Flywheel- Battery Hybrid for Grid Stability

Presentation to EERA Workshop, San Sebastian
22nd March 2017
Overview

• Use of Energy Storage in Smart Grids
• Introduction to Schwungrad Energie
• Demonstration Project
• Interaction with Grid and Market for System Services
• Benefits of dynamic energy storage – results of modelling
• Applications for the Hybrid flywheel-battery
Ireland’s electricity generation mix

• Renewable generation, mainly wind, has experienced significant growth
  • Gas remains dominant in the fuel mix
  • Low price of coal keeps plants in merit despite high emissions

• Paradigm Shift
  • Centralised to distributed generation
  • Synchronous to non-synchronous

Source: Adapted, Commission for Energy Regulation: Fuel Mix Disclosure
System Operation Issues

• Ireland is island with limited interconnection + high renewable generation targets => Grid experiencing issues now

• Renewable generation gives rise to two issues
  1. Intermittent and/or unpredictable output
  2. Lack of inertia/grid stability

• These require storage in different timeframes
  1. Storage over many hours
  2. Dynamic storage over, say, 20 minutes with a fast response time of a fraction of a second
Grid Stability

- Conventional plant with heavy generators and steam turbines had sufficient momentum to stabilise the grid – to ride through the bumps
- The more wind and PV running, the less heavy conventional plant there is to provide stability
- Need plant to provide system services to stabilise the grid without having to also provide energy
- Flywheels and batteries will do this, providing synthetic inertia and other system services
Schwungrad Energie

• Founded 2010 and formally established in 2013
• Team of industry experts
  • Generation, Maintenance, Markets, Project Management, Planning and Environment
• Identified growing demand for energy-less stabilising inertia
  • Variable renewable plant substituting conventional plant
• Targeting the Irish market initially and expanding to UK and Mainland Europe
  • Grids with high variable renewable (wind and solar) penetration
Hybrid flywheel-battery pilot

- 400kW Hybrid flywheel-battery pilot
  - Rhode, Co. Offaly, Ireland
- The site is equipped with the following:
  - 2 by Beacon Power Gen. 400 FESM flywheels
    - 160 kW and 30 kWh
    - 160 kW for 5 min and remainder for 10 min
  - 192 by Hitachi Chemical LL-1500-WS Valve Regulated Lead Acid batteries
    - LL 1500-WS = 160 kW and 576 kWh
    - 160 kW for 3.5 hours
  - 400kW connection to the 20kV distribution network

Source: EirGrid
Hybrid flywheel-battery pilot
How Flywheel Energy Storage Works

- Motor/generator spins a heavy flywheel which stores kinetic energy
- Energy taken from grid to speed up the flywheel
  - The flywheel is connected to the grid via a Power Control Module AC-DC-AC
- If grid suddenly needs more generation the flywheel control system will respond immediately and draw energy from the flywheel
- Flywheel slows down converting its kinetic energy into electrical energy
- Flywheel operates in a vacuum on magnetic bearings
  - Noise and vibration are negligible
- Flywheel isolates battery from excessive cycling, extending its lifespan
Flywheel/Battery Hybrid
(System Services Application)

**Flywheel**
- Kinetic Energy Storage
  - Capabilities:
    - High Power
    - Restricted energy storage
    - Fast response
    - Millions of charge/discharge cycles
  - System Services:
    - Frequency Regulation
    - Response << 1 sec
    - Fast Freq Response
    - POR
    - SOR
    - TOR₁

**Battery**
- Chemical Energy Storage
  - Capabilities:
    - High energy storage
    - Fast response
    - Thousands of charge/discharge cycles
  - System Services:
    - Response << 1 sec
    - Fast Freq Response
    - POR
    - SOR
    - TOR₁
    - TOR₂
System (Ancillary) Services

- **Ancillary Services**
  - Stabilise the grid frequency
  - Maintain 50Hz (±0.1Hz)
  - Manage Rate of Change of Frequency (RoCoF)

- **New services designed to maintain stability with increased penetration of variable renewables**
  - Fast response – additional power injection (500ms)
  - Hybrid flywheel-battery capable of providing power without energy
    - Avoids curtailment of renewables
    - Effective and efficient source

