Fostering Innovation Cooperative Energy Storage Systems: the Storage4Grid Project

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***Abstract*—Storage4Grid is a 36-months project funded by the European Commission under call LCE-01-2016, Area 1 (Storage). Storage4Grid aims at boosting the uptake of storage technologies between the distribution grid level and the end-user level, by developing a novel, holistic methodology for modeling, planning, integrating, operating and evaluating distributed Energy Storage Systems (ESS) including storage at user premises and storage at substation level, Electrical Vehicles (EVs), innovative energy metering and energy routing technologies. This paper shortly outlines the challenges tackled by the project, its goals, the chosen methodology and its reference scenarios and test sites.**

I. Introduction

With the 2020 and 2030 Climate-energy packages, the EU committed to reduce by 20% greenhouse gas emissions (from the 1990 levels) by 2020 and 40% by 2030, to reach a share of Renewable Energy Sources (RES) of 20% by 2020 and at least 27% by 2030. With a projected share of 15.3% of renewable energy in 2014 in the gross overall energy consumption, the EU and the majority of Member States are making good progress [1].

Maximizing the share of variable RES in a well-functioning EU-wide energy system is a major challenge for grid operators. For example, it has been assessed that when the share exceeds the limit of 20-25%, operators are forced to curtail intermittent RES during low consumption periods to avoid grid perturbation (frequency, voltage, reactive power) and grid congestion, unless the RES excess can be stored.

Statistics [2] show in fact that such RES limits are already being reached today. For example, during the period 2003-2013 the quantity of electricity generated from wind turbines in the EU-28 increased more than fivefold (26.5% of the total quantity of electricity generated from RES in 2013) and the electricity from solar power rose even more, from just 0.4 TWh in 2003 to 85.3 TWh in 2013 (i.e. from 0.1 % to 9.6 % of all electricity generated from RES).

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Within this context, integration of cooperative Energy Storage Systems (ESS) in Smart Grids is becoming more and more important, as one of the most viable solutions to cope with the increase in intermittent renewable energy (e.g. from wind and sun) and to the demand peak increase.

Within this context, the Storage4Grid project [3] focuses on next generation storage-related models, systems and technologies addressing some of the technological challenges arising from the Energy Union strategy of creating privacy savvy electricity distribution grids in an EU-wide smart energy system, with consumers at the center and a larger share of energy from renewables.

II. The Storage4Grid Project

The Storage4Grid concept is built upon two main pillars: a *Planning Concept* and an *Operations Concept*.

The Storage4Grid Planning Concept is depicted in Fig. 1 and is centered on the development and validation of a Decision Support Framework (DSF) featuring predictive control algorithms for ESS.

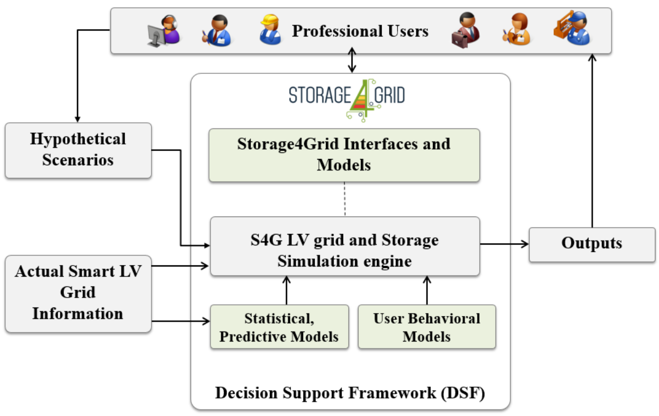

Fig. 1. The Storage4Grid Planning Concept

The DSF is meant as a tool that performs analysis, planning and impact evaluation of ESS when these are deployed and

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integrated with distributed generation and EVs in the Low-Voltage (LV) grid.

Its core is represented by the *Storage4Grid LV grid and Storage Simulation engine* which is a software component orchestrating a set of heterogeneous, pre-existing simulators, each specialized to model the behaviour of the diverse components involved.

