Smart Storage and Mobility

Study for Academia

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with the support of academic partners from the AlpStore consortium

Project: **AlpStore**
A model to develop and decide upon holistic solutions to increase regional renewable energy supply and outbalance volatility with appropriate buffering means.

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Foreword

In the scope of the AlpStore project, several different aspects of smart storage and mobility implementations have been investigated. This document represents a summary of results of the scientific efforts invested during the project. The document aims at providing an insight in activities performed by academic institutions involved in the AlpStore project. It describes the main challenges faced by the project partners, brings short descriptions of the main achieved results, presents contributions by each academic partner individually and gives the list of publications that resulted from research conducted in the scope of the project. With this document we aim at providing solid foundations for further research in the field as well as sparking the discussion on some advanced topics concerning possible future scenarios.

The study describes different perspectives, approaches and AlpStore viewpoints of smart storage implementations. The main intention is to provide a valuable contribution to the discussions on various smart storage and mobility aspects, elements and structures. Our goal is to spread research attention on challenges of wide smart storage implementations beyond the project duration and outside the project consortium. This document is complementary to other AlpStore documents such as 'Guidelines for Decision Makers' and 'AlpStore Guidelines for Planners and Practitioners'.

1 AlpStore Project

Energy storage cannot be considered as a standalone instrument but rather as an integral part of wider power systems efficiency management. Besides intelligent grids, storage systems will be key enablers for a future mostly renewable energy supply. The ultimate objective of energy storage is to help meeting human needs such as lighting, motion, heating, cooling, transport, information, products, etc. For that purpose, energy is required and depending on how these needs are addressed, the required form of energy might be electricity. As these needs are fundamental, the provision of energy must be secure, reliable, and affordable, but also non-detrimental to the climate and ecologically friendly.

A broad consensus exists that an energy supply system that fulfils these criteria must be mainly based on Renewable Energy Sources (RES) on a worldwide scale by the middle of the 21st century at the latest. Sun, water and biomass are a natural capital of the Alpine Space. It is necessary to use them for the production of energy. An analysis of the potentials of different RES shows that a suitable mix of renewable energies will be dominated by electricity generating technologies making use of the intermittent sources of solar radiation and wind power. At this point storage comes into play on a larger scale than ever before.

AlpStore concentrated on the Alpine specific challenges and opportunities related to energy storage. Partners in seven countries created regional master plans for the deployment of storage technology. Pilot implementations in all participating regions have shown the feasibility of mobile and stationary storage in public infrastructure, business parks, enterprises and smart homes. From there the STORM concept and 'Guidelines for Decision Makers' as well as 'AlpStore project Case Studies' (to be obtained from the AlpStore website) have been derived.

For more information about the project, partners, pilots, activities, news, resources etc. please visit www.alpstore.info.

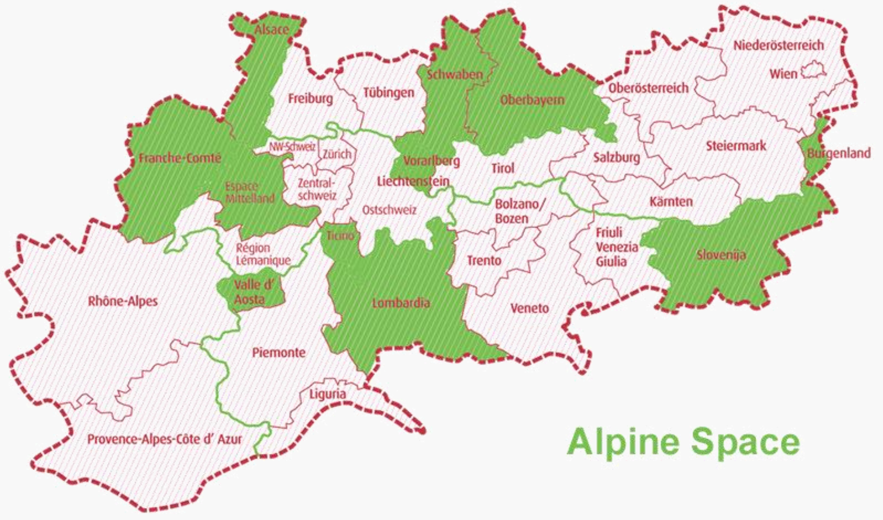

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Fig. 1 **AlpStore activities spread over the entire Alpine Space**

