# Summary Report of the RGI Workshop on:

# Storage Needs, Options and Challenges Today and Tomorrow

At the first RGI workshop, the technical questions regarding transmission technologies for grid expansion were explored in order to improve a shared understanding among and across TSOs, NGOs and relevant stakeholders. RGI identifies grid expansion as inevitable to allow for effective integration of large shares of renewable energy sources in the European power grid.

However, RGI acknowledges that grid expansion alone is not capable of mitigating the variability of renewable electricity generation. Expansion of storage technologies is often considered pivotal to allow for this renewables European power grid but the storage requirements are not clearly understood. For this reason, RGI organized its second workshop[1] around the role of storage on the 27th of January 2011 in Montreux, Switzerland, which was hosted by Swissgrid and SGN Swiss Association for Grid Infrastructure Research. The workshop's speakers and participants formed a group of representatives from TSOs, NGOs, technology suppliers, research, utilities and technical consultancies. The broad spectrum of experts present at the workshop enabled RGI to stir an active dialogue that brought to the front the issues and concerns different stakeholders have when dealing with the expansion of storage technologies.

The workshop consisted of three sections that aimed at addressing the technical (technological/operational), regulatory and political complexities of storage related to today's and the future's production mix based on renewables.

- The first section revolved around the current situation of storage. Speakers from RGI, Laboratory for Hydraulic Machines (Ecole Polytechnique Federale de Lausanne) and Statnett contributed to this section which covered three topics:
  - potential applications of storage technologies
  - pumped hydroelectric storage and technological developments
  - market design requirements for efficient use of hydro power

- The second section focused on alternative approaches for storage. Speakers from the Regulatory Assistance Project (RAP), ABB and KEMA led this section which covered three topics:
  - qualitative comparison of storage vs. transmission expansion and demand side measures
  - impact of smart technologies on storage strategies
  - overview of storage technologies

- The third section presented the challenges of integrating storage technologies. Speakers and panelists from WWF Switzerland, Mainstream Renewable Power, Swiss Energy Foundation, Scottish and Southern Energy (SSE), Swissgrid and TenneT provided their insights on the political, technical and system flexibility challenges of storage integration.

Complementary to the workshop's agenda, 50Hertz Transmission presented its System Trainer; a training centre providing support to professionals working in the electricity sector.

[1] All figures used in this document were extracted from the presentations of the workshop

## First Section: Today's Situation

Over the last century, power systems have developed from isolated power plants to regional and continental systems. The fundamental challenges of power systems have changed accordingly. From challenges related to the operation of power systems and how to make them work, to challenges related to the expansion of such systems and interconnecting them. Today's challenges are directly related to the sustainable nature of power systems and their transition from being fossil-fuelled to renewables-fuelled. Storage is expected to play a crucial role in this transition and many European countries are assessing storage technologies and their potential.

The unique operational characteristics of storage have positioned it as a candidate for a number of potential applications, including:

- balancing services[2] (primary, secondary, tertiary)
- capacity displacement (generation, transmission)
- arbitrage
- voltage support
- power quality
- decentralized storage

When related to renewables, the above applications can be seen as means of effective integration of renewables; both from the perspective of maintaining system stability and avoiding the curtailment of renewables. Today, only one technology has significant amounts of installed capacity that is providing the benefits of such applications. Almost all storage capacity in Europe is coming from hydropower storage.

Different technology methods exist including vertical ternary pumps, hydraulic bypass and reversible pump turbines. A crucial element in designing such systems is variable speed technology as it controls power when in pump mode. The Laboratory for Hydraulic Machines of the Ecole Polytechnique Federale de Lausanne is currently undertaking several research projects on pump turbine hydrodynamics and looks into different technical elements of pump turbines that address the requirements of storage technologies and position it as an enabling technology.

### Potential of hydro

Switzerland and Norway have the potential of becoming Europe's green batteries and handling the variable production from wind and PV. Both countries have large hydro capacities and it is expected that over the next 10 years their pumped storage capacities will increase by 4GW (Switzerland) and 15-20GW (Norway). Sweden is another country with large hydro capacity but geographically is more focused to Finland and the east.