The DSF handles a set of statistical and predictive models which are buld upon smart grid data, including static, historic and real-time information from the SCADA infrastructure and other tools used by Distribution systems Operators (DSO) such as Geographical Information Systems (GIS). Such models, joint with user behavior models are combined and exploited to evaluate the hypothetical scenarios of interest.

The DSF supports analysis of feasibility and potential impacts of different scales of ESS (from large substation-level systems to small-scale storage at user premises) and EVs (from private EVs to commercial fleets) on hypothetical grid scenarios.

The DSF is used in the project to evaluate performance of innovative cooperative strategies exploiting ESS flexibility. This includes the evaluation of the Storage4Grid predictive control algorithms in different scenarios, as well as the evaluation of advanced cooperative techniques jointly optimizing Demand Response (DR) techniques applied to EV chargers and ESS control. This will eventually be supported by devising new control *interfaces and models* to be proposed by the project.

The Storage4Grid Operations Concept is depicted in Fig. 2 and focuses on the technical infrastructure required to control ESS in cooperative scenarios, building upon several innovative components developed in previous projects such as the Unbundled Smart Meter (USM) and the Energy Router (ER) developed by FlexMeter and Nobelgrid [4], [5], [6].

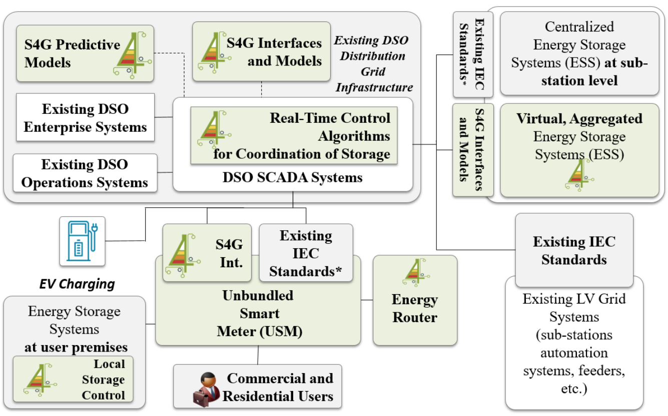

Fig. 2. The Storage4Grid Operation Concept

The USM is connected to the local communication network at user premises and interacts with the EV charging stations, storage, local users and other local systems. It extends a suitable commercial smart meter with a set of Smart Meter eXtensions (SMX) able to read real-time data from all connected components and to run local software components needed to support the Storage4Grid predictive control algorithms.

The ER is a power electronics device that integrates and manages energy from different sources (AC distribution grid, renewable energy sources), loads (AC and DC home grid) and storage system. It also executes intelligent algorithms and provides distributed ancillary service to the grid (frequency control through active power injection and absorption, voltage regulation by reactive power compensation).

Both USM and ER rely on open interfaces that can be eventually proposed for standardization - and aligned with existing interfaces for storage monitoring and mapped towards the Common Information Model (CIM) entities pre-designed within Storage4Grid.

Such set of dedicated interfaces and related CIM models represent the common language among all the various system components engaged in storage control use cases (Battery Management Systems, Hybrid Inverters, DSO SCADA systems, Smart Meters, user interfaces, etc.) and will be developed by extending current and emerging smart grid standards within the IEC 61850 family of standards and in compliance with current or emerging regulations for cyber security, data protection and privacy.

A. *The Storage4Grid Methodology*

Storage4Grid will follow the iterative methodology depicted in Fig. 6 which allows for flexible requirements collection and maintenance.

Extensive scenario analysis activities are performed starting from existing standardized business cases and new storage-centric business cases developed with User-Centered Design (UCD) methods.

Starting from the initial high-level concept and scenario as defined in this paper, extensive scenario analysis activities are performed starting from existing standardized business cases and new storage-centric business cases including: DSO-funded installation of storage at user premises, storage power stations at substation level for EVs and grid stability, new price schemas for energy retails leveraging cooperative charging and collaborative storage control, distributed storage coordination for ancillary services, etc.