2 Main Scientific Challenges

The AlpStore project aims at fostering storage utilization across Alpine Space by identifying and adopting the most appropriate strategies at local level given specific societal, geographic, legal, commercial and climatological characteristics. A number of pilots has been set up with an aim of cross-border best practice and technology transfer. Even though the project itself is essentially based on storage technologies application and field implementations, there has been a number of challenges to be tackled by scientific approaches, these include:

- Technical issues for storage integration with renewables
- Commercial and legislative framework for sustainable storage utilization
- Rural and urban development implications
- Multidisciplinary approach to comprehend and relate all the different aspects that can impact previously listed aspects.

A number or research institutions worked together in the scope of AlpStore projects with a common goal to identify from an academic perspective the most important problems, challenges and opportunities as well for massive storage deployment. The involved research partners are:

- University of Technology Belfort-Montbéliard (UTBM) – Belfort, France
- University of Ljubljana, Faculty of Electrical Engineering (FEE) – Ljubljana, Slovenia
- University of Liechtenstein (UL), Chair for Sustainable Spatial Development – Vaduz, Liechtenstein
- Research Center for Energy Economics (FfE), Munich, Germany
- University of Lugano, Advanced Learning and Research Institute (ALaRI), Lugano, Switzerland
- Politecnico di Milano - Energy Department - Electric Power System research group (POLIMI), Milano, Italy (as a subcontractor of Euroimpresa)

In the sequel, we present specific considered topics, adopted strategies and results achieved by the project partners related to the aforementioned challenges.

3 General Scientific Approaches Adopted

The implementation of smart storage and mobility concept has been highlighted from different perspectives and a number of key issues have been identified. The main scientific topics addressed by the AlpStore project include:

- **Sustainability** of solutions for wider acceptance of storage technologies such as small hydro pumps and compressed air storage in combination with biogas plant and wind mills. A number of pilots has been implemented in the scope of AlpStore so that different experiences have been made in terms of availability of technologies, prices of energy, legislative framework and self-sustainability in small urban areas [1,2]. The research centre FfE has studied some of these issues as well as social perspectives and user acceptance [3] and simulated proper scenarios for the pilot implementation in Grafing.
- **Technical implications** of wider storage deployment – grid planning and grid impact, ancillary services (e.g. voltage and frequency control), different storage technologies etc. These issues have been tackled by POLIMI and FEE [7,15] as well as renewable exploitation and generation dispatch [4,6] and links between energy production and mobility [5] tested in the pilot project in Legnano. The work performed covers the technical aspects of the entire energy conversion chain, from production through renewable sources to storage and to reintegration in mobility.
- **Spatial development** and possibilities for integration of energy storage technology into our built environment, their spatial effects on urban design, but also their potential in combination with architecture, in particular in Alpine Space, has been studied by UL in the scope of AlpStore [16,17,18].
- **ICT solutions** for various pilot implementations have been studied by ALaRI and a reference model capturing the best practices has been developed. This model aims to serve as a starting point for technology transfer of the ICT solutions developed in the scope of AlpStore as well as dissemination of results obtained from pilots in this aspect [21]. Additionally, ICT solutions for EV integration have been proposed [8,19,20].
- **Simulation and validation** of the concepts for integration of storages as well as electric vehicles for various scenarios including micro-grids have been performed by FfE [1,2]. On the other side, thescientific approach applied by UTBM has been used to analyze systematic case studies based on small scale real world data and its extrapolation to large scale scenarios using virtual simulation platforms [8-13]. The main goal was to contribute to the removal of unnecessary costs and provide reliable results while cutting back on investment risks. Finally, FEE has performed simulation and validation on utilization of specific storage technology for ancillary services in distribution networks [15].

The detailed contribution by each partner is explained in section 4.

