Energy Storage Solutions and Their Role in Offshore Wind Energy Networks

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Agenda

- ORE Catapult: Overview
  - Network, Facilities

- Grid Forming & Black Start: Requirements for Storage
  - Principal Stages, Current State, The Future of Black Start, Grid Forming

- Energy Storage Integration in Offshore Wind Networks
  - Overview, Technology Integration

- ORE Catapult Activities
The Catapult Network

Innovate UK

• Designed to transform the UK's capability for innovation

• Core grant leveraged with industry and other public funding
Grid Forming & Black Start: Requirements for Storage
Grid forming & Black Start: Overview

- Offshore Wind Farm
- Transmission Network
- Distribution Network

Energise cable sections
- Grid Forming
- Black Start Generators
- Connect Load Blocks

Transmission Network
**Black Start – Principal Stages**

### Partial or Total Shutdown
- **Power Down**
- **Emergency Power**
- **Power Up**

### Black Start
- **Outward Energisation**
- **Control Functionality**

### Restoration
- **Join a Power Island**

### Shutdown/Commissioning Stage
- Site de-energisation
- Emergency Power
- Intervention resources
- Control/communications system
- Auxiliary starting

### Black Starting Stage
- Self Starting
- Grid forming
- Network energisation
- Block loading
- Reactive Power
- Frequency Control
- Availability and Reliability

### Restoration Stage
- Joining a Power Island
- Performance in a Power Island

Source: National Grid ESO
Current State

- The current strategy is largely unchanged and based on a transmission-led approach of starting large synchronous generators, energising the transmission network, and controlling demand.

- Black Start providers must meet certain technical requirements, including the ability to start up without external power supplies.

The Future of Black Start

- National Grid ESO is fully committed to understanding the future of Black Start in GB.

- Non-traditional, renewable and DER technologies are already known to be capable of providing certain services that form part of a Black Start. E.g. frequency control.

- Projects in pipeline to understand the capability of black start with non-traditional technologies:
  - Black Start from Non-Traditional Technologies (NG ESO)
  - Black Start Capability of Offshore Wind Farms (Carbon Trust’s OWA)
  - “Distributed Restart” NIC project (working towards trails)
Grid Forming

Grid-Following
matches AC grid voltage and frequency
provides reactive current equal to the steady state rated current during AC faults

Grid Forming
regulates both instantaneous AC frequency and AC voltage
provides reactive current equal to the steady-state rated current during AC faults

Synchronous Grid-Forming
Grid-Forming converter able to operate in parallel with other AC frequency regulating equipment and converters

Virtual Synchronous Machine
(Synchronous) Grid-Forming converter with energy storage delivers extra energy for short time
provides more than steady-state rated current during a fault

Figure 1: Grid following converter equivalent*
Figure 2: Grid forming converter equivalent*

(1) Source: T&D Europe “Grid Forming Control in HVDC Systems”
Current State

ENTSO-E Technical Group (TG) looking at High Penetration of Power Electronic Interfaces and Grid Forming Capabilities linked to satisfying system needs.

TG focus on seven challenge / characteristics during high penetration:

1. Create system voltage
2. Contribute to fault level / fault current contribution
3. System survival to allow effective operation of LFDD
4. Sink for harmonics
5. Sink for unbalances
6. Prevent adverse control interaction
7. Contribution to inertia

Latest report from workshop available online.

- National Grid work group (GC0137) starting to look at on Minimum Specification Required for Provision of Virtual Synchronous Machine (VSM) Capability
Energy Storage Integration in Offshore Wind Networks
**Energy Storage: Overview**

**SHORT TERM STORAGE**
- High Power Delivery and Low Energy Capacity
- **Pros**: Fast reaction times is good for dynamic loading conditions.
- **Cons**: Last for shorter durations (< 2hrs)
- Examples: Ultra-capacitor, Lithium-ion battery, Lead Acid battery, flywheels

**LONG TERM STORAGE**
- Low Power Delivery and High Energy Capacity
- **Pros**: Last for longer durations (> 2hrs)
- **Cons**: Slower reaction times
- Examples: Redox flow batteries and Hydrogen Fuel Cells

**HYBRID STORAGE**
- Low Power Delivery and High Energy Capacity
- **Pros**: Short term storage allows for dynamic loading conditions
- **Cons**: Life cycle of Long term storage improved
- **Trade off**: More power electronics and energy management controls

Source: Wind Europe (2017) Wind energy and On-site energy storage
Considerations for Selection of Storage

• Cost: The cost of the battery per kilowatt use of energy (£/kWh)

• Energy Density: The energy derived per unit volume of cell (kWh/L)

• Power Density: The power derived per unit weight of cell (W/kg)

• Charge/Discharge Cycle: The response time necessary to charge and discharge and the availability of the battery.

• Efficiency: The ratio of power available to power lost during charging and discharging.

