SEVENTH FRAMEWORK PROGRAMME
THEME 5 - ENERGY

Project acronym: **eStorage**
Project full title: **Solution for cost-effective integration of renewable intermittent generation by demonstrating the feasibility of flexible large-scale energy storage with innovative market and grid control approach.**
Grant agreement no.: **295367**
Grant agreement for: **Collaborative project / Demonstration project**

eStorage Project Reporting
Attachment to 4th Periodic Report
PUBLISHABLE SUMMARY

Number of deliverable: **D6.8**

Date of preparation of the deliverable (latest version): **02/10/2016**
Date of approval of the deliverable by the Commission:

European Commission – Directorate General for Research

Revision chart and history log

Version	Date	Org. name	Comments
v0.1	02/10/2016	ALG	First draft sent to WP leaders to be completed
V0.2	19/04/2017	ALG	Compiled version sent to partners for final inputs
v1	03/05/2017	ALG	Final version sent to Steering Committee members for validation before submission
fv	10/05/2017	AHF	Final version ready to be submitted

Table of content

1 Self declaration of the coordinator

I, as scientific representative of the coordinator of this project and in line with the obligations as stated in Article II.2.3 of the Grant Agreement declare that:

- The attached periodic report represents an accurate description of the work carried out in this project for this reporting period;
- The project (tick as appropriate) [1]:
  - ☑ has fully achieved its objectives and technical goals for the period;
  - ☐ has achieved most of its objectives and technical goals for the period with relatively minor deviations.
  - ☐ has failed to achieve critical objectives and/or is not at all on schedule.
- The public website, if applicable
  - ☑ is up to date
  - ☐ is not up to date
- To my best knowledge, the financial statements which are being submitted as part of this report are in line with the actual work carried out and are consistent with the report on the resources used for the project (section 3.4) and if applicable with the certificate on financial statement.
- All beneficiaries, in particular non-profit public bodies, secondary and higher education establishments, research organisations and SMEs, have declared to have verified their legal status. Any changes have been reported under section 3.2.3 (Project Management) in accordance with Article II.3.f of the Grant Agreement.

[1] If either of these boxes below is ticked, the report should reflect these and any remedial actions taken.

2 Publishable summary

2.1 Summary description of project context and objectives

The objective of eStorage is to develop cost-effective solutions for the widespread deployment of flexible, reliable, GWh-scale storage across EU, and to enhance grid management systems to allow the integration of large share of renewable.
The key issue we plan to address is the need for power regulation during low demand periods, when only inflexible baseload generation and intermittent renewable generation are operating. In contrast to conventional generation, a storage plant able to regulate its consumption could help to avoid curtailing wind. Conventional Pumped Storage Hydro Plants (PSP) can only regulate their power in generation mode; variable speed technology for PSP can bring the additional flexibility in pumping mode as well.
Developing technically and economically feasible solutions in eStorage will allow upgrading a significant part of European PSP capacity to variable speed, providing up to 10 GW of additional regulation capability with no environmental impact and little administrative burden, all at a much lower cost than developing new plants. We will also develop and demonstrate solutions for coupling the dispatch of storage plants with renewable generation using advances Energy Management Systems.
This will enable storage plants to maximise their value in the balancing markets. From simulation studies, demonstration results and storage potential analysis we will evaluate the system-level benefits of storage and identify development barriers.
eStorage gathers major stakeholders from the entire value chain across EU (Elia – TSO, EDF – Generation Company, Imperial College – Academic Institution, Kema – Engineering Consultancy and Alstom – Equipment Manufacturer)

2.2 Description of the work performed since the beginning of the project and the main results achieved

2.2.1 Demonstration activities (WP1/WP2)

The key objective of WP1 was to demonstrate the feasibility of the conversion of an existing PSP to variable speed. Despite the decision to stop le Cheylas conversion, three years of studies have been performed, leading to the complete validation of the detailed design studies. The validation of these studies confirms the technical feasibility of a conversion of an existing PSP to variable speed

In Period 4, EDF, supported by GE, released a summary of the main achievements over these three years of studies, highlighting the difficulties encountered (some of them had been solved, some were still pending when the decision was made to stop the upgrade), and explaining the roots of their decision to stop the conversion. This analysis represents a valuable feedback of experience, publicly shared in the deliverable D1.3.

- Additional research and development on electro-mechanical equipment were performed by GE during Period 4 taking into consideration the lessons learnt from the design of Le Cheylas upgrade and the findings highlighted in the conclusions of WP4 (Feasibility and technical cost benchmark of PSP sites in Europe) to improve the design guidelines, GE undertook:
- A measurement campaign performed on an existing variable speed motor-generator to reach breakthrough understanding of physical phenomena under operation. Measurements of key

parameters such as temperature and axial movement at different operation points are needed to review the design space for potential optimization, particularly for the winding overhang support.