[2] Thoughout this summary report the terms ancillary and balancing services have the same meaning

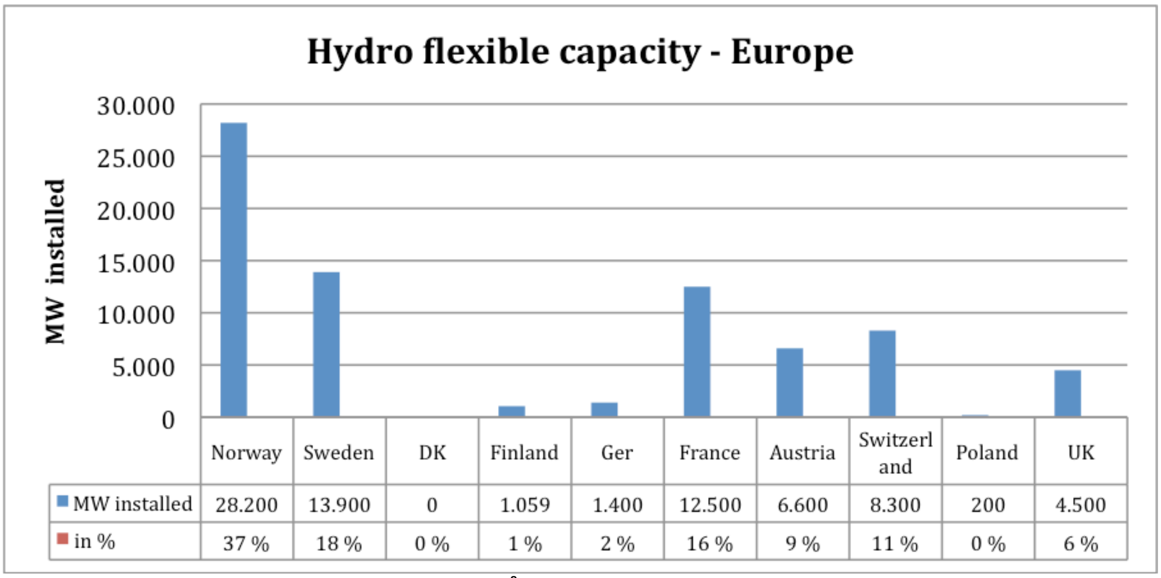


Figure 1: Flexible hydro balancing power in Europe[3]

To facilitate this storage expansion, Norway is upgrading its grid and interconnectors capacity. As interconnections increase so will their expected revenues, which are based on congestion rents. However, as this will probably have no impact in the near future due to the lack of interconnector capacity, more cross-border interconnectors are planned in order to benefit from hydro's advantages (figure 2). Hydro storage can not only contribute towards this variability through short and long-term storage, but also provide benefits to the stability of electricity prices. Overall, hydro's benefits can be summarized in the following points:

- Pumped storage (short-term) can accommodate for the variability of renewables by pumping water into the reservoir at periods of high renewables output and produce electricity at periods of low renewables output. By providing secondary reserves storage can avoid the curtailment of renewables and/or avoid forcing the TSO to make inefficient choices by operating fossil-fuelled power plants at part-load.
- Hydro reservoirs can provide longer-term storage of water and compensate for seasonal patterns in renewables generation and demand.
- Connecting hydropower systems to thermal/wind plants has proven to flatten out electricity prices. This occurs due to the different price structure and volatility of thermal and hydro. Thermal power is capacity constrained and is governed by fuel and emission costs, while hydro is energy constrained and governed by precipitation.