The main focus of the analysis is centered on storage-related gaps, needs, constrains and includes a representative analysis of existing products and previous results generated by related projects. The analysis takes into account Smart Grid EU policies and regulatory issues, including above all data security and protection issues, as well as existing and emerging standard interfaces and models.

Different UCD methods, for example scenario analysis activities and end user interviews feed the iterative requirements engineering process, which collects all users/stakeholders needs and constraints using a structured methodology. Additionally, relevant standardized Smart Grid requirements are considered.

Building upon the initial requirement engineering activities, development activities are performed. Those include further

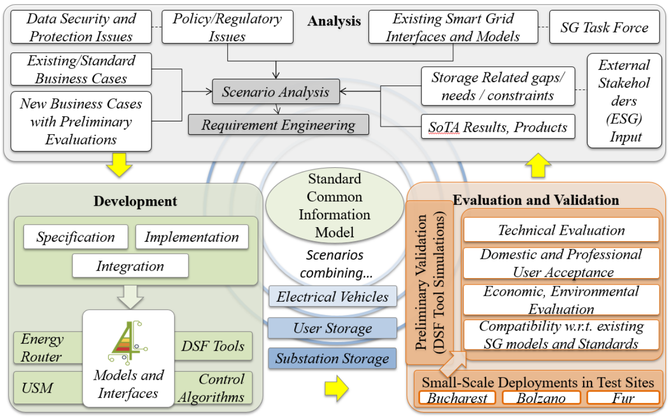

Fig. 3. The Storage4Grid Methodology

requirements updating and gathering, specification, implementation and integration of DSF and control tools.

Developed outcomes are fed into validation activities, which are performed involving domestic and professional users in using and co-designing the tool to realize simulations and interacting with battery systems and EV systems installed in three test-sites.

Evaluation activities aim at assessing the technical feasibility and value of the developed solutions. Moreover, the acceptance by domestic and professional users, the potential economic and environmental impact generated by using the proposed tools and the level of compatibility/disruptiveness of the proposed solution will be evaluated. This will be done based on existing standards with the goal of determining the current Technology Readiness Level (TRL) of the various developed features.

Storage4Grid also engages an External Stakeholder Group (ESG) [7] i.e. a group of external, independent experts of recognized knowledge in different kind of background and area of expertise including market, technological trends and standards. The ESG is constructed properly representing all domains and market roles relevant for the Storage4Grid goals, including above all representatives of industries providing storage solutions, but also experts in metering, utilities, experts in international standardization, privacy.

III. Scenarios and Test Sites

The Storage4Grid project has identified three scenarios, which will be addressed in three separate test sites.

Lower TRL solutions will be experimented and evaluated in a lab-scale test site.

Higher TRL developments will be evaluated in two different real test sites. Real test sites will specifically be used to evaluate Storage4Grid outcomes in realistic settings, benefiting from the diversity of distribution grid infrastructures and energy consumption patterns in northern and southern Europe. Real test sites will also allow to assess initial acceptance of Storage4Grid solutions by selected professional and residential end-users.

These test-sites will be used to test and improve developed prototypes and to compare different approaches in terms of ease of deployment and maintenance, customer acceptance and behavior change, impact of self-consumption/uptake of renewables sources, economical cost/benefit ratio.

More details about each scenario are given in the following.

A. Advanced Cooperative Storage Systems

The “Advanced Cooperative Storage Systems” scenario (Fig. 4) will be set up in Bucharest (RO) at the MicroDERLab facilities (part of European DERLAB network).

It will feature all the lower-TRL solutions proposed by Storage4Grid, namely the ER, the use of storage jointly with DC buses and it will also address Vehicle to Grid (V2G) services. In particular, a laboratory demonstrator will integrate innovative solutions with user’s internal DC bus for direct energy transfer from/to storage units and critical consumptions which will allow 24/7 functionality for both DSO and prosumer, and for selected home appliances which can be related to survivability during blackouts.

