Stabilizing and maximizing renewables using a flywheel-inverter system.
Renewable Energy Integration
Microgrid solutions – Maximize and Stabilize

Types of microgrids:
- Islanded
- Embedded

Integration technologies
- PowerStore (flywheel and inverter system) for stabilizing the microgrid
- MGC600 control platform

Applications - Project references
- Hybrid islanded systems
- Grid connected microgrids
Islanded Microgrids – Where ABB has come from

- Island communities (Caribbean, Hawaii)
- Off-grid communities (Alaska, Northern Canada)
- Mine sites not connected to main grid
- Generation source is typically diesel/HFO
- High generation costs – upwards of 30c/kWh

Renewable Energy Integration
Islanded Microgrids
Solution to high generation costs - Renewables

Renewable Energy Integration

Solarfarm
Windfarm

Diesel Power Station
Load
Renewable Energy Integration Challenges

Tasks fulfilled by a conventional power station

- Frequency & Voltage Control
- Fault Current
- System Inertia
- Spinning Reserve
- Step Load (load increase & reject)
- Unbalanced load supply
- Firm Capacity
- Active & Reactive Power Supply
- Load-sharing between generators
Renewable Energy Integration Challenges
Low Penetration System – 10-20%
Renewable Energy Integration Challenges
High Penetration System – 100% = Maximising renewables

Solarfarm

Windfarm

Renewable Energy Integration

Diesel Power Station

Load
Cloudcover causes large output changes in SolarPV generator.
Renewable Energy Integration Challenges
Managing Power Output Fluctuations – Wind Instability

Windfarm Output

kW

Windfarm Output

Hours December 6th [hours]

10hrs
Renewable Energy Integration Challenges
.....keeping the system together

Wind/SolarPV/Diesel System

- Spinning Reserve
- Unbalanced load supply
- Active & Reactive Power Supply
- Loadsharing between generators
- Automatic dispatch control
- Diesel gensets hunting load become very inefficient
## Solutions to Integration
### Microgrid Technology Solutions

<table>
<thead>
<tr>
<th>Wind/Solar/Diesel Systems</th>
<th>Annual Average Penetration</th>
<th>Peak Penetration</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Integration</td>
<td>7%</td>
<td>20%</td>
</tr>
<tr>
<td>Automated Dispatch (MGC600)</td>
<td>10%</td>
<td>22%</td>
</tr>
<tr>
<td>Grid Stabilizing (PowerStore)</td>
<td>50%</td>
<td>100%</td>
</tr>
<tr>
<td>Automated Demand Response</td>
<td>60%</td>
<td>100%</td>
</tr>
<tr>
<td>Energy Storage</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>
Renewable Energy Integration Challenges
Managing Power Output Fluctuations – Wind Instability

Windfarm Output (kW)

Hours December 6th [hours]
How do you design the correct solution
Dynamic Stability & Control Modelling

Input
- e.g. $V_{\text{WIND}}(t)$, ...

Power System Dynamic Model

Output:
- $U(t)$, $f(t)$, ...

Power System Dynamic Stability Modelling
(transients, disturbances ...)

Recorded data from real system:

Simulation tool

Output of Simulation
(Voltage, Frequency, etc)
System Offering
Distributed Power Control & Dispatch System

PV/CPV Generation
MGC600 P *

Wind Turbine Generator
MGC600 W *

Control Centre

Pumping Load
MGC600 L *

Cooling/Heating Loads
MGC600 L *

MGC600 N *

Other Consumers/
Micro-Grid

Smart Consumers
MGC600 L *

Power Micro-Grid

Diesel Generator
MGC600 G *

Energy Storage
Grid Stabilising System
MGC600 E *

*MGC600: Microgrid control systems with generator-type/load-type specific control and monitoring application software that react and, if connected, interact according to a chosen grid operation philosophy
How do you design the correct solution
Contribution of the different players

