Environmental assessment of Marine Pumped Hydro technology: a case study for Italian Islands

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SUMMARY

Recent increases in electricity generation from renewable energy sources in response to EU targets have led to renewed interest in energy storage to help integrate renewable energy into the grid. Large scale energy storage can help to increase the penetration of wind and other variable renewable energy sources. Up to now, the most important technology, suitable for a large scale storage, is pumped hydro energy storage (PHES), being more than 300 PHES schemes operating in the world. In Italy PHES capacity is slightly more than 7500 MW, however with a decreasing utilization factor: from 2002 (the start-up of electricity market in Italy) and 2011 the generated energy fell from around 10 down to 3 TWh/year.

“Variable” RES generation, mainly from wind and solar PV, is located in the Centre and South of Italy, where the T&D network often is not able to dispatch the production, with an evident system inefficiency. Moreover, in the Italians Islands (mainly Sicily and Sardinia), besides the “weakness” of Transmission Network (with “zonal” prices that can be quite different from those of Continental Italy), there could be part of the day where RES generation exceeds the local load, again with a loss of system efficiency.

Finally, the Italian Authority for Electricity and Gas (AEEG) recently established that imbalance between the energy offered in the “day ahead” market and the quantity really generated shall be charged to the involved producers themselves, thus stressing the need of accurate generation forecast and/or storage capacity.

Marine Pumped Energy Storage (MPES), where the upper reservoir is located on top of a steep shoreline and the lower reservoir is the sea, is more and more being considered as a viable alternative for energy storage, especially for islands and coastal areas with significant density of non dispatchable RES generation. One MPES scheme (30 MW, 136 m net head) is in operation in Okinawa (Japan), others being foreseen (e.g. the MAREX project, 1200 MW / 6 GWh, in Mayo County, Ireland).

The main MPES environmental challenges are as follows:
- Seawater Leaching from the Upper Reservoir
- Seawater Spray from the Upper Reservoir (Vegetation)
- Adherence of marine organisms (fouling)
- Corrosion of hydro machinery and electro-mechanical components
- Landscape/visual impact
RSE, in the frame of the nationally-funded “Electric Power System R&D” Program, developed the project of a MPES scheme for a site in South-western Sardinia Island. The site has been chosen according to the character of the coastal area (e.g. enough steep cost profile, flat or gently rolling area on the top) and to the presence of wind power parks in the surroundings. In the environmental assessment phase, all the environmental (e.g. protected areas…) and territorial (e.g. landscape issues, historical building presence …) constraints have been examined and evaluated. Particular attention has been devoted to carefully choose the proper location and the size of the reservoir, in order to optimize the balance between material digging and dragging and therefore to minimize both the visual impact and the need of material disposal. Finally, the construction phase impact have been analyzed and the appropriate mitigation measures identified.

KEYWORDS


FOREWORD

Recent increases in electricity generation from renewable energy sources in response to EU targets have led to renewed interest in energy storage to help integrate renewable energy into the grid. Large scale energy storage can help to increase the penetration of wind and other variable renewable energy sources. Up to now, the most important technology, suitable for a large scale storage, is pumped hydro energy storage (PHES), being more than 300 PHES schemes operating in the world.

In Italy PHES capacity is slightly more than 7500 MW, however with a decreasing utilization factor: from 2002 (the start-up of electricity market in Italy) and 2011 the generated energy felt from around 10 down to 3 TWh/year. Recent data suggest, however, that pumped hydro storage plants located in Central and Southern Italy operates on the Balance and Dispatch Services markets, with good economic margins, despite the reduced load factor.

“Variable” RES generation, mainly from wind and solar PV, is located in the Centre and South of Italy, where the T&D network often is not able to dispatch the production, with an evident system inefficiency. Moreover, in the Italians Islands (mainly Sicily and Sardinia), besides the “weakness” of Transmission Network (with “zonal” prices that can be quite different from those of Continental Italy), there could be part of the day where RES generation exceeds the local load, again with a loss of system efficiency.

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MAIN ENVIRONMENTAL ISSUES

The main MPES environmental challenges are as follows:
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- Seawater Spray from the Upper Reservoir (Vegetation)
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- Corrosion of hydro machinery and electro-mechanical components
- Landscape/visual impact
- Soil Erosion
- Biodiversity and Fisheries
- Impact on marine life at sea outlet.

Salted water leaching from the reservoir appears one of the most important potential impacts, because of the high pollution risk of soil and aquifers. Coating of the reservoir with suitable materials, together with drainage system and leaches monitoring and early warning are effective solutions. During the first five years of operation, no leaching has been detected at Okinawa plant.

Seawater spray from the upper reservoir, with a pollution risk for the reservoir surrounding vegetation, has been proven—via simulation models and wind tunnel experiments—negligible.

Fouling issues could be managed, following the 2001 London International Anti-Fouling Convention, using silicon-based varnishes, copper ions releasing systems, electro-chlorination systems. Moreover, the new materials used to prevent seawater induced corrosion, such as the FRP—Fiber Reinforced Polymers or the electrolytic treated stainless steel, are also able to prevent fouling phenomena.