The reference, emulated house is instrumented with, beyond the traditional AC bus, with 3 DC buses to directly interconnect Photo-Voltaic (PV) systems, DC Home loads and any available battery management system. The ER, derived from the power electronics solid state transformer concept, acts as “power gateway” between the local renewable PV production, the local electrical storage through the battery pack and the prosumer’s power network. Various configuration and sizes of ER could be tested (e.g. 3 kW mono-phase or 6 kW three-phases solutions). The setup includes an USM integrated with a commercial smart meter (MID, metrology enforced, used for billing) connected to a set of Smart Meter eXtensions (SMX) for each relevant bi-directional sub-meter or sensor of interest.

The SMX read meter data from the commercial meter in real-time and use the information for various local purposes (local optimization of generation, storage and consumption) and for remote purposes – e.g. for DSO observability and control using the appropriate communication standards.

In the lab configuration, all loads and PV sources are logically interconnected with the hybrid simulation sub-system of the Storage4Grid DSF, so to enable the generation of synthetic test scenarios, including various combination of AC or DC load patterns simulating a wide set of sources and loads including: EV chargers; heat pumps; Heating Ventilation and Air Conditioning systems (HVAC); white goods; etc. The chosen hybrid simulation approaches have been devised to allow evaluation of predictive control algorithms logically deployed in different physical locations of the simulation scenarios. For instance, the set-up could be used to test the effect of remote signals sent by the DSO SCADA via the USM, as well as simulating the behavior of a local control algorithm performing user side ESS control, running on-board the ER.

The proposed setup will enable controlled evaluations about the performance in terms of: ability to store and exploit produced energy; ability to store efficiently and exploit cheap

