Experiences with large grid-forming inverters on various island and Microgrid projects

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Experiences
grid-forming
Inverters

1. **Background, technical basics**
   Integration of VRE and grid-forming inverters

2. **Functionalities**
   Basic grid-forming functionality and added features

3. **Project references**
   St. Eustatius and other realized projects

4. **Learning and experiences**
   Topics, challenges and measurement details

5. **Outlook**
   Application and transfer to public grids
Integration of VRE in a Microgrid

Phases of VRE Integration
- Higher shares requires more efforts for integration
- Possible measures to achieve the according share of solar integration in an isolated Microgrid

<table>
<thead>
<tr>
<th>Phase</th>
<th>Measures to achieve stable operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Limit installations</td>
</tr>
<tr>
<td></td>
<td>Using existing flexibility</td>
</tr>
<tr>
<td></td>
<td>No measures for operation</td>
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<tr>
<td>3</td>
<td>Curtailment</td>
</tr>
<tr>
<td></td>
<td>Limits the injection to an allowable share by curtailment</td>
</tr>
<tr>
<td>4</td>
<td>Storage</td>
</tr>
<tr>
<td></td>
<td>Reserve-power</td>
</tr>
<tr>
<td></td>
<td>Must-Run units</td>
</tr>
<tr>
<td>5</td>
<td>Grid-forming</td>
</tr>
<tr>
<td></td>
<td>Allows switching off all conventional Voltage-Sources</td>
</tr>
<tr>
<td></td>
<td>100% penetration allowed</td>
</tr>
</tbody>
</table>
Integration of grid-forming inverters

Required measures on Microgrid-level allowing 100% inverter-based operation

Design considerations

Protection and energization

Interface with existing generation (e.g. Genset-Controllers)

monitoring and control

Energy Management

Deciding upon different operation modes

Managing and executing transfer of system states

Frequency and Voltage Control

Power dispatching

Secondary frequency and voltage Control
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Control Schematic
Grid-forming in SMA large scale storage inverters

P Reference:
(Active power at nominal frequency)

Q Reference:
(Reactive Power at nominal voltage)

Active power/ frequency -droop

Reactive power/ voltage- droop
Blackstart
- Topics of realization

Benefits and motivation
- Self-energization allows easier design
- Additional service for grid-tied battery-plants
- Resiliency for Back-Up-operation

On inverter-level
- Internal precharge from DC-side
- External Aux supply

On plant-level
- Synching the start of several devices
- Start-up of large transformer fleets
- Integration into grid-infrastructure
Synchronization
- Topics of realization

1. **Benefits and Motivation**
   - Flexibility for Microgrid operation
   - Back-Up operation and seamless Re-Sync
   - Stacking of application and services

2. **Measurements**
   - Frequency, amplitude and phaseshift
   - Often remote-location of POI

3. **Control and operation**
   - Conditions for De-Sync and Re-Sync
   - Speed, precision and timing of synchronization
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Project St. Eustatius II, Caribbean Island
— operational since 11/2017, refer to SIW18_252

Intensive SAT

Fault-clearing
Online-UPS
Resiliency

Fed-In Energy

Total injected energy 6.49 GWh in the first year met design target of 6.4 GWh very well

Frequency and Voltage Control

An already installed synchronous condenser was decommissioned again because of high losses and no noticeable advantage

Immediate Backup

Within the first 6 months, in 7 events genset failures during night were compensated by the battery plant

Efficiency

Difference between power and energy application

Customer’s Feedback

more reliable than the well-established diesel genset fleet

Project Integration done by SMA Sunbelt Energy GmbH
Project basics Saba, Caribbean Island
– operational since 02/2019

- Installation in two phases
- ~1 Mio l Fuel saving per year
- Up to 10 h per day no genset running

Project Integration done by SMA Sunbelt Energy GmbH

- 2.0 MWp Solar
- 2.3 MWh Battery capacity
- Hybrid Controller
- 4 MVA genset capacity
- ComApp genset-controller
- Load of ~1.2 MW
Project basics Graciosa, Azores, Portugal
– operational since end of 2018