<table>
<thead>
<tr>
<th></th>
<th>Solar Inverter</th>
<th>Wind Turbine</th>
<th>Diesel Generator</th>
<th>ESS CSI</th>
<th>ESS VSI</th>
<th>Grid Stabilization e.g. flywheel</th>
<th>PS Control Software</th>
</tr>
</thead>
<tbody>
<tr>
<td>V/f control</td>
<td>X</td>
<td>X</td>
<td>Y</td>
<td>X</td>
<td>Y</td>
<td>Y</td>
<td>X</td>
</tr>
<tr>
<td>Fault current</td>
<td>X / Y</td>
<td>X / Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>X</td>
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<tr>
<td>System inertia</td>
<td>X</td>
<td>X</td>
<td>Y</td>
<td>X</td>
<td>Y</td>
<td>Y</td>
<td>X</td>
</tr>
<tr>
<td>Spinning reserve</td>
<td>X</td>
<td>X</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>X</td>
</tr>
<tr>
<td>Step load support</td>
<td>X</td>
<td>X</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
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<td>X</td>
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<tr>
<td>Imbalance correction</td>
<td>X</td>
<td>Y</td>
<td>Y</td>
<td>X</td>
<td>Y</td>
<td>Y</td>
<td>X</td>
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<tr>
<td>Firm capacity</td>
<td>X</td>
<td>X</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>X</td>
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<tr>
<td>Reactive power support</td>
<td>X</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>X</td>
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<tr>
<td>Load sharing with other generations</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>X</td>
</tr>
<tr>
<td>Automatic dispatch control</td>
<td>X</td>
<td>X</td>
<td>Y</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Y</td>
</tr>
</tbody>
</table>
Microgrids, components or system
Keeping the system together

- Solar farm power output fluctuations
- Wind farm power output fluctuations
- Negative unknown load “out there” e.g. distributed SolarPV
- Minimum loading of diesel generators
- Reverse power of diesel generators
- Lower fuel efficiency
- Frequency and voltage control setup for slow load changes
- Power system setup for one way loadflow (protection, breakers etc.)
- Diesel generator low power factor operation
Grid stabilizing: PowerStore-Flywheel System Microgrid technology solutions

Features:
- High power; low energy
- High Duty Cycle
- Grid Stabilizing
- Grid Forming
- Scalable & Modular
- Frequency Control
- Voltage Control
- Fault Ride Through
- Spinning Reserve
- Step Load Capabilities

SCADA, System Control

Grid Converter

Flywheel Converter

ECMS

440Vac 50/60Hz
Fixed Frequency

440Vac 60-120Hz
Variable Frequency

2.9T

1,800 - 3,600 RPM

Inverters 500– 1,500 kVA

18 MWs Flywheel

18 October 2013 | Slide 17
Power Store Grid Stabilising Generator

Power Converters

- Power Converters are based on ABB PCS100
- Converter pairs (flywheel and grid) are housed in racks
- Depending on size of PowerStore different size racks are used
- Racks are suitable for indoor installation only
Performance Data:
Net. energy content 18 MWs
Max Input/output power 1650 kW
Speed range 1800 to 3600 rpm
Total weight 6000 kg
Rotor weight 2900 kg
Idling losses 12 kW
Greasing frequency 5 years
Bearing service life 8 years

Features:
• Helium filled
• Magnetic support
• Redundant bearings
PowerStore Grid Stabilizing Generator
Option of two control modes

Virtual Generator Mode
- Parallel with conventional generators
- Frequency control, like a generator
- Voltage control, like a generator
- Provide fault current
- Operates stand alone

(Grid Support Mode
- Parallels with conventional grid
- Frequency support
- Voltage support (like a STATCOM)
- Renewable energy smoothing
- Peak lopping

(renewable energy only)
PowerStore Grid Stabilizing Generator Capabilities

- Able to sink and source up to its maximum power rating (based on inverter sizing)
- Capable of responding sub-cyclically to power system changes with a ramp-up time of approximately 4ms to change from 100% sinking to 100% sourcing of the peak power.
- No capacity degradation and the lifetime of the flywheel is almost independent of the depth of charge and discharge cycle.
- It can operate equally well on shallow and on deep discharges.
Voltage Source Mode (VSI) Only a few ESS inverter offer this mode. It is different in its ability to provide power to the grid in the same manner as a regulator generator. This has many benefits for the grid;

- A grid can be established by the ESS inverter
- Ability to source negative sequence current to correct grid unbalance
- Stabilization of small grids through ‘synthetic’ inertia
PowerStore Grid Stabilizing Generator Capabilities – embedded grids

PowerStore has the capability to transition from current source mode (Utility Grid connected) to voltage source mode.