### New Services

<table>
<thead>
<tr>
<th>Service</th>
<th>Type</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIR</td>
<td>Synchronous Inertial Response</td>
<td>2s – 10s</td>
</tr>
<tr>
<td>FFR</td>
<td>Fast Frequency Response</td>
<td>25 – 105</td>
</tr>
<tr>
<td>DRR</td>
<td>Dynamic Reactive Response</td>
<td></td>
</tr>
<tr>
<td>RM1</td>
<td>Ramping Margin 1 Hour</td>
<td>1h – 3h</td>
</tr>
<tr>
<td>RM3</td>
<td>Ramping Margin 3 Hour</td>
<td>3h – 9h</td>
</tr>
<tr>
<td>RM8</td>
<td>Ramping Margin 8 Hour</td>
<td>8h – 16h</td>
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<tr>
<td>FPFAPR</td>
<td>Fast Post-Fault Active Power Recovery</td>
<td>250ms – 15min</td>
</tr>
</tbody>
</table>

### Existing Services

<table>
<thead>
<tr>
<th>Service</th>
<th>Type</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>SRP</td>
<td>Steady-state reactive power</td>
<td>5s – 15s</td>
</tr>
<tr>
<td>POR</td>
<td>Primary Operating Reserve</td>
<td>5s – 15s</td>
</tr>
<tr>
<td>SOR</td>
<td>Secondary Operating Reserve</td>
<td>15s – 90s</td>
</tr>
<tr>
<td>TOR1</td>
<td>Tertiary Operating Reserve 1</td>
<td>90s – 5min</td>
</tr>
<tr>
<td>TOR2</td>
<td>Tertiary Operating Reserve 2</td>
<td>5min – 20min</td>
</tr>
<tr>
<td>RRD</td>
<td>Replacement Reserve (De-Synchronised)</td>
<td>20min – 1h</td>
</tr>
<tr>
<td>RRS</td>
<td>Replacement Reserve (Synchronised)</td>
<td>20min – 1h</td>
</tr>
</tbody>
</table>
Example of real system frequency event

Grid Frequency (Hz)

± 0.10 Hz – Acceptable deviation

Problem

20/02/2014 22:38:49
49.345 Hz
Sample of frequency events - RoCoF

Sample High Frequency RoCoF

Sample High Frequency RoCoF (with quick Frequency Drop)

Sample Low Frequency RoCoF (with quick Frequency Rise)

Sample Low Frequency RoCoF
Response of Hybrid flywheel-battery

Simulated response of Hybrid flywheel-battery (160kW) to real grid event

Event – rapid drop in frequency

Nominal frequency

Frequency threshold for full power output

Frequency drop

Frequency recovery

11/03/2014 10:12:44 – 10:16:43
Full power for 4 minutes

On/OFF Load Changes

Power (kW) — Frequency (Hz)

Power (kW)

Frequency (Hz)
Benefits of Dynamic Energy Storage - Modelled

• Model of Irish Grid developed by University of Limerick (Robert Lynch, Nathan Quill, Catherine Leninhan)
• Effect of battery energy storage under different scenarios
• Some examples of results under a scenario of insufficient Primary Operating Reserve from conventional synchronous generators
Frequency Plot with Insufficient POR

Frequency Plot for 0 MW Battery

- SNSP = 50%
- SNSP = 40%
- SNSP = 30%
- SNSP = 20%
- SNSP = 10%
- SNSP = 0%

Frequency (Hz) vs. time (s)
Frequency Plot with Insufficient POR
Minimum Frequency with Insufficient POR

![Graph showing minimum frequency with different POR levels and battery capacities.](image-url)
Maximum RoCoF with Insufficient POR
Effect of Battery Response Time

![Graph showing the effect of battery response time on RoCoF (Hz/s over 500 ms) as a function of battery response delay (s).]
Applications for Hybrid Energy Storage

- Dedicated System Service Facility
  - DS3 Market in Ireland
  - EFR market in Great Britain
  - Similar markets in other European countries and worldwide (JV in China, visit to Vietnam in April)

- Co-Location with existing/new build Conventional or Renewable Generator
  - Enhance performance of conventional plant
  - Improve “firmness” of renewable plant

- Co-location with renewable generation and demand (large industrial customers or microgrids)
Conclusions

- Integration of high levels of non-synchronous intermittent and unpredictable renewable generation onto the grid will require hybrid energy storage for
  - Load shifting, load balancing
  - Grid stability
- Grid stability an issue already in Ireland and will become an issue across Europe as all countries reach high levels of non-synchronous plant
- A hybrid of flywheels and batteries has been demonstrated by Schwungrad to provide reliable rapid response to changes in system frequency
- EU policies on electricity markets, grid codes etc. must support and not hinder the roll-out of dynamic energy storage to stabilise the grids with increasing levels of renewable generation to allow the decarbonising of electricity
Thank You