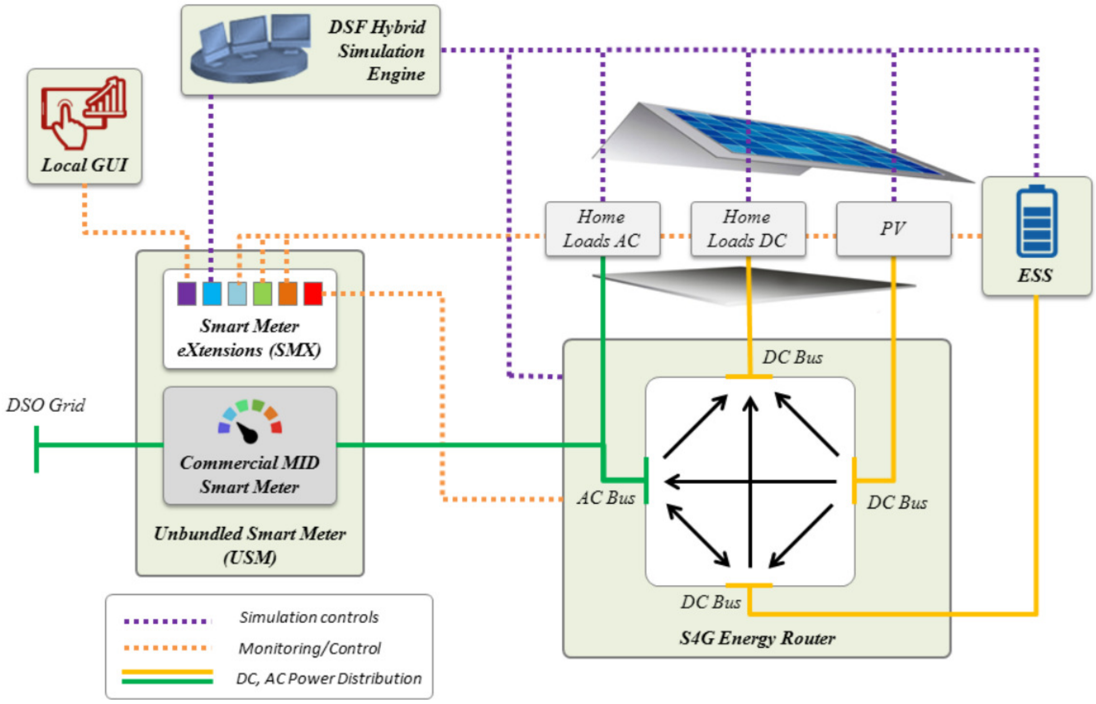

Fig. 4. The Advanced Cooperative Storage Systems Scenario

energy available from the DSO network; ability of the ER to act as a secondary Voltage controller reacting to DSO signals by using active power modulation; ability of the ER to act as a frequency variations mitigating unit e.g. as part of a scenario where several ERs are controlled by an aggregator; the ability of the ER to provide phase balancing services; self-consumption possibilities; ability for the overall system to react to complex demand response requests only employing storage and without shaving non-controllable loads; ability of the ER and ESS for peak shaving and to cope with high shares of variable renewables in the grid. Moreover, the setup will be used as a test bench to devise other innovative market and grid services, e.g. V2G.

B. Cooperative EV Charging

The "Cooperative EV Charging" scenario (Fig. 4) will be addressed in Bolzano (IT). It will be focused on studying methodologies for planning, evaluating and controlling storage installations communicating and cooperating with EV charging systems in two different settings, namely a commercial case and a residential case.

In the commercial case, a substation-level ESS, compliant with Storage4Grid interfaces and models will be used in conjunction with a commercial charging station featuring a combination of slow and fast Charging Points (CP). Storage4Grid will deploy modified "smart charge boxes" in each of the charging points so to enable fine-grained monitoring and control of the charging process from the DSO SCADA. Thanks to the deployed infrastructure, a number of predictive control algorithms will be developed, deployed and tested to establish a cooperative behaviour between the EV charging and storage control processes.

From the planning point of view, the Storage4Grid DSF, will be employed in this scenario to study optimal sizing and design of the ESS. At this purpose, the Storage4Grid DSF will provide key information about the costs and benefits of such installations, as well as suggesting the best control strategy for such system once the storage enters the operational phase, therefore benefiting DSOs, service providers and organizations interested in jointly investing in EV fleets and their charging infrastructure. Overall, the commercial case will also be significant for DSOs interested in planning deployment of charging stations in city centres where the process of reinforcing the grid, e.g. by digging new distribution cables, is expensive and cumbersome.

In the residential case, Storage4Grid will consider a prosumer owning a residential PV installation integrated with a local ESS, as well as a plug-in EV, normally recharged at home during nightly hours through a dedicated 3kW residential CP. In this case, a dedicated USM will be deployed and interconnected to the storage, PV and CP, enabling also in this case the possibility to run predictive control algorithms aiming at maximizing self-consumption and minimizing energy costs for the user. Moreover, a dedicated local Graphical User Interface (GUI) interconnected to the USM will allow the user to enter preferences and be more aware about the storage and EV status. From the planning point of view, in such case, the Storage4Grid DSF will be employed to support the design and sizing of local ESS and evaluate their impact on the cost, manageability and environmental sustainability of the EV

