EERA
European Energy Research Alliance

Coordinating energy research for a low carbon Europe

EERA Workshop on Hybrid Energy and Energy Storage Systems

Date: **22 March 2017 – 09:00h to 16:00h**
Venue: **IK4-CIDETEC** (see map)
P° Miramón 196, 20014 - DONOSTIA / SAN SEBASTIÁN (SPAIN)

Agenda

09:00		**Start**
09:00	**I**	**Opening and Introduction** • Atle Harby – SINTEF (NO) / EERA JP ES SP4 Coordinator • Giovanna Cavazzini – University of Padova (IT) / EERA JP ES SP4 Deputy
09:25	**II**	**CASE STUDIES**
09:30		**1- Contribution of hybrid energy and energy storage systems to the integration of variable renewable energy in the power system** • *«Hybridisation with fast energy storage technologies» - Marcos Lafoz – CIEMAT (ES)* • *«Integrating renewables and storage» - Atle Harby – SINTEF (NO)*
10:15		**2- Control and Energy Management Systems for hybrid energy and energy storage systems** • *«Control strategies and sizing of a flywheel energy storage plant for the frequency control of an isolated wind-hydro power system» - Juan Ignacio Perez Diaz – UPM (ES)*
11:00		**Coffee Break**
11:20		**3- Regulatory barriers for the deployment of hybrid energy and energy storage systems** • «Regulatory framework for energy storage systems, barriers and recommendations» - Raquel Garde – CENER (ES) • *«EU regulatory barriers to energy storage – how to unlock the grid code?» -* Alfons Westgeest – EUROBAT (BE)
12:05		**4- Hybrid energy and energy storage systems in a Smart Grid: New concepts and future potential** • *«Flywheel- Battery Hybrid for Grid Stability» -* Frank Burke – Schwungrad Energy (IE) • *«Novel concepts of increasing the storage at Pumped Storage Power Plants» -* Pål-Tore Storli – NTNU (NO) • *«An innovative configuration of Pumped Thermal Electricity Storage System» –* Anna Stoppato – University of Padova (IT)
13:00	**III**	**DISCUSSION** (all)
14:00		**Lunch** (BIZI restaurant)
15:00	**IV**	**PLAN for FUTURE WORK** (all) - Publications - Research needs
15:50	**V**	**CONCLUSIONS**
16:00		**End of meeting**

List of Participants

	Last Name	First Name	Organization	Country
1	Benitez	Ignacio	ITE	ES
2	Burke	Frank	Schwungrad- Energie	IE
3	Cavazzini	Giovanna	UNIPD	IT
4	Chladil	Ladislav	Brno	CZ
5	Epelde	Maider	Tecnalia	ES
6	Faik	Abdo	CIC Energugune	ES
7	Fernandez	Alvaro	Schwungrad- Energie	IE
8	Ferraro	Marco	CNR	IT
9	Garcia	Alberto	Tecnalia	ES
10	Garde	Raquel	CENER	ES
11	Gil Bardaji	Myriam	KIT	DE
12	Goede	Adelbert	DIFFER	NL
13	Granados	Xavier	CSIC	ES
14	Harby	Atle	SINTEF	NO
15	Ihssen	Holger	HGF	DE
16	Lafoz	Marcos	CIEMAT	ES
17	Marino	Iker	Tecnalia	ES
18	Merlo	Leonardo	ENEL	IT
19	Miguel Crespo	Oscar	IK4-CIDETEK	ES
20	Murta-Pina	Joao	FCT-UNL	PT
21	Navarro	Helena	U Birmingham	UK
22	Pascual	Carol	Tecnalia	ES
23	Penazzi	Nerino	POLITO	IT
24	Perez Díaz	Juan Ignacio	UPM	ES
25	Saez de Ibarra	Andoni	IKERLAN	ES
26	She	Xiaohui	U Birmingham	UK
27	Sheridan	Edel	SINTEF	NO
28	Stoppato	Anna	UNIPD	IT
29	Storli	Paul Tore	NTNU	NO
30	Tresso	Elena	POLITO	IT
31	Vanysek	Petr	Brno	CZ
32	Vita	Antonio	CNR	IT
33	Villarreal	Igor	IKERLAN	ES
34	Westgeest	Alfons	EUROBAT	BE

Minutes

The workshop has tried to analyse the combination of the different renewable generation sources as well as storage technologies, how they can fit together and how can be integrated in the electric grid or in smart grids to enhance their performance.