4 Activities and Results by Individual Project Partners

As dictated by the AlpStore approach, the identified key issues have been faced by different partners at different levels – local, regional and national. At the same time, a general cross-border approach has been embraced so that problems and solutions have been mutually discussed and exchanged. In fact, local situations may differ in various aspects and at different levels, which complicates adoption of general approaches and solutions. Nevertheless, a close collaboration between industrial and academic partners has been established which provided solid ground to academic partners for access to data from real-life implementations as well as possibility to validate theoretical assumptions and simulation results with real ones.

A number of publications resulted as an outcome of the involvement of academic institutions on the AlpStore topics, such as ICT solutions for storage deployment, integration of electric vehicles, storage technologies for urban design etc. We briefly present activities and results of each research group:

University of Technology Belfort-Montbéliard (UTBM) – Belfort, France

In the scope of AlpStore, UTBM has developed methods and protocols for exploiting battery and fuel cell based electric vehicles as energy storage solutions. The main goal was to develop a holistic approach to the problem of electric mobility/electricity production. The activities have been directed to reduce fossil fuel emissions in modern transportation, by motivating the general public to switch to electric vehicles, and on the other hand, reduce pollution related to electricity production by providing a large scale electricity storage capacity, allocating a greater role to intermittent renewable energy in the overall energy sector. In this regard, the work in scope of the project addressed the difficult issue of electricity storage at different levels. On the regional level, this issue is the central to the technical feasibility of opting out of nuclear production, for countries like Germany and Switzerland. In fact, a decentralized storage capacity that is operable in real time (as offered by the EV batteries) is necessary for mass-production and exploitation of renewable energy that these countries wish to develop. The specific goals included:

- Verification of a solution for energy storage and transportation through vehicles (energy on demand; vehicle);
- Study of a model infrastructure for administration and management of a V2G solution;
- Feasibility and possible integration of fuel cell based energy solution in micro or nano-grid.

The applied scientific approach has been aimed at developing and analysing systematic case studies based on small scale real world data and its extrapolation to large scale scenarios using virtual simulation platforms. This avoids unnecessary costs and provides reliable results while cutting back on any investment risks so associated. A prototype ICT architecture and a simulator for fleet based vehicle-to-grid (V2G) operation resulted from that work. The prototype is based on IEC standards and has been developed to optimize messaging and information exchange such that communication delays are minimized and bottlenecks are avoided. The developed prototype can be used to develop an architecture for EV fleet operators, on any scale. The work has been described in details in [8].

When it comes to fuel cells, Polymer Electrolyte Membrane Fuel Cells (PEMFC) are extremely sensitive to load variations and rapid load variation can damage the system in many ways. For this reason, a Load Governor (LG) based on constrained Extremum Seeking (ES) approach has been proposed in the project. The LG controller ensures that the physical constraints of the system are not violated and the ES controller varies the LG bandwidth parameter to optimize the net power output. The proposed controller has been tested on a Hardware-In-Loop (HIL) emulation test bench, based on a commercial centrifugal compressor and a real time PEMFC emulator. Experimental results have shown a good performance of the proposed scheme during load variations [12]. Moreover, an adaptive algebraic observer has been proposed for a PEMFC air-feed system, based on Higher Order Sliding Mode (HOSM) differentiators. The goal was to estimate oxygen and nitrogen partial pressures in the fuel cell cathode side, using measurements of supply manifold pressure and compressor mass flow rate. As the proposed technique requires the time derivatives of the states, Lyapunov-based adaptive HOSM differentiators are synthesizedand implemented for estimating these derivatives without *a-priori* knowledge of the upper bounds of their higher order time derivates. The performance of the proposed method has been validated through experiments on a Hardware-In-Loop (HIL) test bench. These results illustrate the feasibility and effectiveness of the proposed approach and they are presented in details in [11].

In addition, Lyapunov-based robust and adaptive higher order sliding mode (HOSM) controllers for the air-feed system of polymer electrolyte membrane fuel cells, which is a nonlinear single-input, single-output system with bounded uncertainty, have been designed. The system consists of a motorized compressor, which is driven at its optimal point in order to minimize the internal energy consumption of the system. Experimental demonstration of the applicability of the recently developed fixed-gain robust controller and adaptive controller for this problem has been performed. Third-order controllers have been developed in order to obtain a continuous profile for the input current of the compressor motor. In this regard, a complete adaptive arbitrary HOSM control has been presented for the first time, with Lyapunov-based proof. The arbitrary order nature of controllers permitted to extend the air-feed system from second to third order, resulting in continuous input current profile. The proposed controllers showed good performance in simulation and in experiments conducted on a PEMFC air-feed test bench as shown in [9].