• Cycle Life: The number of charge/discharge cycles it can undergo during its lifetime.

• Degradation: a natural process that permanently reduces the amount of energy a battery can store, or the amount of power it can deliver
Considerations for Selection of Storage (Inverter)

- **Connection Topologies**: Feasibility of different points of connection as shown below (1),(2), (3),(4),(5),(6),(7)

- **DC Voltage rating**: The engineering design of stacking cells and modules in batteries depend DC voltage rating of the inverters.

- **Cost**: The additional cost of an inverter and storage need be justified in deciding the size of the installation making the business.

- **Auxiliary Power Requirements**: The size of the battery required to cover all the wind turbine auxiliaries during operation.

- **Control Coordination**: New control states need be introduced to allow for existing wind turbine and farm controllers with management systems of the batteries.

- **Engineering Design**: Balance of Plant (BOP) modifications with added storage (i.e. power train modifications, storage system modifications)

Energy Storage: Overview

- **Reduced number of power converters but DC voltage depends on both technologies**

- **Higher cost of two converters but independent controls for each energy storage. DC voltage can be controlled effectively.**
Energy Storage: Technology Integration

Power Train Modifications
What modifications need to be made in drive train & their controllers?
What modifications need to be made to converters & their controllers?
• Inclusion of islanding and grid forming operation modes
• Co-ordination of wind turbine controller in wind farms during black starting and grid forming

Embedding Energy Storage
What modifications need to be made to coordinate energy storage with the turbine and/or wind farm?
• How will storage be embedded within the turbine and wind farm.
  • Challenges with weight, operation environment, service maintenance, H&S regulations, recyclability, cost require further analysis;

Black Start Hierarchy Control

Source: Equinor (BatWind–Hywind)
**Energy Storage : Grid Codes**

**Current State (Grid Codes)**

ENTSO-E an three expert group (EG) to consider and clarify the requirements for other forms of storage are applicable under the three network codes (CNCs).

They resulted to clarifying this by classifying storage into two categories namely:

**Synchronous storage technology**
“a storage plant which is connected to the grid directly through a synchronous machine” i.e. covers technologies such as compressed air energy storage (CAES)

**Non-synchronous storage technology**
“a storage plant which is connected partly or in full by power electronics converter or via an asynchronous machine” i.e. covers other technologies such as batteries, supercapacitors and fuel cells etc

<table>
<thead>
<tr>
<th>Task Group Recommendations</th>
<th>Synchronous Storage</th>
<th>Non-Synchronous Storage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Clarification of the definition of storage</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Electricity storage defined as “the conversion of electrical energy which can be stored, the storing of that energy and the subsequent reconversion of that energy back into the grid”</td>
<td></td>
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</tr>
<tr>
<td>2. Clarification of the definition of storage in demand scenarios</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>An energy storage plant would be classified as demand or demand response service if they convert electricity into another energy medium for onward conversion without re-converting that energy back into electrical energy at the grid connection point.</td>
<td></td>
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</tr>
<tr>
<td>3. When in discharging mode, an synchronous storage device would be treated in the same way as synchronous PGM</td>
<td>✓</td>
<td>✗</td>
</tr>
<tr>
<td>4. When in discharging mode, an non-synchronous storage device would be treated in the same way as PPM</td>
<td>✗</td>
<td>✓</td>
</tr>
<tr>
<td>5. Synchronous flywheels, synchronous compensators and regenerative braking systems should be excluded from the requirements since there is less availability and controllability of these devices</td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td>6. The current scope of the RfG technical requirements is believed to be applicable appropriately to all storage technologies. (i.e. including voltage and frequency support requirements)</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

Source: Connection Network Codes assessment: The outcomes of the first three Expert Groups established under Grid Connection European Stakeholder Committee * in 18th Int’l Wind Integration Workshop, October 2019.
ORE Catapult’s Activities
Our facilities – Power Train Testing & Validation

We have a range of advanced testing and validation facilities, and we operate the largest turbine test rig and electric grid emulator in the world.
Levenmouth Demonstration Turbine
ORE Catapult Activities

Levenmouth Demonstration Turbine
- Levenmouth Storage of Networks Development Programme
  - Black Start Feasibility Studies (11kV Network)
  - Techno economics for Storage Options
  - Full poverty around Levenmouth Fife,
  - Levenmouth Power-to-Gas-to-Power Feasibility Study

Others
- Power Networks & Offshore Renewables (PNOR) Joint Research Program Development (Collaboration with PNDC & University of Strathclyde)
  - Battery Storage for Offshore Renewable Optimisation
  - Electricity Storage acceptance Test protocol development
  - Multi-site hardware-in-the-loop platform development
- ORE Catapult Academic Research Hubs
  - PDRA & PhD Projects
- Future projects on System Planning for Energy Storage in Offshore Networks (Ancillary Services)
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