Provide voltage reference to other inverter based generation / renewables

Currently doing a proof of concept project with Duke Energy:

Key regulatory issues that need to be addressed – primarily safety
PowerStore Grid Stabilising Generator
Smothes PV output variations
PowerStore Grid Stabilising Generator
Mitigates variable wind power output

Wind speed 6.4 to 7 m/s

PowerStore kW

+ = discharge

- = charge

Flywheel -150 kW to +130 kW

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October 18, 2013  |  Slide 26
PowerStore Grid Stabilising Generator
Loss of diesel genset – Spinning Reserve / Step Load
# Project References

## Project History

<table>
<thead>
<tr>
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<tbody>
<tr>
<td></td>
<td>Napperby</td>
<td>Denham</td>
<td>Mawson</td>
<td>Coral Bay</td>
<td>Marble Bar &amp; Nullagine</td>
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<tr>
<td></td>
<td>Northern Territory</td>
<td>Western Australia</td>
<td>Antarctica</td>
<td>Western Australia</td>
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<td></td>
<td>Automation of</td>
<td>Wind/Diesel</td>
<td>Wind/Grid Stabilising</td>
<td>Wind/Diesel/Flywheel</td>
<td>Solar/Diesel/Flywheel</td>
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<td></td>
<td>Diesel Power Station</td>
<td>(Battery System)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>0% Penetration</td>
<td>15% Penetration</td>
<td>85% Penetration</td>
<td>95% Penetration</td>
<td>100% Penetration</td>
</tr>
</tbody>
</table>

Penetration means peak penetration, i.e. peak renewable energy as percentage of total energy generated.
Project References
Australia
## Project References

### Projects and Renewable / Fossil fuel installed power

<table>
<thead>
<tr>
<th>Station</th>
<th>Wind (or Solar)</th>
<th>Diesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Denham</td>
<td>990kW</td>
<td>1,600kW</td>
</tr>
<tr>
<td>Mawson/Antarctica</td>
<td>600kW</td>
<td>550kW</td>
</tr>
<tr>
<td>Esperance</td>
<td>5,600kW</td>
<td>14,500kW</td>
</tr>
<tr>
<td>Hopetoun</td>
<td>1,200kW</td>
<td>2,560kW</td>
</tr>
<tr>
<td>Cocos Island</td>
<td>100kW</td>
<td>950kW</td>
</tr>
<tr>
<td>Bremer Bay</td>
<td>600kW</td>
<td>1,250kW</td>
</tr>
<tr>
<td>Rottnest Island</td>
<td>600kW</td>
<td>1,300kW</td>
</tr>
<tr>
<td>Coral Bay</td>
<td>825kW</td>
<td>2,560kW</td>
</tr>
<tr>
<td>Graciosa/Azores</td>
<td>900kW</td>
<td>3,200kW</td>
</tr>
<tr>
<td>Flores/Azores</td>
<td>600kW (Hydro 1100kW)</td>
<td>4,000kW</td>
</tr>
<tr>
<td>Ross Island/Antarctica</td>
<td>900kW</td>
<td>9,360kW</td>
</tr>
<tr>
<td>Marble Bar</td>
<td>300kW SolarPV</td>
<td>1,280kW</td>
</tr>
<tr>
<td>Nullangine</td>
<td>270kW SolarPV</td>
<td>960kW</td>
</tr>
</tbody>
</table>
Stage 2 plans are to increase the number of wind turbines, creating a high penetration system.

**RIWE Stage 1 – Crater Hill Wind Farm**

- Low penetration Wind-Diesel System (22% average, 61% max).
- 3000kg Flywheel (1800 - 3600rpm) that can sink or source 500kW for 30secs
Project References
Ross Island, Wind/Diesel System Antarctica

1. Two power systems coupled by frequency converter:
   - 6 x 1500kW/60Hz diesel
   - 3 x 225kW/50Hz diesel
   - 3 x 330kW wind turbines (60Hz side)
   - 1 x 500kW flywheel

2. Option to include electric heating load

3. Integration of US/NZ power system network
### Project References

**Marble Bar, Solar/Diesel System Australia**

1. Power system consisting of:
   - 4 x 320kW Diesel
   - 1 x 300kW PV
   - 1 x 500kW Flywheel

2. PV/Diesel system without battery storage

3. Opportunity to deploy load control to maximise PV penetration

4. 100% Penetration
"The Project is supported by the Australian Government through the Renewable Remote Power Generation Program. The Program is implemented by the State’s Office of Energy in Western Australia".
1. Power system consisting of:
   - 7 x 320kW/50Hz diesel
   - 3 x 200kW wind turbines
   - 1 x 500kW flywheel

2. Demonstration of utility Power Quality despite large wind disturbances

3. Opportunity to deploy load control with desalination plant next door
Project References
Coral Bay, Wind/Diesel System Australia
High penetration Wind/Hydro/Diesel power station

PowerStore enables to operate Flores on Hydro and Wind alone.
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