 [-]*
Physic model	None	2.49	2.14	0.650
Model 1 (2.5k)	7 (340 values) -15min res.	1.38	1.00	0.890
Model 2 (5k)	7 (340 values) -15min res.	1.36	0.98	0.900
Model 3 (10k)	7 (340 values) -15min res.	1.34	0.99	0.903
Model 4 (10k)	2 (1000 values) -1min res.	1.20	0.82	0.917
Model 5 (10k)	7 (2000 values) -1/15min res.	0.98	0.67	0.941

We select model 5 as it performs best with 1 [V] of average error.

As in the case of FMA, this model allows us to size the storage according to the desired voltage quality and the required PV clamping.

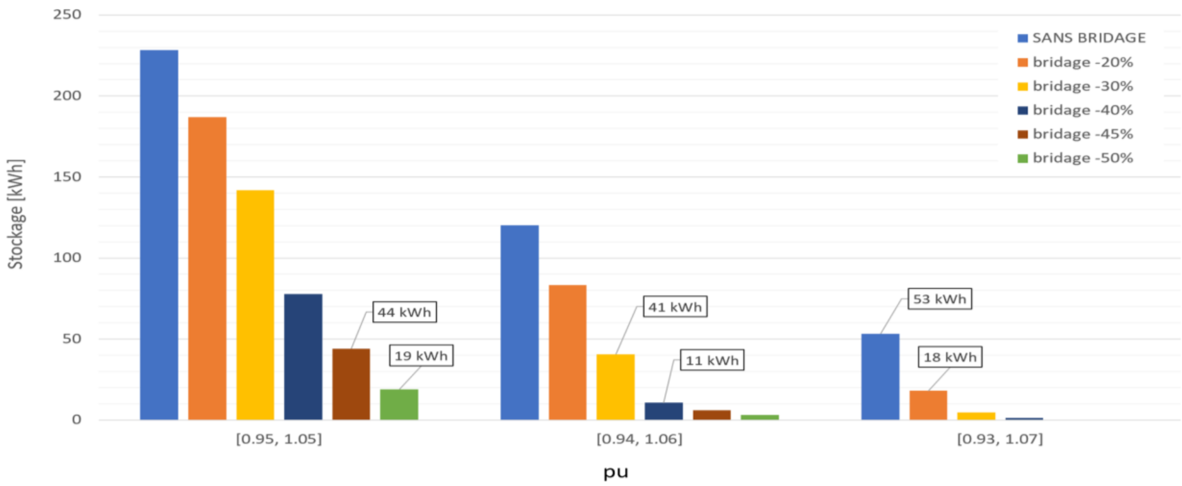

Figure 49 Optimal storage capacities as a function of voltage constraints and solar production curtailment (OIKEN site)

The monitoring demonstrates the effectiveness of voltage smoothing. The surplus power is fed back into the grid during voltage dips caused by sudden high consumption during a decrease in solar production. Thus, in addition to limiting high voltages, the storage system also limits voltage dips.

4.4 On-site measurements between September-November 2022

On site 2 of OIKEN, with the solarlog device, we obtain the necessary information on the measured voltage of the solarmax inverters. This voltage information is collected by the control unit of the HES-SO Valais-Wallis. With the help of this value, we are able to determine whether there is an increase in voltage, for example, as a result of excessive solar production.

For this OIKEN site, we have created an algorithm that allows the battery to maintain the state of charge between 45% and 55% which will give us a margin to charge the battery when the voltage is too high. With the latest version of this algorithm, when the voltage is above 230V, the battery will charge up to 90% to reduce the voltage.

The data in the graph below (Figure 50) was taken during the day of 16 November 2022, when the battery reached a state of charge of 90%, the modbus register 52 (chargeAllow) of the Studer-Innotec Xtender was modified to not allow the battery to charge beyond 90%.

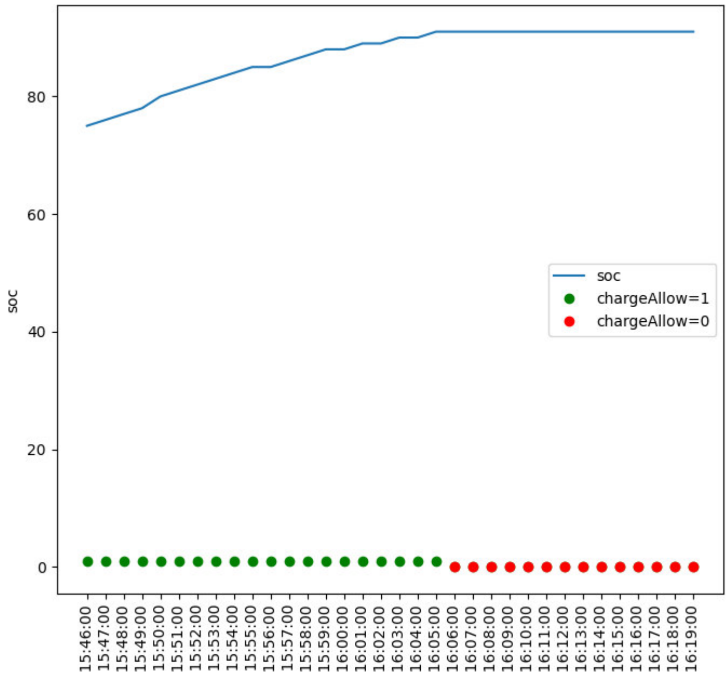

Figure 50: Data for the day of 16 November for the OIKEN site measuring the impact of the steering algorithm on grid voltage

The data of the second graph (Figure 51) was measured during the day 15 November 2022, when the last algorithm was implemented (at 16:05), the maximum defined voltage of 230V was already reached. The modbus register managing the charge of the Xtender was automatically modified by the algorithm in order to allow the storage of electricity in the battery.