University of Ljubljana, Faculty of Electrical Engineering (FEE) – Ljubljana, Slovenia

In scope of AlpStore project, FEE has focused on voltage regulation in low voltage networks with converter connected photovoltaic and storage units (Vanadium Redox Flow Batteries – VRB). The decoupled current control method applied to the production of reactive power of the PV-VRB converter has been used. The aim of this control strategy was to ensure appropriate voltage profile and increase the integration of renewable distributed generation units into the distribution networks. Within the AlpStore research project framework, an experimental prototype has been implemented in the Slovenian remote Alpine Space area. Main goal of the pilot project was to assess benefits of employing storage technologies in such environment, where small villages are often supplied by a long (radial) overhead distribution lines. As these lines are heavily exposed to the external influences (trees, snow etc.) that are causing short-circuits on the line, short- and long-term power supply interruption are more often than average. Also, connecting DG units at the end of such lines, can cause unacceptable voltage deviations.

On the other hand voltage regulation in distribution networks is carried out mainly by automatic tap changers at the HV/MV transformers. In networks with distributed generation the following methods of maintaining proper voltage levels are possible: reinforcement of the network, DG reactive power control, DG active power control, installation of voltage regulators, use of compensators. Apart from the reinforcement of the network all other methods represent an active approach of voltage regulation. For the last two methods from the list, installation of some additional equipment is required, while regulating the voltage with active and reactive power control usually does not require any additional equipment.

The MV/LV transformers are usually without automatic tap changers. However, depending on the voltage conditions in the network, a transformer’s tap changer can be adjusted manually under off-load conditions. The voltage control algorithm implemented is based on the VSC d-q mathematical model. The modified VSC mathematical model is defined in [15].

Simulation results showed that PV-VRB DG with the proposed reactive power control is capable of effectively compensating the voltage rise, while maintaining constant active power injection [15].

University of Liechtenstein (UL), Chair for Sustainable Spatial Development – Vaduz, Liechtenstein

As an architecture and urban design institution, UL in AlpStore focused on a set of spatial impacts of storage technologies and their possible integration in our built environment in particular in Alpine Space. The use of RES is key to establish a mostly renewable energy supply for the future. But only a change in the technique of energy production is not enough to accomplish this challenge. Without the ability to store and dispatch energy on demand there will be a big gap between production and consumption. Nevertheless, every storage technology has its spatial effects on the environment, which need to be considered. In fact, only a successful and convincing solution of a spatial integration of energy storage systems into architectural and urban design will be acceptable by the end user. To that end, new approaches in architecture are needed. A example would be a new kind of expression, which brings together architecture and technology. A good example for this is the «Heliotrop» by Rolf Disch. By really following the course of the sun, having a cylindrical shape with a steel-glass-facade and harmonious integrated solar collectors and PV systems, it takes off architectural approaches of its time and creates its own identity.

UL's perspective is based on experiences obtained in several research projects dealing with the issue of bringing together architecture, energy and storage such as "Solarquartier Ackermannbogen" in Munich (http://www.g-h-a.de/wohnen_oly.htm) and "Landrad Vorarlberg" (http://www.landrad.at/).

In the scope of AlpStore, UL adopted the scientific approach of designing a draft for a solar storage settlement in a community of Liechtenstein. The design gave insights of how a settlement could work in the future. It described the rate of density, between a harmonic setting and enough exposure to the sun. UL found out how we can integrate heat storage tanks into an existing building structure and for which buildings it makes sense to create an energy community, which uses one big storage entity.

The mobility sector needs to be more flexible in the future. The user should not only be able to decide between bus or car, but also between shared car, electric bike and electric vehicle. A higher variety of vehicles will match the right transportation system to its needed usage. All these findings led to the result that we should not stop increasing renewable energy production, disregarding the fact that we only will need vast energy storage at around 40% and more of renewables in the grids.