CASE STUDIES

1- Contribution of hybrid energy and energy storage systems to the integration of variable renewable energy in the power system

- *«Hybridisation with fast energy storage technologies» - Marcos Lafoz – CIEMAT (ES)*

  Due to the grid codes (regulations), the quality of the electricity injected into the grid has to meet strict requirements. That makes renewables, with variable power generation, to adopt strategies in order to satisfy them, such as: sizing of the system, improving control strategies and including Energy Storage (ES). The integration of these measures allows to deliver the maximum power from a generation system into the grid. A restriction in the generated power could be imposed in case of not fitting the grid codes.

  Which ES should be selected, depends on the requirements of: Power and Energy needed, Cycles/year, Time response.

  Power and Energy can better fulfil an application with two technologies instead of just one, where one of the two variables is usually oversized.

  The four rules to define the technologies to hybridise are: Optimize power output; Minimize Losses; Optimize State of Charge; Optimize State of Health.

  Several combinations of storage hybridisation are possible (Batteries+EDLC (Electric double-layer capacitors), Fuel Cells +EDLC, LAES+Flywheels, PH +Flywheels) depending on the application requirements (a matrix has been defined and a review of the combinations would be required from the rest of participants in order to complete the table short-term/long-term hybrid storage combinations, also considered as fast-slow -even an hypermatrix should be considered to take into account other aspects-). Some examples of hybridisation projects were mentioned: Batteries + SMES at Bologne, LAES+Thermal (Birmingham), TES + Batteries.
  The use of fast response energy storage technologies is currently economically challenging.

- *«Integrating renewables and storage» - Atle Harby – SINTEF (NO)*

  Examples of the combination of batteries and pumped-storage are presented as well as combination of solar PV generation with hydropower. Although apparently the hydro-storage is fast enough to response instantaneously to the frequency regulation, the concept of “instantaneous” is relative. The use of flywheels, batteries or other type of fast energy storage devices on hydropower systems gives the hybrid ES technology an "instantaneous response" to the grid demand. The natural response of hydropower (10 s) is moved forward to miliseconds by fast technologies response performance.

2- Control and Energy Management Systems for hybrid energy and energy storage systems

- *«Control strategies and sizing of a flywheel energy storage plant for the frequency control of an isolated wind-hydropower system» - Juan Ignacio Perez Diaz – UPM (ES)*

  Wind energy is not considered to provide inertia to the electric systems when analysing the behaviour of an electric system.

  The study case of integration of flywheels with pumped-storage is analysed. The system has been optimized using a control strategy approach (non-linear proportional scheme) with a better behaviour than a conventional droop-based control, resulting in a better smooth of the power fluctuations. Moreover, the use of the flywheels reduces the fatigue of the turbine technology.

  An additional control loop to optimize the state of charge of the short-term energy storage devices is interesting to be included in the control strategy.

  Cost of the system is a problem: cost of the technology plus the shipping cost

3- Regulatory barriers for the deployment of hybrid energy and energy storage systems

- *«Regulatory framework for energy storage systems, barriers and recommendations» - Raquel Garde – CENER (ES)*

  The concept of energy storage is not mentioned in the European Electricity Directives, neither as generation system nor as a load. Only pumped-storage is considered as a power generating system connected to the grid and shall fulfil the requirements both in generating and pumping operation modes.

  The main identified barriers for the energy storage are:

  - The current business model, which does not include ES because the investments are risky, lack of business cases, lack of data and knowledge about ancillary services
  - There is no financial support
  - Administrative barriers when connecting to the distribution grid
  - Connection rules should be defined as well as technical standards
  - The market must provide clear signals to reflect the new requirements for flexibility in balancing the ancillary services
  - Insufficient market access

  The main recommendations to overcome these barriers are:

  - It is required a clear definition of what Energy Storage is. It has to be the 4th element after generation, distribution and consumption.
  - removing the financial support for any type of electricity storage as it distorts competition with other options that can offer flexibility
  - TSO should be to define the products needed for balancing and for the stability of the system and use market based mechanisms for procuring these products
  - need for storage on the distribution level is growing fast

Comments:

Nowadays in Europe there is not yet a common market: 28 states with 28 different regulatory electricity markets. In some countries in Europe ES has been considered and regulated for some applications like Italy (batteries+ PV), Belgium (TSO can own ES). Countries like USA have modified the regulations for example for frequency control. In others like Spain, the law forbids explicitly ES.

ES has enough flexibility to consider other ancillary services to be used related to grid quality, not only primary, secondary or tertiary regulation.