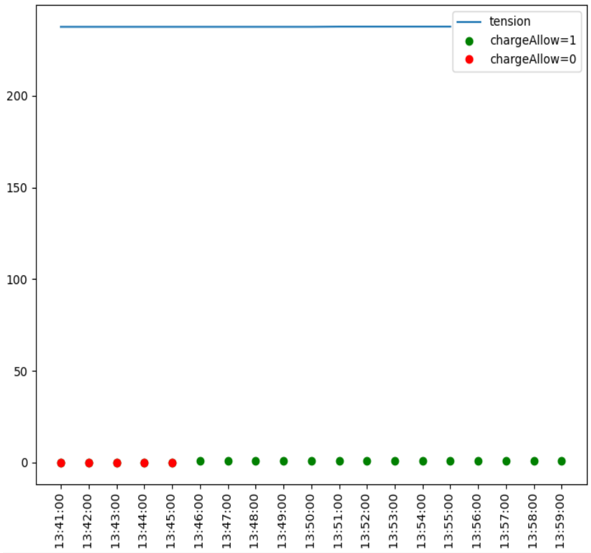

Figure 51: Data for the day of 15 November for the OIKEN site measuring the impact of the steering algorithm on grid voltage

Finally, a second site was investigated for the voltage problem. In this installation in Cergnement, it was a problem of undervoltage, as the farm is at the end of the FMA distribution network. For the FMA site, 3,500 litres of fuel oil were required annually for the farm's milking machine, which causes voltage drops. A Next3 inverter and three 5kWh Weko stacked batteries for a total of 15kWh of battery power were installed to allow voltage stabilisation.

With the Studer Innotec Next3 inverter, we have access to voltage data and can trigger a battery discharge when the grid voltage is too low. In a first algorithm, we have defined that when the voltage is less than or equal to 225V, the battery must be discharged up to 50% to compensate for this lack of voltage.

Looking at Figure 53, we can see that when the algorithm triggered the discharge of the battery on 22 January 2023 at 23:28, the grid voltage increased from 225V to 230V. We can also see that when the discharge is completed, the voltage has dropped from 232V to 227V.

Figure 52 Battery discharge in the FMA network initiated by the algorithm

This algorithm will also charge the battery to 100% when a voltage of 235V or more is detected during discharge or when a voltage of 230V is recorded after discharging the battery. Looking at figure 54, we can see an increase in voltage that triggers the charging of the battery, which subsequently reduces the grid voltage. However, charging will continue as long as the voltage does not drop below 220V, otherwise the discharge will be triggered again to correct the undervoltage problem.

Figure 53 FMA network battery charge initiated by the algorithm

5 Combinatorial strategies and aggregated valuation in VPP

5.1 Introduction

The objective is to combine the functionalities from the two previous themes in one tool. This tool offers the possibility for DSOs to view the data of their site(s) as well as to manually or automatically control the charging and discharging of their battery(ies) and other flexible loads (ECS, etc). The algorithms created from the user interface combine the research work carried out in this project. Several combinatorial strategies have been created in the VPP platform allowing the user to optimise the use of batteries.

5.2 Competencies

The skills developed in this stage are :

- Collecting and understanding data from the various electronic components of the sites
- Representation of VPP data on an online web platform
- Parameterisation of combinatorial algorithms
- Financial optimisation with the GB-Flex marketplace to value small capacities in the balance sheet subgroup
- Manual control of flexible loads by control algorithms
- Managing infrastructure to prepare for a planned energy shortage risk

5.3 Achievements

Financial optimisation (link with the GB-Flex marketplace)

To enable the economic valorisation of small capacity batteries, we have developed an interface with the GB-Flex system (SFOE project). We carried out the tests and validated the process with the INERA balance sub-group. By activating the GB-Flex system, the DSO can discharge or charge a customer's battery according to the spot price prediction in order to offer this flexibility to the local balance sub-group.

Two of the DSOs present in our OFEN MSID project were also part of the GB-Flex balance sheet sub-groups (OIKEN and Inera, of which SEIC-Télédis is a member).

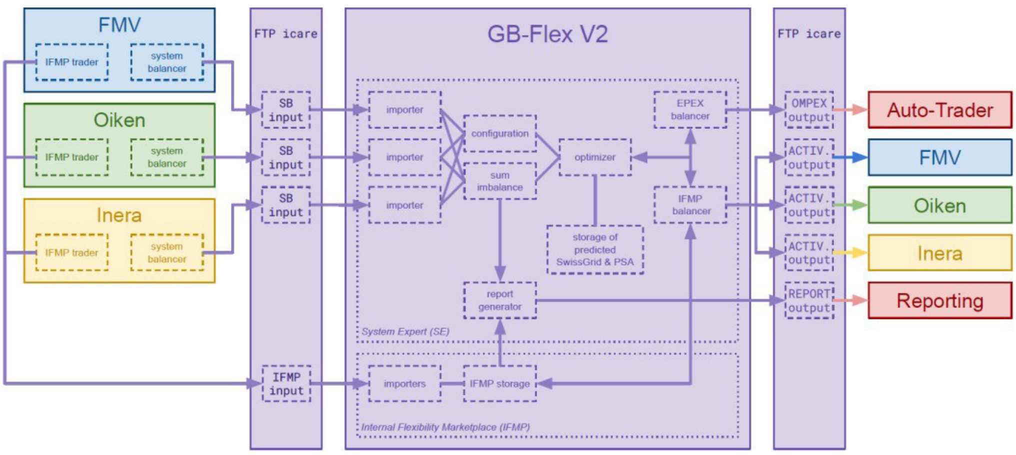

Figure 54: GB-Flex architecture

In the OFEN MSID project, the DSO has the possibility to activate or deactivate the GB-Flex system via a button on the VPP platform. When the system is activated, the aggregation of the DSO's batteries will be offered to the GB-Flex system every hour. In the SEIC-Teledis pilot site, for example, there are 2x 6kW of batteries and about 12kWh ready to be charged or discharged to help the DSO correct estimation errors as quickly as possible, which it would then have to pay to Swissgrid.

From an IT architecture point of view, a CSV is sent every hour with the availability of the batteries. The OFEN GB-Flex system processes the CSV and, as an output, returns a second CSV that indicates to the OFEN MSID project control module the action to be carried out (charge/discharge and quantity accepted by the balance sub-group).