We have to decrease energy consumption, not only by our own behavior, but also by designing mixed use settlements and cities, which will create shorter daily distances and decrease energy consumption in the mobility sector. These measures will help to minimize the amount of energy we have to store. The typology of the house will undergo a development towards an energy unit, which is not only supplying power and heat to its inhabitants, but is also able to produce and store energy for others. The future building as a mosaic piece in a big picture of energy flow. These scientific efforts resulted in a number of publications [16,17,18].

Research Center for Energy Economics (FfE), Munich, Germany

The Research Center for Energy Economics (FfE) has performed a scientific analysis of sustainability of wider adoption of storage systems coupled with renewable generation on an AlpStore project pilot performed in Grafing (Germany). The analysis considered social aspects in the sense of end user acceptance of different proposed "energy transition" solutions [3] as well as a simulation of different proposed energy systems for the given pilot considering results of the survey [1,2].

The involvement of citizens in the Implementation of energy policy plays an important role for several reasons: Firstly, for many projects the consent of the municipal authorities is needed, second, the success of the energy transition relies on readiness of the population to reducing their energy consumption and the availability of power supply (wind and solar energy) to adapt. The survey was intended to show what the inhabitants of Grafing think about the energy transition and the resulting changes [3]. In addition the willingness for change in behavior and investing in various technologies have been investigated. The survey was conducted with the tool LimeSurvey on the site of FFE. 115 people answered the survey. Analysis of master data of respondents revealed that people of all ages, from every income level, of every household composition and different energy situations have been reached, so that a representative picture of Grafing has been achieved. Nevertheless, the data base with 115 participants is relatively small. From the results of the survey it may be concluded that respondents see the energy transition at both the federal and local level positive, a quarter rated this trend to be too slow. The different renewable technologies such as biomass, photovoltaic or wind power have been marked by less than 20% as critical. The criticism is mostly related to technical problems such as fluctuation of solar and wind supply.

More than half examinees had already installed or are planning the purchase of a distributed generation system such as photovoltaic, solar thermal systems, mini-CHP or a heat pump. Also, despite economic concerns electric vehicles and battery storage have arrived in the consciousness of the residents. Around 50% of respondents would still consider buying an electric vehicle. In a possible change in user behavior, the survey participants showed openness. 85% of them are ready to reconsider their consumption patterns for a higher proportion of energy generated from renewables. Most of the residents would still postpone the launch of large-scale consumers control of home appliances. Moreover, more than half of respondents do not know what a smart meter is.

In summary, it can be said that the energy policy both locally and at the federal level is accepted by the respondents and also desired. In the eyes of residents, the most important aspects are increased share of renewable and locally generated energy. About to achieve this goal, the majority is willing to invest in technologies of renewable energy and change their usage of energy consumption [3].

FfE developed a tool to simulate the effects of photovoltaic-systems, electric vehicles and home storage systems on the grid. The work addressed how these systems will affect the load and feed-in from low-voltage grids and shows the amount of energy which can be shifted by the corresponding operation modes [1,2].

Due to an advancing development of battery electric vehicles (BEV) the prizes are expected to fall in the years to come. Accompanied by a decline in the price of renewable energies, especially photovoltaics (PV) for private households, it can be very attractive for households to charge electric vehicles at home and thereby reduce their total cost of mobility. This effect will lead to an increase of the number of electric e-vehicles and especially the penetration in rural areas. Furthermore, electric home storage systems (HSS) can become economically reasonable for households with PV plants in the upcoming years. In combination with intelligent charge controllers, electric vehicles could then be utilized as "functional energy storages" on the energy markets. Nonetheless, these functional storages would be in competition with home storage systems concerning their ability to relieve low voltage grids from excessive voltages in the future. In AlpStore, the Research Center for Energy Economics (FfE) investigated if smart charge controllers for electric vehicles are suitable to relieve the grid and has drawn a comparison to house storage systems. An investigation on what type of storage would be optimal for the pilot city of Grafing has been performed [1,2]. Generation prices of different types of energies, storage costs as well as energy demand of households have been considered and correlated with different available technologies such as photovoltaics, windmills, biogas, power2heat, cogeneration and heat-only boilers. Four different scenarios have been defined. Finally, the conclusions were that there is a large dependence of the optimal storage size from the base scenario in a sense that good forecast for the development of renewable energies, prices and consumption are necessary. Furthermore, electric storage in wind based scenarios is more efficient as there is less overlap between wing generation and consumption than in photovoltaic scenario. These results are described in detail in a respective publication [2].