- «*EU regulatory barriers to energy storage – how to unlock the grid code?*» - Alfons Westgeest – EUROBAT (BE)

  The analysis in 2015 of the energy storage technologies distribution shows a clear advantage of pumped storage over the rest.

  The barriers for Energy Storage start with its definition in regulatory framework as it is not considered an asset, as already mentioned before. It is proposed a definition for Energy Storage by the Electricity Directive, Chapter 1, Art. 2.47: "in the electricity system, deferring an amount of the electricity that was generated to the moment of use, either as final energy or converted into another energy carrier".

  TSOs/DSOs shall not be allowed to own, develop, manage or operate energy storage facilities.

  Final customers are entitled to generate, store, consume and sell self-generated electricity in all organized markets either individually or through aggregators without being subject to disproportionately burdensome procedures and charges that are not cost reflective (Electricity Directive, Chapter 3, Art. 15).

  Member states shall ensure that electricity prices reflect actual demand and supply. (Electricity Directive, Chapter 2)

  The only way to consider storage under the law is to get a demonstration plant, which, on the other hand, is almost impossible taking into account the level of power considered (MWs).

  Battery energy storage technologies are rapidly developing worldwide and in Europe.

4- Hybrid energy and energy storage systems in a Smart Grid: New concepts and future potential

- «*Flywheel - Battery Hybrid for Grid Stability*» - Frank Burke – Schwungrad Energy (IE)

  Intermittency and stability are the main problems of introduction of renewables in electric grids. Stability is provided in conventional grids by the synchronous generators which provide inertia. New generation concepts do not provide inertia. Energy Storage can provide synthetic inertia to the electric grids if they are able to respond fast enough.

  Energy Storage is required in different timeframes: over many hours on one hand and dynamic storage over some minutes with a fast response time of a fraction of a second on the other.

The study case of Rhode Pilot Plant has been explained. The facility uses batteries and flywheels. Lead acid batteries have been selected because they just remain waiting to provide power to compensate the frequency drops and they are recharged very slowly. Limitations of the batteries are solved by the flywheel. It is demonstrated that the hybrid system provides rapid response to changes in system frequency.

In Ireland, which has currently above 20 % of renewables integration, TSO has been qualified to procure frequency response solutions (a response of 0.5 Hz per second is required from the Irish TSO).

EU policies on electricity markets, grid codes etc. must support and not hinder the roll-out of dynamic energy storage to stabilize the grids with increasing levels of renewable generation to allow the decarbonizing of electricity.

Hybrid energy Storage is able to enhance performance of conventional generation plants as well as improve the "firmness" of renewable plants. It is also capable of providing power without energy, avoiding the curtailment of renewables.

- «*Novel concepts of increasing the storage at Pumped Storage Power Plants*» - Pål-Tore Storli – NTNU (NO)

  New concepts of energy storage hybridisation are continuously in our minds. A new concept based on hydro pumped and compressed air energy storage (CAES) has been presented, still under development and without the knowledge if there is already a patent related to it. Maybe there are intellectual property conflicts. The concept uses air pressure in balloons or similar in water reservoirs to increase the storage capacity.

- «*An innovative configuration of Pumped Thermal Electricity Storage System*» – Anna Stoppato – University of Padova (IT)

  A new approach for existing technologies related to thermal storage has been presented. The system does not need geographical requirements. The technical concept just need a blower, not a compressor since it operates at atmospheric pressure. Only high temperature is required.

  No new elements or technologies are required for this solution, just the integration of already existing devices. Only control strategies would be new. The system is still under investigation, the next step is the study of the whole system. The preliminary round trip efficiency is 15%.

General discussion

Summary of concerns and barriers

A higher penetration of renewable energies is needed in the electric system to improve the sustainability and CO_2 reduction. Renewable energies are changing the electric market business model, displacing in some cases fossile-based power plants (in many cases being dismantled). However, a maximum of around 36% is allowed if no energy storage technologies are used due to their intermittency, lack of flexibility and stability problems.

Due to renewable energy inheriting characteristics, it is produced on low populated areas and has then to be provided to high populated areas: new transmission lines are needed. Micro/isolated grids have to be considered too.

On the other hand, from the demand side, consumers can displace/smooth the demand/generation windows with the introduction of renewable energies combined with energy storage systems. That can lead a new life style. A demand management should be considered.