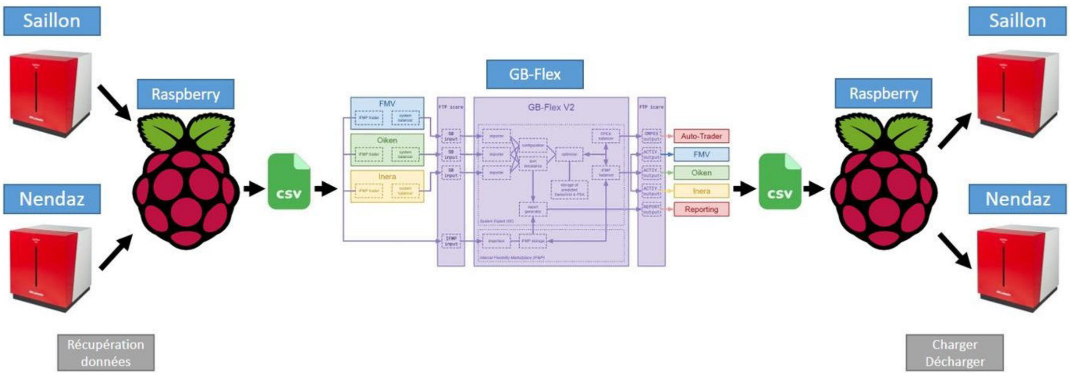

Figure 55: Integration of the GB-Flex marketplace into the OFEN MSID architecture

Virtual Power Plant platform

A VPP platform is developed with basic functionalities such as :

The secure login per DSO allowing exclusive access for its aggregated site(s):

Figure 56: Platform - Login

User and DSO management (viewing, editing, deleting) for the main administrator:

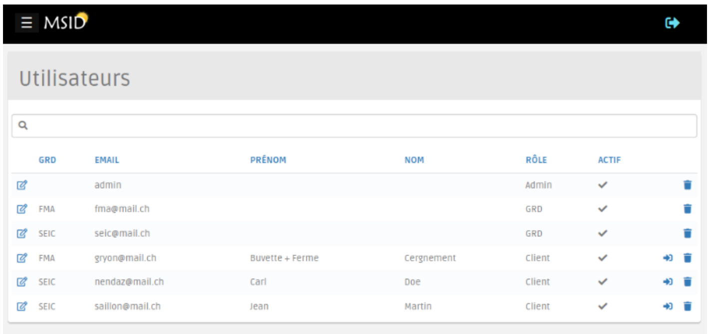

Figure 57: Platform - User Management

Viewing the dashboard of a pilot site :

Figure 58: Platform - Battery Aggregation Dashboard

Control algorithm

The VPP platform allows the creation of control algorithms. It is possible to parameterise the DSO site by adding, deleting or modifying elements (Figure 59).

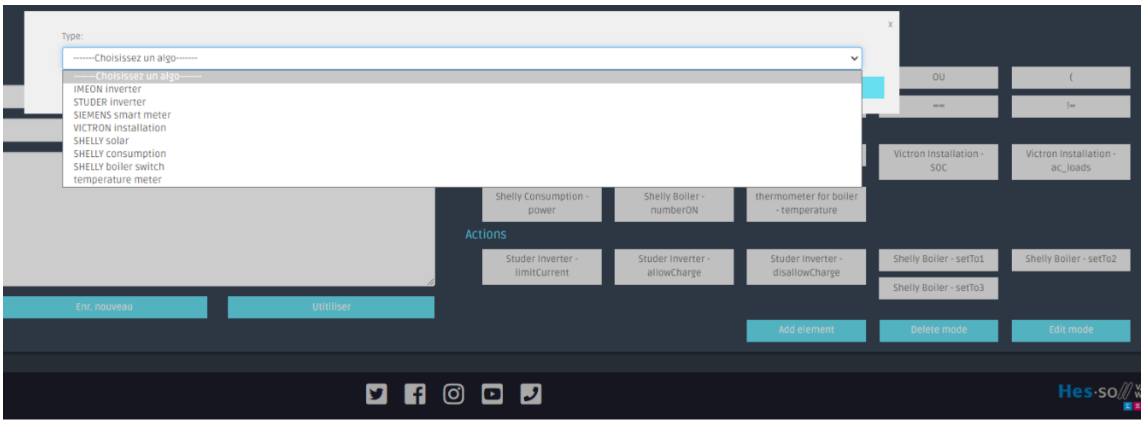

Figure 59: Interface for adding elements to the steering algorithm

With the algorithm creation interface (Figure 60), we allow DSOs to create their algorithms according to their needs with measures and actions defined according to the elements added in the previous step. The creation of several algorithms offers the user the possibility to define seasonal algorithms for example or specific algorithms depending on the installations. It can be deactivated and reactivated at any time. The user can also display the system logs (Figure 61) to see the actions taken by the algorithm.