Landscape and visual impact are strictly dependent on the plant site, but could be mitigated with careful planning and construction optimization, as it will be shown for the Foxi-Murdegu plant.

Soil erosion issues could arise from the upper reservoir realization and from the cavern excavation, to accommodate the hydraulic machinery and other power station equipment. Accurate geological investigation and design.

To prevent any significant impact on fauna during construction, the upper reservoir should be surrounded by fence, in order to avoid small land animal to enter into the work area. Moreover slope-type side ditches should be realized, to let small animals and young birds to exit by way of the slope in the direction from which they entered, even when they fall into the side ditches.

To reduce impact on marine life at the sea outlet, suitable barrier e.g. of pre-cast concrete block could be used to limit the discharge velocity.

THE “FOXI MURDEGU” PROJECT

RSE, in the frame of the nationally-funded “Electric Power System R&D” Program, developed the project of a MPES scheme for a site in South-western Sardinia Island.

The site has been chosen according to the character of the coastal area (e.g. enough steep cost profile, flat or gently rolling area on the top) and to the presence of wind power parks in the surroundings.

Project description

The plant is located in the south-western Sardinia Island (see Figure 1) and it will operate according the scheme depicted in Figure 2.
The main plant data can be summarized as follows:

- Reservoir volume: 1,200,000 m³
- Pumping power: 173 MW
- Turbine power: 137 MW
- Penstock: diameter 3 m, length 488 m
- Maximum flow-rate: 44.2 m³/s
- Average Head: 360 m.

Figure 1 – Foxi-Murdegu plant location (left) and view of the upper reservoir (right)

Figure 2 - Simplified hydraulic scheme of the Foxi-Murdegu plant

Variable-speed pump-turbine has been chosen, in order to maximize the plant efficiency, even at partial loads: in the project refinement phase, going on at present, the optimal hydraulic machinery size is being examined.

The plant area has been chosen keeping into account different factors, namely:

- the presence of wind power plants and of high-voltage lines (see Figure 3), with frequent impossibility to dispatch the whole renewable energy generated;
the topography of the site, with a steep cost profile and a flat or gently rolling area on the top (see Figure 4);
- the land use, with prevailing pastures and no significant human settlements (see Figure 5).

Figure 3 – Main wind power plants and 150kV power lines in the plant area

Figure 4 - Digital terrain model of the shoreline and the upper reservoir area

The environmental impact assessment

In the environmental assessment phase, all the environmental (e.g. protected areas…) and territorial (e.g. landscape issues, historical building presence …) constraints have been examined and evaluated.

First of all, any interference with human settlements (more than 10 km far away), viability infrastructures and protected areas has been avoided, by choosing the plant site, as shown in Figure 5. The presence of an area identified as of “botanic interest” in the surrounding of the plant should not constitute a major problem.

Particular attention has then been devoted to carefully choose the proper location and the size of the reservoir, in order to optimize the balance between material digging and dragging and therefore to minimize both the visual impact and the need of material disposal, as can be seen from the following
table. It should also be noted that the dam, realized using the excavation material (instead of concrete), is oriented in a direction perpendicular to the shoreline and inside a natural canyon, whose eastern side reduces the visibility of the structure itself.

<table>
<thead>
<tr>
<th>Re-used Volume [m$^3$]</th>
<th>Digged Volume [m$^3$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dam</td>
<td>85,000</td>
</tr>
<tr>
<td>Reservoir bottom leveling</td>
<td>65,000</td>
</tr>
<tr>
<td>Lateral embankment</td>
<td>30,000</td>
</tr>
</tbody>
</table>

Figure 5 - The land use in the plant area (left) and the plant location in the frame of the Sardinia Regional Landscape Plan (right)

The geological study showed that no underground aquifer is present in the plant area, thus reducing the consequences of any eventual salted water leaching. Moreover, the reservoir will be equipped with a suitable coating, based on already well-established technologies.

Figure 6 – Sardinia Region Hydro-Geological Risk Chart
The Sardinia Region Technical Geological Chart (see Figure 6) doesn’t highlight any area of hydro-geological and/or stability risk in the plant site and for a long distance from this. Therefore, the cavern construction has been deemed without any significant risk; all the machinery could be housed underground, with great advantage for the landscape, helping in avoiding visual issues, together with the already-mentioned optimization of the re-use of the excavated materials.

The impact mitigation measures relevant to terrestrial and marine fauna will be dealt with during the Environmental Impact Assessment Study, being necessary a detailed local survey.

Finally, the construction phase impact have been analyzed and the appropriate mitigation measures identified, being the operations analogous to the realization of civil works, connected e.g. to a road or a bridge.

CONCLUSIONS

The Foxi-Murdegu MPES will contribute to a better integration of RES (especially wind power) into the Sardinia Island Electric Power System, allowing to maximize the energy dispatched, with the relevant self-evident environmental benefits. On the other side, the adoption of a MPES (Marine Pumped-hydro Energy Storage) scheme will avoid any interference with the available (and in Sardinia, scarce) river water resource and will operate with a reduced –or even negligible- environmental impact on the most important components, namely landscape, aquifer, soil stability, flora and fauna.

BIBLIOGRAPHY

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