- The development of a real-time test facility for variable speed control systems. This tool aims to predict the operational behavior of the whole control system and prove compliance with the grid code requirements. This real-time simulation was used and tested during the commissioning of an existing variable speed unit in parallel to the progress onsite.
- Hydraulic developments for reversible fully-fed synchronous machines, trying to enable safe and efficient operation from 0 to 100% of load, especially in pump mode. First computational fluid dynamic (CFD) calculations then scale model testing were implemented to develop a new turbine hydraulic design.
- A lab-test campaign for converter fed windings. These tests aimed to provide major learnings for design criteria of insulation and corona protection system.

The results of these additional developments are summarized in the deliverable D1.4, publicly available on the project website.

Regarding WP2, the Balancing Market Application Functional Design was the main deliverable of task 2.1. This document has defined the general objectives of the clearing engine application, the context of its utilisation and the functional requirements for the implementation that has been done in task 2.2. This functional design has been done in order to comply with the draft version of the ENTSO-E Network Code on Electricity Balancing. It included the definition of new flexible energy products that have been designed to maximise the benefits of flexibility offered by storage assets in balancing markets.

In task 2.2, a Balancing Market Clearing Engine has been implemented and tested with representative datasets that have allowed validating the benefits obtained with the new flexible energy products. Some recommendations on improving the balancing process have been formulated in order to utilize the full benefits of the flexible energy products. These results have been presented during the 4th Annual Workshop and captured in a report for public dissemination.

In task 2.3, a smart dispatch application has been extended to be able to manage the specific aspects of variable-speed PSP (VS PSP) units, and in particular their capability to provide regulation services in pumping mode. Moreover, the PSP unit models have been improved with new specific hydro plants functions (hydro plant efficiency, implicit energy models). Then the PSP Smart Dispatch has been used to carry out studies performed with a representative generation portfolio dataset. These studies have demonstrated that the combination of the smart dispatch look-ahead capabilities, its energy and reserve co-optimization feature, and the variable-speed related flexibility provides a better anticipation of the coming events, such as an increase or decrease of the intermittent generation. Moreover, the case studies carried out to test and validate the smart dispatch application have also allowed the demonstration - in the unit commitment and scheduling phase - of the variable-speed technology flexibility benefits compared to the fixed-speed in facilitating a cost-efficient integration of intermittent generation technologies. These results have been presented during the 4th Annual Workshop and captured in a report for public dissemination.

2.2.2 RTD activities (WP3)

The main activity within Task 3.1 was the determination of feasible development scenarios for the determination of the Economic and Environmental Value of Storage in the Future EU electricity Systems in task 3.2. Further activity within this task was the assessment of role of storage, in particular of PSP. Deliverable D3.1 is the result of the work performed in Task 3.1 and served as an input for the other tasks of WP3, especially for Task 3.2.

Deliverable D3.1 contains the approach of the scenario development and the choice of the scenarios. It also contains a summary of the four internal reports developed in the first year and a summary of the discussions on the grid study and the role of storage. The scenarios describe different pathways of how the electricity system may change from the current state towards 2050 with increasing renewable capacity. Key components of the scenarios are the projections of future high-level network and conventional generation capacity, capacity and availability profiles of renewable resources, and the forecasts of electricity demand.

In Deliverable 3.2 a comprehensive analysis has been carried out to establish the value of energy storage, both from a fundamental system perspective as well as for participation in competitive electricity markets. The *fundamental analysis of economic and environmental value* of bulk energy storage focused on evaluating the economic and environmental benefits of deploying PSP in the future European electricity system, looking at four scenarios developed in Task 3.1 for the period between 2020 and 2050. The evaluation included the whole-system modelling of the entire interconnected European electricity system. The analysis found that the system benefits of PSP are significant and can reach up to €13bn per year in a high RES scenario (with 80% RES in 2050). Key fundamental drivers for the value of storage include the reduction of firm generation capacity in the short term, while in the long term the dominant component was the savings in OPEX, especially at high RES penetrations, delivered by avoided RES curtailment and improved system efficiency. As a consequence, carbon emissions from the electricity system were also significantly reduced as the result of deploying PSP. Upgrading the PSP with variable-speed drive was found to increase the economic benefits by 10-20% in the long run (2050). The analysis has further shown that the integration of balancing markets across Europe may reduce the value of variable-speed PSP, while on the other hand a higher value may be observed in a weakly interconnected system. Finally, the analysis identified Demand-Side Response (DSR) as a potentially serious competitor to transmission-connected PSP as provider of flexible system services.