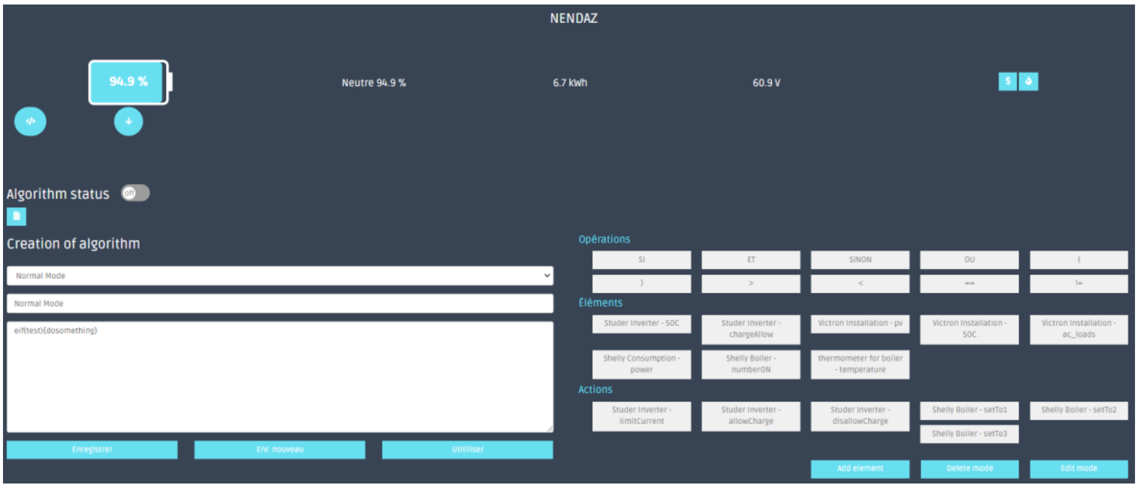

Figure 60: Interface for creating a control algorithm

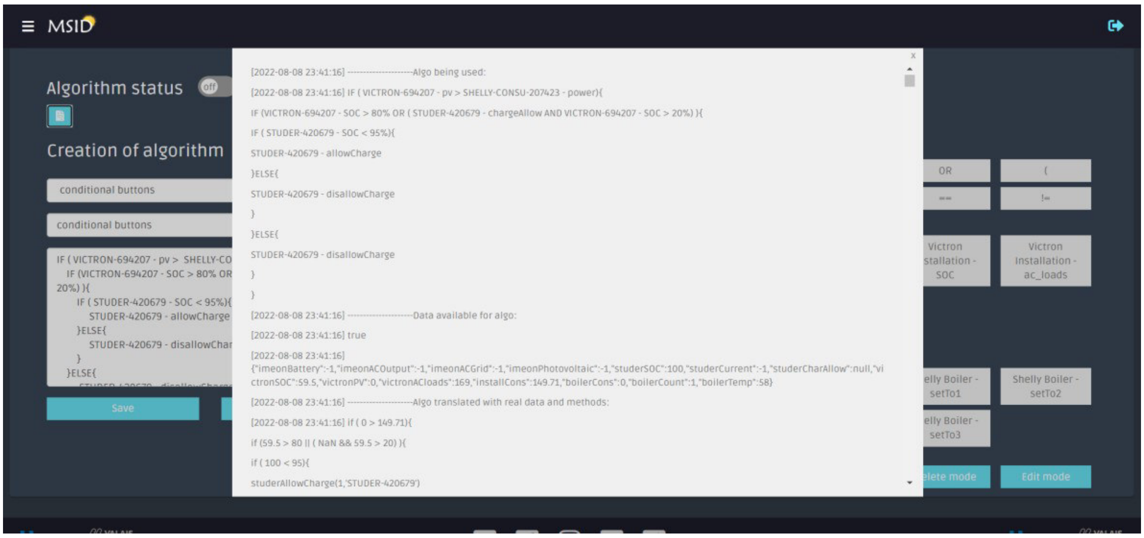

Figure 61: Display of the logs of the control algorithm

SMS notification system - Preferential rate for recharging electric vehicles based on the spot price

To improve the impact on the network of charging for electric vehicles, a combinatorial strategy has been implemented for the Enalpin case. The aim is to send information by SMS to a list of numbers defined by the GRD about a time when charging will be cheaper for the next day. This system will inform Enalpin employees that they can start charging the company's electric vehicles at a specific time. In the following illustration, you can see the configuration that allows DSOs to define the list of telephone numbers and the maximum spot price :

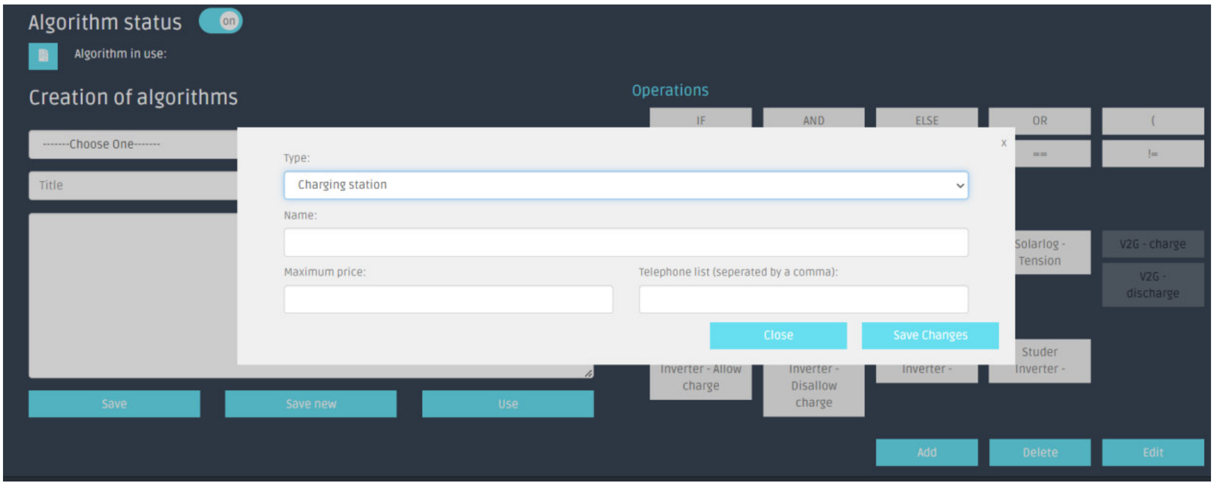

Figure 62: Parameterisation of the information system for optimising the charging of electric vehicles

The DSO by defining a maximum price of 16 cents tells the algorithm that the SMS should inform the registered numbers, during which time slots the previous day's spot price will be lower than 16 cents per kWh. As you can see on the graph below, the SMS will inform users that the tariff will be advantageous between 2pm and 4pm for the next day.