Energy Storage is a feasible solution to provide energy reservoir as well as stability to the electric grid (different timeframes), but there are still different barriers to overcome before its full deployment:

- Acceptance: Energy Storage has to be accepted as a solution and a technology that has to be considered into the electricity network system. Energy Storage needs to have its own identity under the power systems rules to allow the creation of new business models.
- The cost is still high in some of the technologies. The cheapest one is pumped hydro when considered in large scale. Energy Storage will be really developed only if it is able to provide flexibility in the electric systems at a competitive price. Remuneration mechanisms are required to be established by TSO or others in order to promote the development of the industrial sector. Maybe there is need of subsidies for that, at least in a first stage.
- The lack of regulation involving energy storage is a challenge. In some countries renewables complemented with ES can provide ancillary services: Japan wind energy has to have an ES technology coupled to assure the electricity production and Puerto Rico has regulated PV plants + ES systems.
- Hybrid energy storage, as well as in some cases energy storage, is a good solution to a problem that is not still affecting the electric systems at full strength.

Important questions to be answered are:

- *Which is the Technology Readiness Level?*

  Hybridisation of energy storage technologies comprises different storage devices with a high TRL, as they have been already demonstrated in real environments (in the range of 8-9), and a control strategy that usually will have been tested in laboratory in relevant environment or similar conditions and with small-scale prototypes of the storage technologies, which is a TRL 5-6. The combination of all of them results in the lowest TRL involved, said TRL 5-6. This is what now is introduced as "System Readiness Level" (SRL).

- *Are they able to increase the deployment of intermittent renewable energy sources?*

  As it has been demonstrated in different publications, research analysis, research projects and demonstration plants, it is a reality that by using energy storage, and more significantly by using hybrid energy storage, the electric system performance is improved.

- *Are there solutions more promising than other?*

  There are many potential solutions based on different combinations of technologies. Some of them have been more explored in applications and experimentally than others. The combination of technologies that are conceptually complementary is more promising. In this sense, short-term and long-term technologies association fulfils this concept. Batteries +EDLC (Electric double-layer capacitors) is the most extended association as well as combination of batteries with other fast energy storage devices such as flywheels. Additionally, some fast technology combined with pumped hydro is demonstrated to provide improvements in scenarios of high renewable penetration.

- *Which is their potential?*

  The main potential of hybrid energy storage is to be able to provide ancillary services to the electric system, apart from primary, secondary and tertiary regulation, based on grid frequency stabilisation, maintenance of rate of change of the frequency, avoiding of the curtailment of renewables, and increase of the effectiveness and the efficiency of the renewable generation.

- *Are they market-ready?*

  The individual technologies are in general very mature for the market and are already being commercialised. Integration of technologies as hybrid systems, since need to be firstly tested in laboratory or controlled environments, the joint operation as well as to be obtained the real benefits, seems not to be in the market stage yet.

- *Which type of barriers they have to face:*

  - ✓ *Technical challenges?*

    Although many of the technologies accept individual improvement, most of technologies are very mature (TRL quite high, 8-9). Mainly control strategies and its implementation need to be tested. Not really the need of new strategies but to have the opportunity to use them in real systems operating in real environments, and also make sure that SRL can be high.

- ✓ *Market barriers?*

  The barriers to reach the industrial markets are due basically to the high cost in general terms of the energy storage technologies as well as to the absence of remuneration mechanisms for the storage suppliers.

- ✓ *Regulatory barriers?*

  - In Europe there are 28 states with 28 different regulatory electricity markets.
  - Energy Storage is not considered an asset in regulatory framework.
  - The current business model does not include energy storage because the investments are risky, there is a lack of business cases and a lack of data and knowledge about ancillary services
  - There is no financial support
  - Administrative barriers when connecting to the distribution grid
  - Connection rules should be defined as well as technical standards
  - The market must provide clear signals to reflect the new requirements for flexibility in balancing the ancillary services
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- *Do they need any support or market mechanism?*

  Absolutely yes! The support from TSO and regulatory boards is critical. Also market and remuneration mechanisms are necessary to develop the adequate business models to introduce the systems definitely in the markets.

Conclusions

Although we did not achieve definitive conclusions about the role of hybrid energy generation and storage, we identified some lines to keep on working, such as:

1. to prepare a state of the art related to hybridisation of energy storage based on projects and already existing pilot plants.
2. to identify the most promising combinations of energy storage technologies in order to improve their applicability, reliability and level of performance.
3. to work on control strategies as a manner to improve the electric systems response when using energy storage single or hybridised.
4. to develop new demonstration sites with hybrid systems, as the best way to improve the visibility and to probe that energy storage deserves its own in electric systems.
5. to work in the Electric Standards and Electricity Directives to include Energy Storage.