[3] "Requirements to market design for an efficient use of hydropower reservoirs" presentation, Kristin Munthe, Statnett, RGI Storage workshop, 27/01/2011

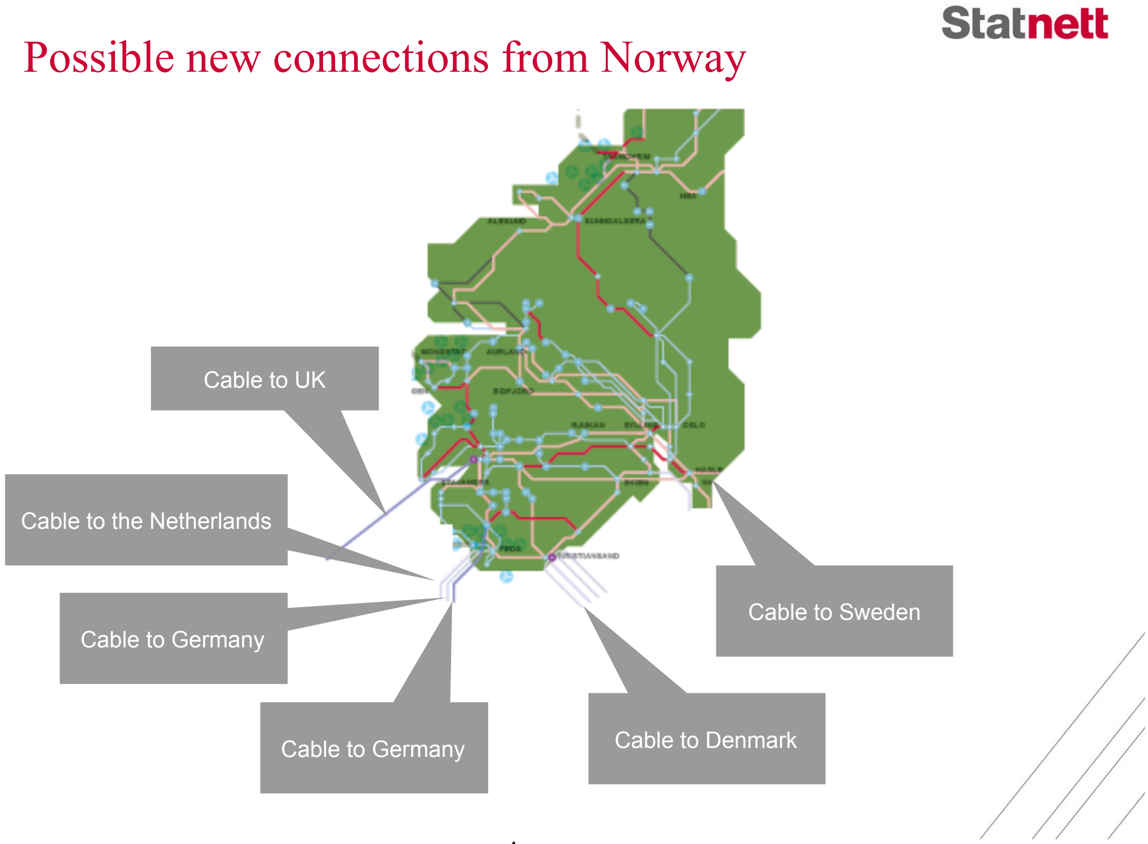


Figure 2: Possible new interconnectors from Norway[4]

## Second Section: Alternative Approaches for Electricity Storage

### Other storage technologies

Besides pumped hydro storage, a range of other technologies exists. Amongst them, the most promising are:

- Compressed Air Energy Storage (CAES)
- Batteries
- Flywheels
- Ultra or Super Capacitors
- Super Magnetic Energy Storage Devices (SMES)
- Hydrogen
- Thermal

The above technologies are at different maturation phases and currently face issues that are related to their efficiency, energy/power density, environmental impact, etc. Each technology has different characteristics that have the ability to provide multiple services and therefore, potentially benefit from multiple revenue streams. When considering which storage technology is most suitable for an application[5], there are a number of elements that need to be taken into account:

- type and size of storage

[4] "Requirements to market design for an efficient use of hydropower reservoirs" presentation, Kristin Munthe, Statnett, RGI Storage workshop, 27/01/2011

[5] For example, thermal storage has proven to be very cost effective for residential applications

- location of installation
- costs/benefits
- timeframe of charging/discharging

Figure 3 below, illustrates a grid of storage technologies according to their power rating and discharge time.