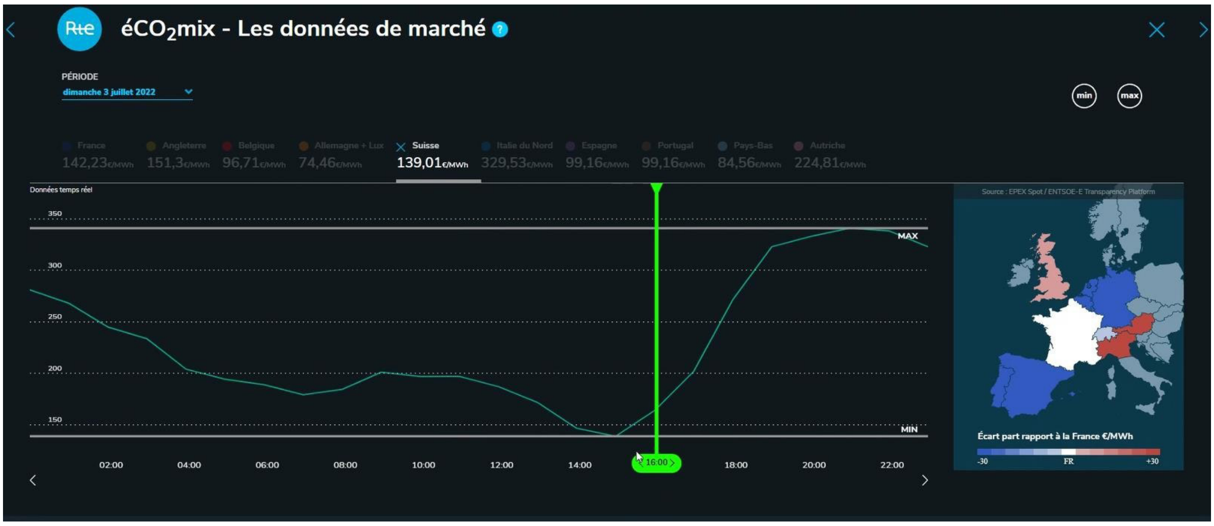

Figure 63: Swiss spot price for Sunday 3 July 2022

Below is an example of an SMS sent to users:

Figure 64: SMS sent to users in case of favourable spot price for the next day

Storage system sizing calculator

With the help of the work done on the network voltage, it is possible to generate graphs of the analysis of voltage and power measured in the installation and at the transformers. These graphs allow users to display voltage and power variations and to understand if the measured voltages exceed the limits of the standard.

The algorithm developed for the calculation and generation of the graphs has been integrated into the platform (Figure 65) and the results can be used to parameterise the thresholds for triggering combinatorial algorithms.

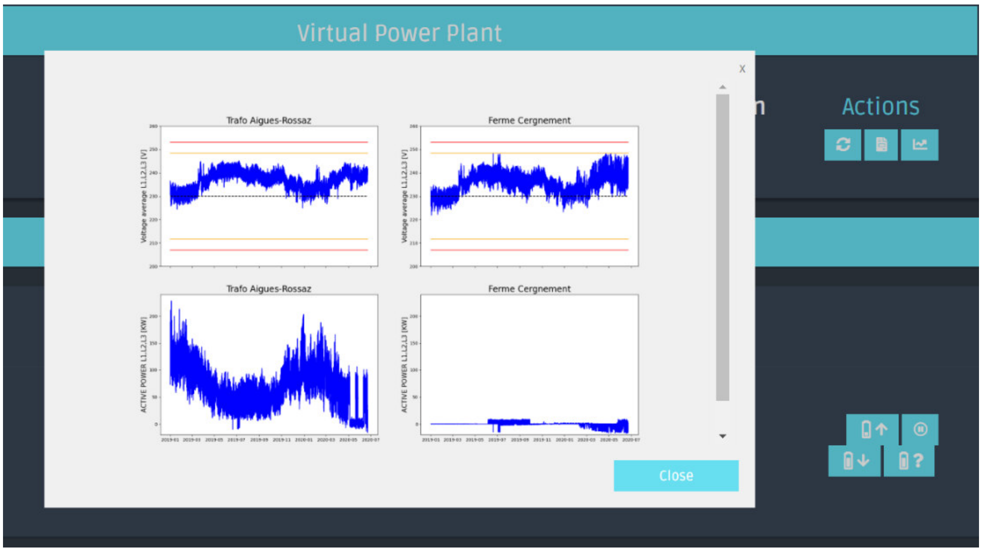

Figure 65 Display of measured voltage and power

5.4 Demonstrator

Control algorithm

The tests of the PV production prediction algorithm took place on September 22, 2022 at the SEIC-Télédis site in Nendaz. In a first step, we created a simple algorithm from the platform.

Figure 66: Test algorithm 1 for the Nendaz site

We activated it for a short time. The test took place from 10:10 to 10:20. The value of
As the "PredictionProd" cannot reach 20,000 because at its maximum it usually reaches the value of 3,300 kW, the objective was to validate that the algorithm would discharge the battery. We can see the result of the algorithm on the graphs set up on Grafana.

Figure 67: Graph of test result 1 22.09.22

Below is an example of a log generated by the control box that is accessible to the DSO.

```
[2022-09-22 08:05:16] ---------------------Algo being used:
[2022-09-22 08:05:16] IF (IMEON-420679 - predictionProd > 20000){
    IMEON-420679 - setCharge
}ELSE{
    IMEON-420679 - setDischarge
}
[2022-09-22 08:05:16] ---------------------Data available for algo:
[2022-09-22 08:05:16] true
[2022-09-22 08:05:16] [{"id":"IMEON-420679","pv":0,"ac_grid":4294964166,"predictionProduction":4797.3745,"predictionChargingStatus":1},{"id":"SHELLY-CONSU-694207","installCons":-1077.93}]
[2022-09-22 08:05:16] ---------------------Algo translated with real data and methods:
[2022-09-22 08:05:16] if (4797.3745 > 20000){
    imeonSetCharge('IMEON-420679')
}else{
    imeonSetDischarge('IMEON-420679')
}
```

Figure 68: from the test result 1 22.09.22

In our second test, we nested several conditions to validate that the algorithm would be able to interpret them consistently.