University of Lugano, Advanced Learning and Research Institute (ALaRI), Lugano, Switzerland

For the purpose of the Alp Store project, ALaRI has adopted a systems engineering process for facilitation of end-user (energy producer, consumer, authorities) requirements and constraints collection, feasibility technical and business studies design. Based on this approach, a reference model for the supporting ICT infrastructure has been created. It is a result of an iterative process of system engineering integrating research findings and AlpStore pilots' best-practice achievements. Furthermore, the developed reference model has been used for an assessment of different pilot implementations as presented in [21].

Storage systems are considered an instrument of essential importance for efficient utilization of energy produced by RES. The main goal of the work was to describe and asses an appropriate ICT model that is applicable for AlpStore pilot projects, where different types of energy storage systems and their implementation, characterization and evaluation are investigated.

The reference model has been developed using SysML language and represents an effort to describe various pilot implementations in a unique way. The model is influenced by state of the art solutions in V2G, G2V and VPS concepts, since AlpStore is intrinsically linked to them. Apart from inputs from relevant state of the art solutions, results from eleven AlpStore pilot implementations have been used to create the unique reference model. The pilots differ as different storage technologies have been used, such as second-life batteries for stationary storage, coming from used EVs' batteries, chemical energy storage, electrochemical storage, etc. With regards to RES production, PV and biogas have been considered. Presenting different pilots in a unified manner can facilitate their assessment and help possible future implementations based on similar concepts.

Assessment is done by comparing ICT models provided by partners with the developed reference ICT model. For the comparison, ICT models for pilot projects in Strasbourg (Freshmile), Valle d'Aosta and Oberallgäu are used. Due to the nature of the reference ICT model, not each one of the blocks is present in each of the selected pilot ICT models . However, pilot projects can be successfully presented using the reference ICT model, which was our goal, reached by using SysML and following above explained steps in the model development process.

In the specific case of the Freshmile pilot, EV has been used as a (mobile) storage [21]. ALaRI has separately considered integration of electric vehicles in Smart Grids trough a smart charging concept presented in form of 'Smart Cells' which relies on both temporal and special mobility of EV charging [19,20]. This work represents a bridge with another project on storage integration – GeoGreen.

Politecnico di Milano - Energy Department - Electric Power System research group (POLIMI), Milano, Italy

As a subcontractor of Euroimpresa, POLIMI has focused its research in the scope of the AlpStore project on various issues related to optimal coupling of renewable generation and storage technologies as well as on the development of a viable model for renewables exploitation in the Alps [4,5,6,7].

Energy provided by photovoltaics is intermittent in its nature and as such should be efficiently integrated in the power distribution system. This issue is a cornerstone for an effective transition to a renewable-based energy system. Weather forecast algorithms can predict photovoltaic production, but, in real life conditions, their reliability is only partially effective with respect to the actual grid operation requirements. In [4], Energy Storage Systems (ESS) are adopted to compensate the mismatch between the injections of a photovoltaic power plant and the day-ahead market power schedule: the final goal is to achieve the full programmability of the photovoltaic resource by minimizing energy imbalances, as defined in the Italian regulatory framework, on an hourly basis. In particular, the optimal design of the storage apparatus (nominal power and capacity) is defined according to the regulating performances required.