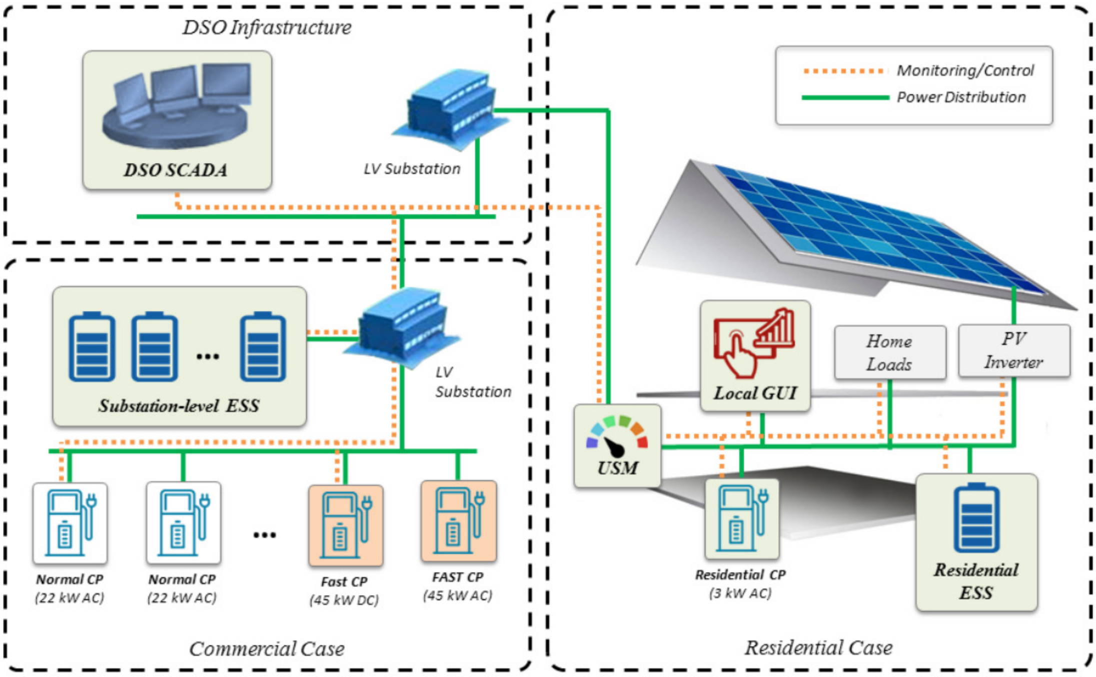

Fig. 5. The Cooperative EV Charging Scenario

charging process, both from the private users and from the local DSO point of view. As a part of this case, Storage4Grid will also consider the deployment of a standard sub-meter interface, part of existing smart metering standards, allowing for separate accounting and billing of EV charging costs, as well as the introduction of DR signals to reduce the impact of EV charging. This will allow deployed ESS to implement an optimal control strategy for jointly controlling the charging process and the storage, to benefit the end-user and minimize impact on the grid.

C. Storage Coordination

The "Storage Coordination" scenario will be addressed in Fur (DK) and features five residential Fur houses, all connected to the same radial, already provided with ESS units paired with PV installations of various size (ranging from 5 to 12 kWh sizes).

Such houses will be provided with an USM, integrated with the residential ESS and a dedicated local GUI. Similarly, a substation-level ESS will be deployed on-site. Overall, all available control capabilities will be interconnected with the DSO SCADA system, thus enabling cooperative behaviors in ESS. Storage4Grid will provide DSOs with tools, control and planning methodologies to perform technical and economic comparative evaluations of a number of control and planning cases where storage is needed as a buffer for fluctuations.

Logically, the system will be evaluated by allowing informed strategic decisions among alternative investment options such in the following:

- **Option 1 – Traditional grid strengthening** (baseline for benchmark). Starting from the most traditional strategies, DSOs consider investments in reinforcement of the grid by deploying larger transformer stations, more radials and thicker cables. This is considered the most conservative, well-known way of ensuring grid stability and security. The cost of such solution may not be sustainable in several cases. This solution would not have major effects on self-consumptions.
- **Option 2 – Private households investing in residential storage**. A first interesting case involving storage should consider investments by private households in RES with ESS. These investments are interesting for the private households mainly due to the economic advantage and a reasonable return of investment. In terms of grid stabilization, the effect of combined RES and storage is expected to be significant and cost-effective for DSOs. With current technologies, however, the DSOs would not have any form of control over the flexibility potentially offered by such systems. In situations where pricing schemas are not designed keeping existence of ESS in mind, the probability of systems discharging to the neighbouring systems which are charging is not negligible, and this would counteract grid stabilization efforts, beyond being a pure waste of energy due to efficiency loss. In order to foster use of storage in such segment, the Storage4Grid DSF should be devised to increase know-how of end-users about performance and control possibilities for residential users interested in investing in energy storage, giving predictable and reliable figures about the expected technical and economic performance.
- **Option 3 – DSO investing in large ESS at substation level**. This option will consider a situation where DSOs is