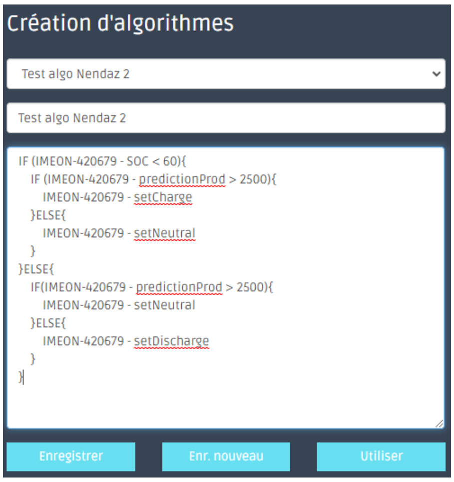

Figure 69: Test algorithm 2 for the Nendaz site

This second test took place from 2pm to 4pm. The solar prediction was between 2'000 and 3'500 W during the test phase. The SOC of the battery was initially 93% and then dropped to 58% before rising again to 94%. Below is a graph showing the charge/discharge of the battery between 14:00 and 16:30.

Figure 70: Graph of test result 2 22.09.22

We can see that from 15:30 onwards the algorithm defined that the battery should be in neutral mode (no charge/no discharge). We can see that in the logs the solar prediction was indeed at 2,893.6655 at that time:

"[2022-09-22 13:30:16] if (2893.6655 > 2500)"

With the battery above 60% and the solar prediction above 2,500 W, the algorithm correctly identified our need and performed the action it was intended to do.

Cybersecurity

At the beginning of 2021, a risk analysis of the multi-manager distribution system architecture (MDSO) in the framework of the SFOE MSID project was carried out using the Octave Allegro methodology. Thanks to this analysis it was possible to determine that the architecture should meet the following criteria

OWASP Top Ten Security Vulnerabilities 2020, which building consumption and PV production data collected are of a personal nature and what are the best options for backup and retention of the collected data. With these findings, we were able to implement a better security strategy with automatic security breach detection tools such as SonarQube and improve the process of handling personal data. In July 2022, the AES published an article about the risks of cyber attacks for Level 7 management systems (AES, 2022). DevSecOps tools have been implemented to apply current best practice.

The installed SonarQube is run on the platform and analyses the implemented code as we can see in the screenshots below:

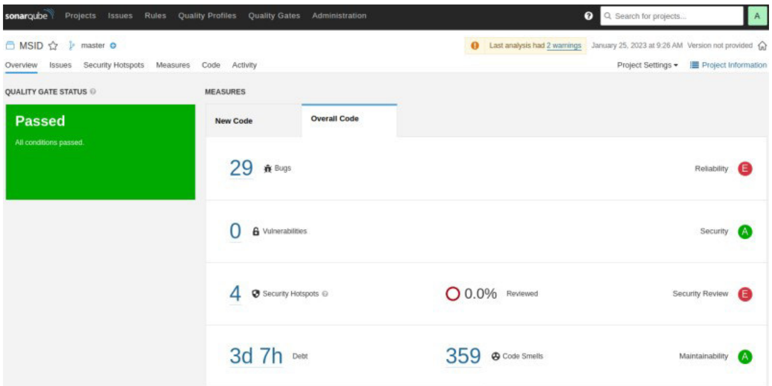

Figure 71: Result of the SonarQube analysis of the MSID platform

As we can see, the SonarQube detected 29 bugs. After each analysis, we perform a more detailed analysis of the results to understand the bugs found and correct them if necessary. In our case, the bugs detected are minor. They are only errors related to the HTML tag:

Figure 72: Analysis of bugs detected by the SonarQube

We can then access concrete graphics detailing the security of the code. The green bubbles in the illustration below indicate that the code is currently secure.

Naturally, security tests will have to be re-run after each code change. To this end, we have set up a DevSecOps process.

Figure 73: Graph of SonarQube code security analysis

Software industrialisation of deployments

Deployment to production is an important step in the software life cycle. This stage involves many risks at different levels. In a DevOps approach, the logical continuation of the industrialisation of deployments is the automation of actions allowing a secure and reliable delivery at any frequency. In this project, we implemented the deployment strategy described in the image below. All functionalities are created in a development environment (also referred to as a "local" environment). Once the functionality is complete, it is sent to the test environment where it can be checked with the rest of the code that is at the same level as what is available to the users (the so-called "Off Grid" test environment). In this way, we can check whether the new code input works with what has already been implemented and whether it produces any errors. If successful, the new code is distributed to the production environment(s) (the so-called "GRD"). New tests are also carried out there and if successful the production deployment phase of the functionality is closed. If an error occurs in the test or production environment, the code returns to the development environment and is corrected by the developers.