Value of storage for participation in competitive electricity markets has been explored from an investor's perspective by optimising the revenues from the spot and balancing markets and quantifying the probability distribution of revenues as well as the expected revenue across the four scenarios developed in Task 3.1. The operational profits of a new-build VS-PSP were found to be in the range of €13-18m per year for the central set of assumptions; this profit level was found to be insufficient for a profitable business case as it resulted in negative overall annual profit. The projected distribution of balancing prices was found to have a strong impact on the operational profit distribution so that e.g. increasing the price spread between balancing prices and spot prices increased the expected profitability, but also increased the spread of possible profits. The analysis with a balancing price spread of four times the basic spread improved the overall annual profits to more than €50m per year. Comparison between variable-speed PSP and fixed-speed PSP showed that the former would see higher operational profits due to improved flexibility in pumping mode, so that it could be profitable already with base case balancing prices. Additional revenues could be achieved by PSP by stacking further services (such as FCR, intraday market and congestion management), however this was beyond the scope of the study.

Deliverable 3.3 provides a comprehensive analysis of *regulatory and market framework* relevant for transmission-connected energy storage across a variety of European countries. The Task partners first conducted a survey of regulatory circumstances in different countries, which was followed by a high-level analysis of key gaps and barriers. Key findings from this analysis include: (i) transmission charging is a challenging area as the locational value that flexible storage can bring on the transmission system is often not recognised; hence, charging harmonisation would be beneficial to pursue on the EU level; (ii) real-time pricing in most countries is not cost-reflective and significant improvements can be made in this area; (iii) balancing and ancillary services represent the areas where flexible pumped storage would be able to deliver significant value; full realisation of this value will depend upon adopting balancing network codes, product harmonisation and cross-border trading of these services; (iv) efforts towards the harmonisation of capacity remuneration mechanisms across Europe should be expedited to ensure that storage is not discriminated against other technologies such as generation or demand-side management.

2.2.3 Other activities (WP4/WP5)

The main activity in Task 4.1.2 was to estimate the potential of new pumped storage plant (PSP) locations by using existing water bodies in the EU-15 countries, Norway and Switzerland. It provided an estimate of the total theoretical and realisable storage capacity potential (GWh) of PSPs, providing industries and governments with an overview of capacity and suitable locations and thus informing decisions to develop new PSP projects. The key objectives of this task are:

1. Compile a list of 'water body pairs' suitable for (future) development of new PSP sites for each country in the EU-15, as well as Norway and Switzerland.
2. Determine a ranked version of this list based on criteria in order to provide the hydro community with more insight on the expected realisable potential of new PSP sites.
3. Provide an overview of total energy storage capacity per country.

In close collaboration with the WP4 expert steering group, the following strategy was established in identifying potential new PSP sites, combining the strength of computer models and expertise of national hydro experts:

1. Computer model: identification of potential water body pairs using high-level selection criteria using a GIS-based computer program to process and analyse geographical information to establish/identify potential pairs of water reservoirs suitable for PSP development, based on high level non-country/region specific selection criteria.
2. National hydro experts: Further refinement of initially established potential water body pairs. The initially established potential water body pairs in each country are further refined with the support of national hydro experts based on regional or country-specific selection criteria;

The results from the GIS model are referred to as the 'theoretical potential'. This theoretical potential is reviewed and a selection is made by industry experts, this resulting data is referred to as the 'realisable potential'. Work in Task 4.1.2 resulted in Deliverable 4.2.

Regarding WP5, the 1st Period focused on building the foundation and content for dissemination, including:

- The visual identity (logo, PowerPoint and Word templates) (Task 5.1),
- A press release announcing the formation of the eStorage project,
- A secure document exchange based on OpenText's Content Server (CS10) (Task 5.2),
- An initial project leaflet which was replaced by a refreshed project brochure (Task 5.6, D5.1, D5.3),
- A website (D5.3) compatible with mobile devices and leading browsers.

Periods 2 to 4 were mainly dedicated to disseminating the results of the project:

Dissemination Action	Task/Deliverable	Key Performance Indicators (KPI)
eStorage Project workshops	Task 5.3, D5.4, D5.5, D5.7, D5.8	• 4 workshops with total attendance of 145
Industry conference participation	Task 5.4, D5.6, D5.9	• 15 conferences with total attendance of 19,000 • 1 world's largest trade fair with attendance of 209,000
Publication coverage	Task 5.5, D5.6, D5.9	• 5 by-lined articles in trade media with total circulation of 74,000 • 2 press releases generating 406 articles • 18,503 eStorage website views • 2629 social media connections

The website will remain live for a period of time with a notice on the home page that the work has been completed. eStorage Project conference papers, reports, deliverables and publishable summaries will remain on the resources page of the website. These documents will continue to be a valuable resource for the eStorage partners for future marketing purposes. GE, for example, has made them available to its marketing, sales, communication and public affairs teams.