Three forecast models have been tested to evaluate the impact of weather prediction accuracy on the ESS design and the benefit/cost ratio of the ESS application is assessed according to the main economic and technical parameters (ESS cost, round trip efficiency, lifespan). The analyses have been performed on data measured on a real power plant, with hypotheses consistent with the actual Italian scenario. In another work [6] the proposed integration of ESS into a model of Virtual Power System (VPS) has been studied, which enables the management of generators and loads as a single (virtual) entity in order to achieve a "global" benefit, i.e. to improve the capability of the grid to host RESs. Moreover, Energy Storage Systems (ESSs) could be integrated in ta Virtual Power System (VPS) in order to provide ancillary services: voltage regulation, primary frequency regulation and exchange profiles adjustment for a better RESs programmability. This work proposed a quantitative approach for ESSs design and integration in a VPS. A mathematical model of the ESS is now available for simulating each of the above-mentioned regulation functions. The results of the analysis have then been exploited to design an experimental prototype, to be tested in the AlpStore research project framework. POLIMI reports numerical results with respect to an experimental application in the AlpStore project. POLIMI carried out the proposed test applications in cooperation with Euroimpresa, a local cluster of SME (Small Medium Enterprise) sited North-West of Milan. The pilot application was based on the monitoring and control of the electric energy needs of the TecnoCity (industrial area sited in Legnano). It turned out that VPSs and ESSs could be a useful resource to support the integration of RESs in the networks, making DG injections more predictable and controllable and providing the ancillary services necessary to the system to effectively manage RESs.

The proposed approach aims at exploiting ancillary resources spread along the network instead of using centralized resources. In order to size the ESS properly, it is necessary to consider the power and energy requirements for each function evaluated separately:

- Voltage regulation: in the worst case (ESS sizing according to the peak power of the PV plant), the storage power must be equal to the difference between the DG size and the maximum DG injections that can be accepted by the grid without violations of the voltage limits, while the ESS capacity can be usually 1-2 equivalent hours of operation of the DG.
- Primary frequency regulation: the ESS power is equal to 3% of the size of the generator, while the ESS energy is equal to 0.25 equivalent hours. Exchange profiles adjustment for forecasting purposes: to achieve imbalances lower than 10% of the DG yearly production, the ESS power has to be equal to 10% of the generator size, while the ESS capacity must be equal to 10% of an equivalent hour of the DG.

This study provided useful indications for the implementation of the experimental application on field of the AlpStore project, sited in the TecnoCity area in Legnano (North-West of Milan city). The results have been published in [6].

In addition to ESS design, a work on dispersed generation for provision of ancillary services has been done in the scope of the AlpStore project [7]. A high penetration of intermittent power plants will reduce the capability of the system to overcome critical events (e.g. frequency oscillations and voltage profile perturbation). This work presents new regulation schemes/functions developed in the AlpStore project framework, devoted to managing dispersed generation in order to provide ancillary services to the main grid. The work developed can be split into two main items: reactive injection regulation and frequency control regulation. The first regulation is devoted to increasing the Hosting Capacity of the distribution grid (i.e. it results to be a local control), whereas the latter aims to guarantee the energy balance of the national electric grid (i.e. it could be classified as a grid control).

On the other hand, the most important system services offered by DG units can be divided into two categories: reactive power modulation service and real power modulation service. The power injected by Distributed Generation (DG), at both medium and low voltage distribution networks, introduces new issues of network management. DG plants affect the voltage quality of the distribution system: in particular, the voltage profile along the feeder is no longer monotonous and over-voltages can occur at the Point of Common Coupling (PCC) of the DG units. Two different control strategies can be adopted. In the first strategy, named Local Control, a) each generator operates without any coordination with other devices; according to the second strategy, named Global Control, b) all regulating resources are coordinated and remotely controlled in order to obtain an optimal voltage profile. As well as the reactive power modulation service, the DG power plant can modulate real power in order to support the frequency regulation capability and improve the system operation in case of relevant power unbalance. Energy Storage System (ESS) integrated with DG can ensure the margin of power required for the service. Research concerning this topic has started focusing on numerical analysis carried out by software simulations. A dynamic model of a Photovoltaic System (PV) integrated with an ESS, was developed with the aim to simulate its contribution to the reestablishment of the power balance among the network. A simplified network model was built in the PowerFactory DIgSILENT software (Fig. 4). The network model is a grid-connected system; it is connected to the 20 kV AC network through an MV/LV transformer (INVERTER-Trafo) and a grid following inverter (INVERTER) with 250 kVA rated power, which controls the real and reactive power injected at the AC side. The PV and the ESS are connected to the DCLink bus (DC-coupled system) with nominal value of 700 V and capacitance equal to 30 mF. Preliminary results obtained by dynamic software simulations point to a quite interesting capability for the future design of experimental prototype; such a prototype was tested in the AlpStore research project framework. In particular, POLIMI carried out the proposed test application in cooperation with Euroimpresa, a local cluster of SME. The results have shown that DG units can also provide different ancillary services for the network operator, meaning DG can be transformed from being a part of the problem into a part of the solution. The paper focuses on two main applications of dispersed generation in the provision of ancillary services of the electrical system, and technical solution are proposed and tested. The proposed approach consists in exploiting ancillary resources spread along the network instead of using centralized resources. The details of the implementation and results have been presented in [7].