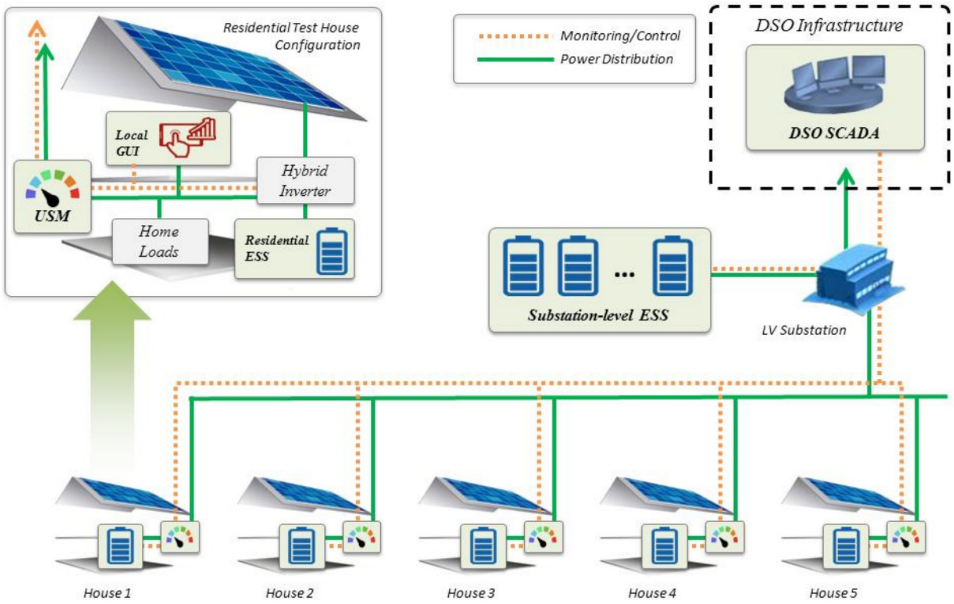

Fig. 6. The Storage Coordination Scenario

interested in installing larger energy storages on radials to act as a collective buffer for production and consumption in a specific neighbourhood. To achieve stabilization in the grid the main challenges in this case will be: selection of the most suitable storage technologies; correct dimensioning; most suitable positioning in the grid; selection of the most suitable control configuration; prediction of the expected performance, lifetime and operational costs of the deployed solution. In order to foster use of storage in this segment, the DSF should be devised to increase know-how of professional users about performance and control, giving predictable and reliable figures about the expected technical and economic performance.

- **Option 4 – Deploying and enforcing distributed controllable storage at various levels**. Generally residential and substation-level storage may be deployed jointly to achieve more flexibility. On the business side, this case would be more complex, as incentives and pricing schemas should be carefully designed to ensure relevance of investments for house owners and for other relevant organizations (e.g. aggregators, energy service companies, etc.). Most likely the incentive will stimulate the house owner to install controllable production, storage or consumption equipment to ensure stabilization within the grid. To achieve stabilization, a system aggregator would require access to ESS control capabilities. While growing in complexity, this case would open interesting perspectives for aggregators ensuring stabilization in a radial by controlling individual ESS as well as groups. This will require a lot of controls, monitoring to ensure the energy flows are not travelling from one battery to another. This option will be the most technically relevant for evaluation, as it will require the exploitation of the overall control capabilities developed by Storage4Grid.

For completeness, Storage4Grid will also exercise the DSF in grid segments outside Fur e.g. to analyse the potential of storage for upgrading or stabilizing the grid in a public setting such as a city centre or near larger renewable plants like wind turbine parks or PV parks.

IV. Conclusion

The Storage4Grid project started in December 2016 and will run for 36 months. All major technical results and lessons learned will be made available on the Storage4Grid Website [3].

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