2.2.4 Management activities (WP6)

The main achievements of the management activities throughout the project are the following:

Ensuring an efficient general project management with the implementation of day-to day management tools and processes; Project management plan, Risk register, Project schedule, Monitoring and Action Management Board (updated every 3 months) addressing work progress and actions to be done, a cost control and resources management to ensure a coherence between both prevision and real achievements

Ensuring the interface with the European Commission through regular formal and informal contacts with the Project officer and Financial officer to inform on administrative issues when necessary and periodic review to provide with in-depth progress status, achievements of past periods and work plan for the coming periods.

Ensuring the organisation of partners meetings related to the coordination of the project in conformity with the governance scheme implemented at the beginning of the project and aiming at sharing operational information and reporting (Core Group meetings), taking formal and strategic decisions (Steering Committee meetings) and providing with recommendation (General assembly). In addition, conference calls and physical meetings with partners were organised when necessary.

Securing the production and the submission of deliverables in due time to the Project officer including each periodic reporting according to a shared project schedule and an efficient and appropriate review process allowing a collaborative way to validate qualitative and valuable deliverables before official submission.

Securing the requests for Amendments through the implementation of a collaborative process aiming at presenting and justifying the modification requested, collecting all necessary inputs from partners concerned and in fine ensuring the validation of new contractual documents.

2.3 The expected final results and their potential impact and use

The general project scope is to develop a global system solution by connecting the intermittent generation to the storage resources through an efficient electricity market, and by maximising the bulk storage resources flexibility. By optimising the global chain value and making recommendations to adapt the regulatory framework to incentivise the adequate bulk storage development maximising the global system value, one expect to maximise the end consumer value and minimise the electricity cost and/or minimise the intermittent generation integration cost impact.

With a typical availability factor above 90% and response time below the minute Hydro-Electric plants are amongst the most reliable generation resources to provide base load or peak power. The variable speed technology applied on Pumped Hydro Storage Plants pushes the flexibility of such plants one step further. With their flywheel capability and a reaction time for large power variation below the second, variable speed PSP can provide power quality service as well as frequency regulation in pumping and generation mode and time shift. They are the ideal partner of intermittent generation, in particular to manage the daily variabilities of wind and solar PV. However the investment cost for new plants and the topology constraints limit the diffusion of the technology. By developing solutions to upgrade existing plants we provide less expensive way to disseminate this technology all through Europe.

The eStorage project objective is indeed to demonstrate in WP1 the economic and technical feasibility to upgrade existing conventional Pumped Hydro storage plants into variable speed ones by designing the upgrade of a 240 MW PSP. This upgrade objective is to increase the plant frequency regulation capacity and to improve its cycle efficiency and therefore provide economic benefit to the plant owner. The project includes also a R&D phase whose objective is to develop solutions that aims to make it possible and economically viable to upgrade in variable speed more than 75% of the 40,000 MW installed base.

IT tools encompassing new market regulatory framework geared to closer to intraday and real-time capabilities and dealing with cross-border transfer constraints will help reducing the impact of disturbances introduced by ever growing penetration of variable energy resources like wind. Studying and assessing new market design will likely help both system operators and Balance Responsible Parties to achieve system and portfolio balancing by introducing closer to real-time products and opportunities to trade energy and reserves. New IT tools will not only consider the point of view of the central grid or market operator but will also help other actors such as generation companies to adjust and optimize their revenue streams by having new energy or reserves trading opportunities.

Several international studies indicate that bulk storage can provide many benefits to electricity grids and markets in addition to facilitating the integration of renewable energy. These include increased efficiency of existing plant and of the transmission system as a whole, enhanced security of energy supply. Thus, PSP can contribute to a reduction of overall generation and transmission system costs and electricity prices.
Variable speed Hydro Storage probably has the shortest response time amongst the transmission scale generation resources.
Bulk storage will reduce the need to curtail wind. Curtailment is already occurring in grid systems having integrated large intermittent generation (Ireland, Spain…) and predicted levels of wind congestion on transmission lines are of concern to System Operators. Thus PSP could provide valuable wind management services to the TSO and command a new payment consistent with market consultation by the Regulators for “new ancillary services” to reward such grid services.
PSP have the potential to provide ancillary services, including operating reserve, reactive power, black start, automatic generation control and system support services. The challenge of integrating increased renewables onto the grid adds greater complexity to balancing of the system and introduces greater risks (e.g. frequency fluctuations) and costs for all stakeholders - existing plants, utilities, the system operator, potential investors and the consumer. PSP have the potential to provide what may be termed Advanced Ancillary Services in providing a powerful and flexible balancing component for systems with high wind penetration.

2.4 The address of the project public website

www.estorage-project.eu