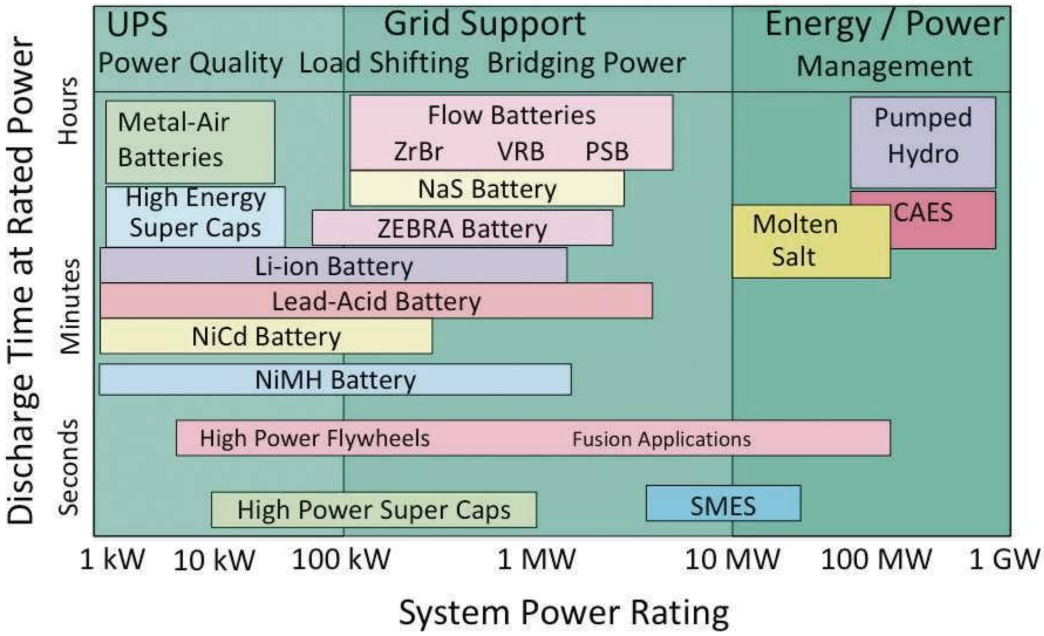


Figure 3: Grid of storage technologies[6]

## Alternative approaches[7]

Besides storage, transmission and demand side management (DSM) are also essential for the effective grid integration of renewables. There are applications where storage is expected to compete or complement transmission and/or DSM. Their qualitative combination in different regions is yet unknown and will be shaped in the coming years as renewables expansion continues. Accordingly, it is also not clear what the quantitative combination of storage (distributed or centralised), transmission and DSM will be.

Transmission

Inter-regional transmission reduces the system-wide impact of demand and supply variability. This can be achieved through leveraging the negative correlation between solar and wind, and the daily and seasonal differences across regions. On the supply side, the impact of transmission is seen in the form of aggregated dispersed volatility of renewable generation and lower backup generation requirements.

Storage

Storage can compete with transmission on displacing the need for additional transmission and/or generation capacity. On the other side, it competes with DSM and complements transmission on types of variable generation that transmission cannot fully balance (extreme weather conditions, day/night and intra-day variations). When the timeframe is in the second, minute or hour range, system and/or dedicated storage strategies can match supply

[6] "Challenges of Integrating Storage Technologies: Technical complexity from a TSO point of view" presentation, Martin Geidl, Swissgrid, RGI Storage workshop, 27/01/2011

[7] A pilot project, by Scottish and Southern Energy (SSE), aims at covering the demand needs (50MW) of the Shetland Islands in Scotland solely from renewables over the next 3 years. Along with renewables generation, distributed storage and large-scale thermal storage will be utilized and tested against the expected pressure on generation and transmission that extreme weather conditions will impose.

with demand. However, when energy shortages last beyond a few hours, storage alone cannot efficiently handle such variations.

DSM:

DSM consists of a set of measures that can reduce demand peaks, shift loads, and in general reduce the overall demand without compromising the level of energy services. DSM is a core competitor for storage. However, in some cases storage and DSM can be complementary. Timely charging/discharging of distributed storage can reduce peak demand and increase the overall flexibility of the system. The potential for synergies of distributed storage with DSM measures is significant and may well compete with centralized storage and/or complement generation. The ability of storage technologies to be utilized in more than one way and act complementary to DSM can be fully exploited with the use of smart technologies both on the transmission and distribution network. The distribution network in particular, is currently 'passive'. Control, sensing and prediction are smart technology areas that can have a direct impact on the balancing needs of the system and its storage requirements.