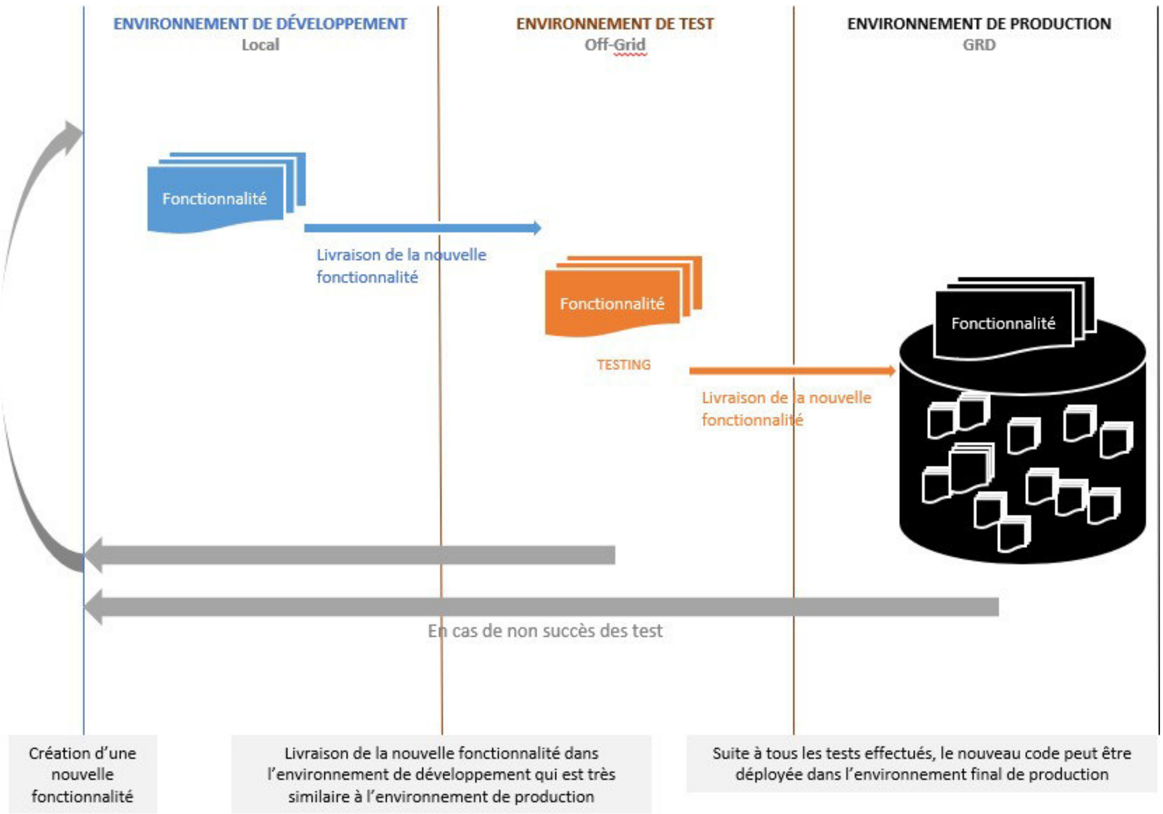

Figure 74: Diagram of software industrialisation

To complete the DevSecOps approach, we have added the execution of security tests in the process that runs after each code upload.

6 Conclusion

In this project it was possible to address energy and economic issues at 5 different sites of 4 different DSOs. In FMA site 1, the need was to replace the farm's generator and guarantee a stable and predictable renewable energy supply according to local consumption and weather. SEIC-Télédis, with sites 2 and 3, aimed to enhance and manage the batteries according to the photovoltaic production and prediction accessible on an online battery aggregation platform (VPP). The fourth site, OIKEN, aimed to use the contribution of local micro-storage to reduce or avoid voltage peaks and the battery clamping. For the last site, EnAlpin wanted to optimise their self-consumption and study new business models linked to EV recharging and V2G potential. These objectives, arising from various issues, were resolved as follows:

- **Optimising self-consumption**. Storing energy or selling it back?

The collection of battery data, the prediction of photovoltaic power, the link to the GB-Flex balance partners of the marketplace and the combinatorial algorithms were carried out.

In the case of site 5 - EnAlpin, with a storage cost of 13 cts/kWh, it was not worth storing the surplus PV production because the difference between the grid demand price of electricity (Visp Energie, winter, peak hours: 15.59 cts/kWh[1]) and the feed-in price of electricity (same conditions: 7.65 cts/kWh[5]) was less than the storage cost (15.59 - 7.65 = 7.94) in 2019. The objective has been shifted to an analysis of recovery in electric vehicles.

- **Mains voltage regulation.**

To correct the voltage management problems described in chapter 4, the battery had to be monitored via Studer-Innotec's Next3 inverter, meteorological data had to be collected and the PV had to be predicted in order to anticipate possible network overvoltages and thus take action to avoid this, in particular with battery management and brigade strategies.

- **Combinatorial strategies**

Thanks to the combinatorial strategies developed, it is possible to realize and face the studied problems. To enable the economic valuation of small-capacity batteries, we have developed a visualisation interface integrating the GB-Flex market place. In this way, the DSO can activate the GB-Flex system at his customer's premises according to the spot price prediction and offer the local balance sheet sub-group an added value in terms of flexibility. Moreover, the DSO can visualize from the VPP platform the aggregation of its customers' batteries and manage their flexible loads remotely. It is possible to create customised control algorithms according to the needs of the DSO, the installations and the local issues. With this system of visualisation and parameterisation of the devices, it is possible to clearly analyse via graphs, the variations of voltages and powers measured in the installations.

The achievements made on the pilot sites of this project have motivated the SwissDigitalCenter in Sierre to go one step further and prepare for a potential planned shortage by implementing the solutions developed and demonstrated in this SFOE-MSID project. This additional infrastructure will be composed of 30 kW photo-voltaic, 2 Next 3 inverters from Studer-Innotec, a 45 kWh Leclanché battery, 2 bi-directional V2G terminals for EV as well as the VPP platform for aggregation and control

[5] Purchase and reinjection values as at 30 December 2019

flexible loads to manage these heterogeneous systems to achieve 4 hours of planned autonomy.

Figure 75 SwissDigitalCenter infrastructure

The first elements such as the 45kWh battery from Leclanché and the OFEN MSID platform have already been implemented. The replicability of the control unit also made it possible to quickly and easily install the system on the SwissDigitalCenter site.

- **Follow-up**
    - A project to scale up to 500 to 1,000 sites piloted by the sites controlled by the platform is currently being developed and discussions on the industrialisation of the platform are underway with a recognised industrial partner in the field.