• 3 Sunny Central Storage 2475
  • Blackstart included
  • 6 MW Leclanché Li-Ion Battery

• Wind-farm 4,5 MWp
  • 5*900kW Enercon

• 1MWp Solar-plant
  • Existing genset-fleet

Project Integration done by Greensmith, a Wärtsilä Company
Project basics “The Brando”, Tetiaroa, French Polynesia
– operational since 12/2018

• Luxury Eco-Resort
• ~ 500,000l Fuel saving per year
• Up to 13h per day no genset running

• SCS 2200 Grid Forming
• Hybrid Controller
• Blackstart on plant-level included

• 1.4 MWp Solar, 32 STP Inverters
• CRE genset-controller
• Solar fraction of ~60%

Project Integration done by SMA Sunbelt Energy GmbH
Project basics Bordesholm, Germany
- operational since 04/2019

- Plant is mainly operating for Frequency Control Application (PRL)
- Can act as backbone for isolated grid operation of the local utility
- 7 Sunny Central Storage 2500-EV
- Hybrid Controller
- Island Operation, Blackstart and plant-resynchronization included
- Extended Site Acceptance Tests with TH Köln

Project Integration done by RES Germany GmbH for the local utility company Versorgungsbetriebe Bordesholm GmbH
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Blackstart of a small Microgrid
- Start with one Inverter

**Softstart of the whole grid**
- Ramp-Up of Voltage
- Transformers are connected
- Obviously some loads are also connected

Logdata: Meas_302
Blackstart of a large Power Plant
- Start with several Inverters

**Blackstart**

- 20% Sync-voltage
- 2 devices used as Black-Start-Devices
- Simultaneously Ramp the Voltage up for 7 transformers

![Diagram of Blackstart system](image)

*Low current required*
Voltage Harmonics

Substantial Improvement

- Very high Harmonics in customer current consumption, especially 5th and 7th
- Typically 4-6% Uthd in Genset-based operation
- Measurement on the MV-Bus
- Improvement by about 2% as soon as the SCS2200 is connected in Grid-Forming-Mode

Logdata: Meas_297
Re- and Desynchronization
- Transfer Grid-tied ↔ Island, Plant of Bordesholm

> Resyncing to the Grid, Desync, stop and Blackstart of the battery plant

Re-Sync caused max exchange power of 250kVA, ~1.4% of the plant nominal power
Side effects
- Switching the gensets off

**Noise and exhaust fumes**
Obvious and noticeable effect for all people next to the power plant

**Consumption**
Aux. Loads of Generator
- Fuel conditioning
- Pumps and fans
e.g. ~10% of total load

**Maintenance**
Less and more convenient maintenance w/o heat and noise of running engines

**Changing a lot**
Tasks of operators change a lot
Fully automated operation
New interfaces to deal with
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Outlook
- Application in public grids

Control stability and reserve power
Paving the way to higher VRE penetrations
Automatic frequency stabilization

Resiliency
Battery plant can act as a backbone for a local Microgrid
Blackstart allow operation according to a cellular approach

Fault-Ride-Through
Robust ride-through
Fast and suitable current limitation
Requirement specification to be done

Grid Codes
Grid-Codes are usually designed for current-controlled inverters
Review of requirements regarding the inherent behaviour and favorable application of grid-forming control
Summary
- Grid-forming experiences in Hybrid Power Systems

Still new but proven
field experience and intensive testing in a lot of different projects realized and successfully operating
Parallel operation with units reaching from 125kVA gensets to public grid

100% VRE are possible
No „must-run” conventional power plants required

Design and integration are crucial
Project engineering is a huge topic for 100% Inverter-based operation

Topics for Grid-tied use
Grid-Codes are usually designed for current-controlled inverters

SMA Solar Technology
Thank you very much for your attention!

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