## System Security Trainer: A Grid Training Centre

50Hertz Transmission, in cooperation with the Brandenburg University of Technology, has created a grid-training centre whose scope ranges from education and training to academic research, teaching and cross-company crisis exercises. The centre[8] offers individual or group training for several TSOs and utilities. Specifically, training can be provided in areas such as grid elements malfunction & overload, high renewables supply under different load conditions, malfunctions at the customer or production unit level and grid restoration (black-spots).

The motivation behind the centre lies in ensuring the highest level of know-how, meeting the ENTSO-E regulations, and meeting new challenges (renewables integration, smart grid, etc). The realisation of such a centre requires multi-stakeholder involvement in order to accommodate for better understanding among key actors. In that respect, a European Training Centre, where TSOs would provide transparent data, would be very useful.

## Third Section: Challenges of Integrating Storage Technologies

The challenges related to storage technologies can be seen from a technical, system flexibility, market and political perspective.

The first three are very closely inter-related as changes in one can have a direct impact to the other. The market should enable and incentivise the storage technologies, which in turn should possess the technical characteristics that can fulfil the system's flexibility needs. From the perspective of a TSO, flexible generation resources are needed irrespective of their nature as long as the desired characteristics are met[9]. Since a TSO cannot own storage installations, what is important is not whether centralised or decentralised storage, DSM or transmission is used, but how these flexible assets are operated in order to provide the required ancillary services. Figure 4 shows the options that can provide flexibility for the TSO in the integration of renewables.

For primary control, it is very important that the TSO coordinates actions in an autonomous manner. For secondary and tertiary control, coordinated communication signals between the TSO and the generation resource are required. Probabilistic tools for grid planning and operation, central coordination, accessibility and availability of flexible resources, effective management of storage portfolio and an appropriate market model that enables these features are key for the TSO in order to provide ancillary services in the most effective manner.

[8] Tennet also uses a similar training centre and, thus, a comparison between them could be useful.

[9] For example, in the case of the Netherlands and TenneT, studies have shown that large-scale storage is not preferable from an economic point of view as long as a well functioning electricity market is in place, interconnection capacity and flexible generation increases.

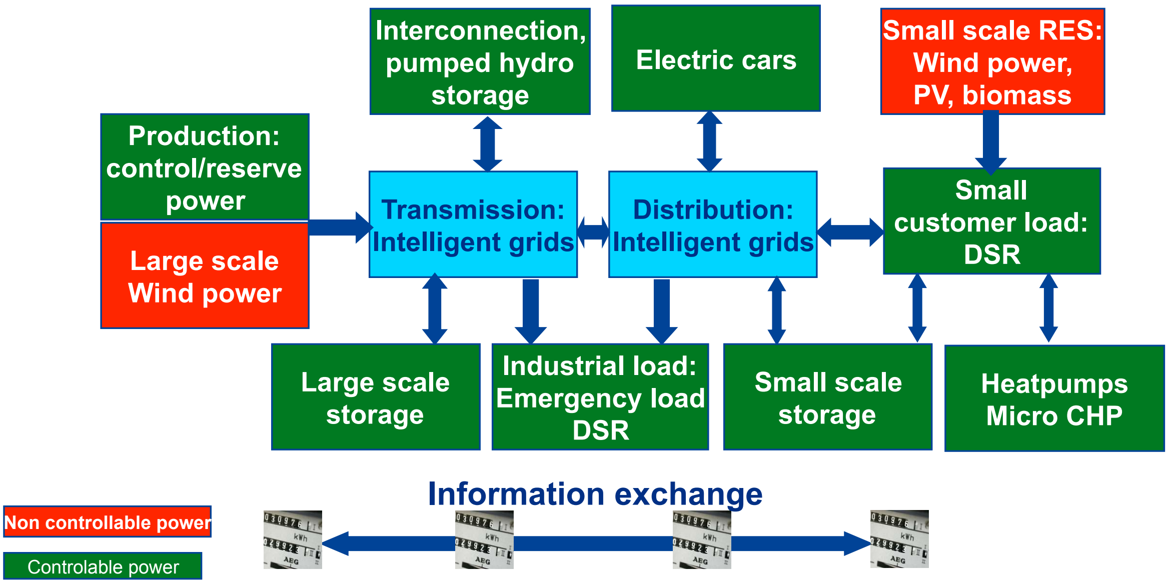


Figure 4: Flexibility measures to integrate growing renewables share[10]