Apart of research activity related to ESS design POLIMI has also experimented with real time modeling and control of an electric vehicles (EVs) charging process [5]. A method for the real-time management of electric vehicles (EVs) charging processes has been developed. The proposed method aims to limit the peak load and to increase the number of rechargeable EVs with respect to the scenario in which no coordination action is performed, while achieving given constraints on the power distribution system. The approach is based on a tight interaction between a scheduling algorithm and a power-flow evaluation procedure. The scheduling algorithm finds the best charging periods for each EV. The power flow procedure checks the achievement of electrical constraints and evaluates the operational parameters of the grid. Simulations have been carried out on a real electricity distribution system of a medium-sized Italian city. The results show that the proposed approach increases the number of simultaneously rechargeable EVs up to 33%. At the same time, the peak load is reduced by 25%. The scheduling algorithm requires an average of 50ms to evaluate each charge request on an ordinary computer, therefore allowing its use in real-time conditions. As the final result of this work a scientific publication has been published [5].

5 Conclusions and Future Research Trends

The AlpStore project brought together researchers from different fields in order to highlight the issue of wide storage adoption in Alpine space in a holistic and multidisciplinary fashion. In that way, various topics such as technical issues, business models, social acceptance as well as spatial development have been addressed. The real added value that this project brought to the scientific community can be represented in the fact that a number of pilots have been implemented so that they could serve as a source of important data for research or as a test setup for previously developed theoretical concepts.

All in all, AlpStore has built bridges amongst industrial, business and research communities which has not only enabled mutual discussions but real-life demonstrators and experimental verifications as well. In general terms, the pilot projects have been conceived, implemented and assessed using scientific approaches as well. The promising results for the utilization of storage for various purposes (e.g. renewable integration and ancillary services for grid stability) obtained in the scope of the project may help further fostering of both implementation and research in the field.

Based on the original and innovative approach enabled by involving stakeholders from different fields (e.g. local authorities, business development agencies, scientists, technicians etc.) encouraging results have been obtained. We expect that AlpStore legacy will represent a cornerstone for similar future projects. A number of ideas that have resulted from discussions and results of AlpStore have sparked proposals for new research directions in the field.

Based on experiences gained from AlpStore we believe that future research in the field will go in the direction of exploiting technology convergence trends for efficient renewables and storage integration. In fact, Smart Grid and Smart City concepts, together with wide availability of novel networking, communication, monitoring and control capabilities will enable better flexibility in sense of smart storage utilization. Therefore, we may say that future research on the topics addressed by AlpStore will have to bear in mind integration of any storage implementation with wider ‘smart’ environment. In parallel to this, focus on novel storage technologies to satisfy requirements for better efficiency at lower cost will represent another important challenge for researchers. This includes the use of second-life batteries (as it will be studied in Horizon 2020 project ELSA with some AlpStore partners participating). In that sense, novel business models for fast adoption and commercialization will be another important subject of research.

In summary, research on storage adoption will have to be based on multidisciplinary and holistic approaches involving experts and scientists from different fields. New methodologies for development, implementation, integration and commercialization of novel storage technologies will be of essential importance for their wide adoption. On the other hand, some ‘side effects’ of storage implementation such as architecture and urban design will gain importance in future as well.

6 ACADEMIC PUBLICATIONS RESULTING FROM ALPSTORE WORK

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