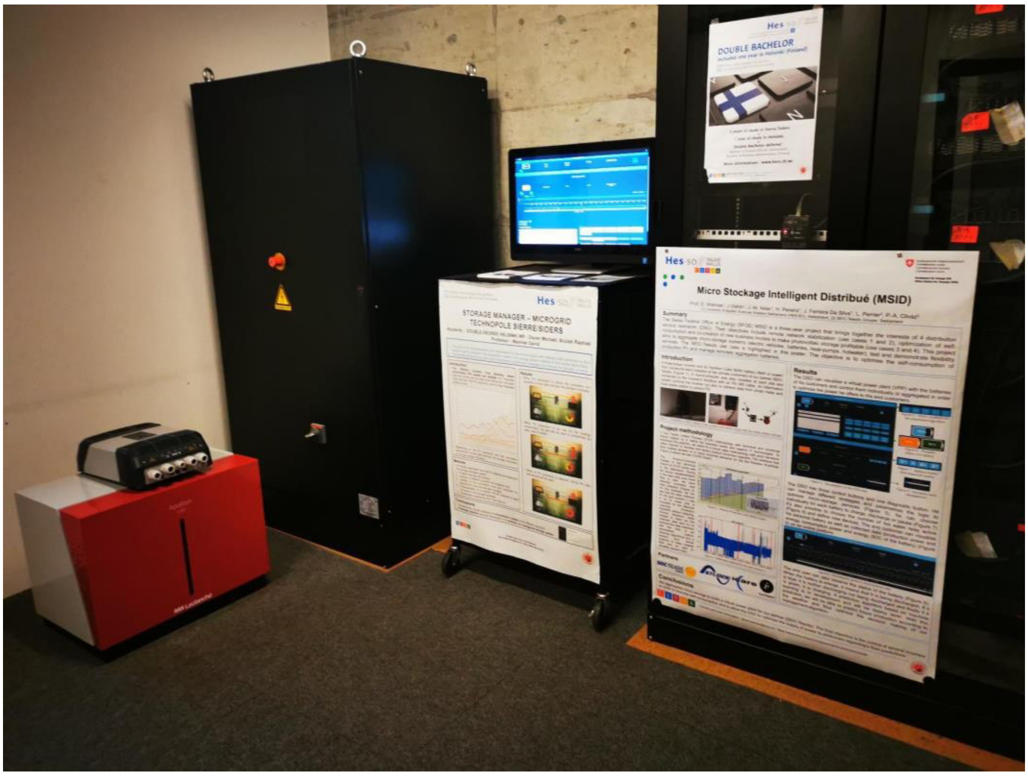

Figure 76: SwissDigitalCenter site with control unit and SFOE MSID visualisation platform

The last point discussed is cyber security. As mentioned in the AES bulletin of July 2022, the control systems of low-voltage infrastructures are real targets for hackers. In addition to the security tests carried out on the development part, we carried out an analysis and applied DevSecOps concepts during the development cycles of the VPP platform. This methodology was presented at the SDS 2022 conference in Luzern (https://www.sds2022.ch/videos- slides).

7 National and international cooperation

The link with the SFOE DC-microgrid project (SI/501512-01) was established by the UAS-SW teams participating in both projects. The skills thus acquired in advance are integrated into our considerations. The link with the SFOE GB-Flex project has enabled the realisation of a proof-of-concept for the economic valorisation of small-capacity batteries in the balance sub-group.

The IIG EASIlab technical team was involved in the InnoSuisse project "Digitalisation SCCER-FURIES" which targets the optimisation of photo-voltaic storage in electric vehicles. It ended with a publication in the MDPI journal "Energies" (https://bit.ly/3P4uVru) with our partner EPFL.

It was also involved in the development of the European H2020 Hotmaps project which ended at the end of 2020. This project provides a visualisation tool for the energy transition that will be used as a basis for the ERANET Open GIS 4 Energy Transition project that we are coordinating until May 2025. The aim is to integrate the evolution of electric mobility, sector coupling and the different temperatures of district heating.

The Horizon OpenMod4Africa project has just been accepted.

The IIG Dudelab and IIG EASILab teams participated in the IDIAP-HES workshop recorded on the platform (https://www.idiap.ch/workshop/valais-wallis-ai-workshop) and sharing the machine-learning algorithms deployed.

The IEM team organised the Energy Forum 2022 conference where we had the opportunity to present the interim results of this SFOE-MISD project.

We also presented the final results at the Swiss Digital Conference 2023 and the DevSecOps development cycle concept at the Swiss Datascience 2022 conference.

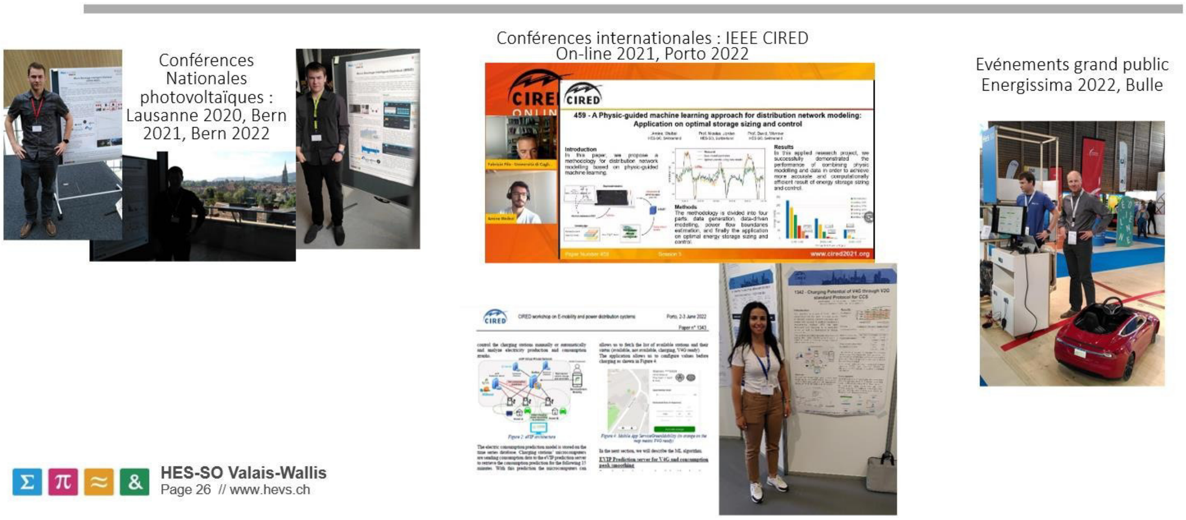

Figure 77: Dissemination of the OFEN MSID project through national and international events

8 Publications

A publication at the CIRED 2021 Conference & Exhibition on Electricity Distribution, focusing on grid issues, was accepted on 14 June 2021 at CIRED (Weibel, Jordan, & Wannier, 2021).

A publication at the "CIRED Porto Workshop 2022 E-mobility and power distribution systems" presenting machine learning algorithms for consumption prediction. (Wannier, et al., 2022).

A publication of the PV production prediction methodology named "Geolocalized Photovoltaic Energy Prediction Methodology using Machine Learning" has been accepted for presentation at CIRED Roma 2023.

Throughout the project we have also presented our progress at various PV Tagung (PV Tagung Lausanne 2020, PV Tagung Bern 2021, 2022 and 2023). The PV Tagung is a key event for photovoltaics in Switzerland that takes place every year.

9 Annex

- Annex 1: Development site algorithm

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