The political perspective can be different according to each country's characteristics. In the case of Switzerland, the goals of the government are focused on efficiency, renewables, nuclear and foreign energy policy. As Switzerland has significant hydro storage potential, it is clear that the balance between transmission and storage needs to be explored so that it accommodates renewables expansion in the most effective manner from an European perspective.
However, from a NGO point of view, there is a lack of a clear strategy on renewables expansion that will pave the way towards both 100% renewables power sector in Switzerland and European integration. The Swiss NGO community is concerned that utilities focus only on pumped hydro storage and that such investments are not realised for the benefit of renewables, but rather for the storage of nuclear electricity during periods of low prices.

## Key Remarks

A number of debatable issues have been discussed between the presentations. Amongst the points raised are:

- Wind and ancillary services: Regulatory trends show that wind could be forced to contribute to the stability of the system through ancillary services and/or smooth predictable generation patterns. Currently, hydro is best placed to provide this in the most efficient manner. However, wind itself has also the potential to contribute to frequency regulation[11]. It is not yet clear which option (or combination of options) is preferable as it is equally a technical and political question.
- Renewables marginal cost: The functionality of current power market rules is questionable when large shares of renewables will be present in the generation mix. Renewables have minimal marginal generation cost and, hence, marginal pricing does not favour them. Prices could become more volatile as they range from negative to peak price levels. For renewables and storage technologies to be succesful in a market environment, it can be beneficial if externalities, such as welfare costs, are internalized. Additionally for storage, the price difference of charging and discharging may not be sufficient, and additional services that pumped hydro offers need to be valued.
- Trading: It is becoming clear that the value of trading balancing services and wholesale electricity between countries needs to be addressed while also taking into account security constraints.

[10] "Electricity storage and system flexibility, a TSO view" presentation, Alan Croes, TenneT, RGI workshop 27/01/2011
[11] Throughout this summary report the terms primary control and frequency regulation have the same meaning.

- DSM: From the TSO's perspective, it is not clear how DSM will be implemented and the TSO's discretionary role. The current market structure is inefficient and, in the UK in particular, trends point to a centralized control market with capacity payments rewarding DSM and storage.
- Renewables variability: A combination of transmission, storage and DSM can to a very large extent compensate for the variability of renewables. However, extreme weather conditions could require several days of compensation. It is not clear whether the aforementioned measures are sufficient. Back-up capacity such as Open Cycle Gas Turbines (OCGT) could be necessary in order to avoid compromising the system's realibility level. The economics and location of such back-up capacity need to be explored in order to establish a business case for them and appropriate market conditions.
- Trade-offs: The business case trade-offs between the different forms of compensating renewables needs to be explored, whether that is centralised or distributed storage technologies, interconnectors or DSM. Complementary to any economic considerations, in any assessment it is imperative to include the impact of any potential institutional framework changes.
- Electric cars: From the TSOs perspective, the potential of millions of cars charging will not have a direct impact on its system. However, the DSOs are the ones that would first need to assess and tackle this issue.

## RGI Upcoming Activities

In May, two RGI members, National Grid and the Royal Society for the Protection of Birds (RSPB), will lead a workshop on environmental impact.

Additionally, two RGI documents will be produced in the coming months. Firstly, RGI has commissioned an external consultant (Roberto Crema) to lead a process in collaboration with RGI members for defining the SuperSmart Grid concept. Secondly, RGI has commissioned Futerra, a sustainability communications agency, to develop a booklet for the general public that clarifies in a plain but meaningful manner the role of electricity grids in a renewables future.

07.03.2011