Hardware-in-the-loop (HIL) Test of Demand as Frequency controlled Reserve (DFR)

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15th September 2016
Outline

• PowerLabDK
• Wind power in Denmark
• DFR control logics
• Heat pump model
• HIL test
• Conclusions
PowerLab Combines Experimental Facilities in a Unique Platform

Flexible multi-purpose laboratories
Lyngby & Ballerup Campus

Large-scale test system
Risø Campus

Full-scale real-life energy system

Stakeholders:
ABB
DONG energy
SIEMENS
ENERGINET/DK
VATTENFALL
IBM

Supported by:
GREEN LABS DK

Investment:
18 million Euro

40,000 people
33% wind power
50% renewable energy
Islanding capability
Bornholm - Full-scale Living Laboratory with 40,000 Inhabitants and 50% Renewable Energy Penetration

Resources:
- Wind power
- Biomass
- Biogas
- District heating
- Combined heat and power
- Solar power
- eMobility
- Active demand

Features:
- Nord Pool market
- Islanding capability
Intelligent Control Lab - Test-bed for Integrated Experiments

- Full-scale control room
- Real-time digital simulator
- Power amplifier 150 kW (1.2 MW)
- LabGrid with 21 LabCells

- SCADA system
- Online control/data
- Models
- Real world
- Control hardware test in lab
- Online control/data

- Blade Center (power market/controllers)
- Online data
- Power hardware test in lab

- Online control/data
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Wind Power in Denmark

Year 2014
Danish wind power generation: 39.1% of the electricity consumption

January 2014
Danish wind power generation: 63.3% of the electricity consumption

December 21st 2013
Danish wind power generation: 102% of the electricity consumption

Single hour July 9th 2015
Danish wind power generation: 140% of the electricity consumption

March 11th 2014
only 9 MW wind power generated out of installed 4,900 MW
but 480 MW out of 580 MW solar units supplied the grid
Wind Power in Denmark

2012
25% wind power

2020
50% wind power

[Graphs showing wind power and demand for 2012 and 2020]
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DFR Control Logic

The DFR control logic type I disconnects and reconnects electric appliances to the grid when the system frequency falls below $f_{off}$ and recovers above $f_{on}$, respectively.
DFR Control Logic

The DFR control logic type II is customized for switching the thermostatically controlled loads by adjusting the nominal temperature set points $T^\text{normal}_{\text{high}}$ and $T^\text{normal}_{\text{low}}$.

$$T_{\text{high}} = T^\text{normal}_{\text{high}} + kf(f - f_0)$$

$$T_{\text{low}} = T^\text{normal}_{\text{low}} + kf(f - f_0)$$
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Heat Pump Model

- The dynamics of a direct air heating system can be sufficiently described by three thermal masses.
- The ambient air of the building interior has smaller storage volume, and defines a faster dynamics of the system.
- The larger storage volume of the building envelope, or structure, describes a slower dynamics of the system.

\[
\dot{T}_i = \frac{I}{C_i} \left( \frac{1}{R_{ie}} (T_e - T_i) + \frac{1}{R_{ia}} (T_a - T_i) + Q_H + A_w \Phi_s \right)
\]

\[
\dot{T}_e = \frac{I}{C_e} \left( \frac{1}{R_{ea}} (T_a - T_e) + \frac{1}{R_{ie}} (T_i - T_e) + A_e \Phi_s \right)
\]
HIL Test

RTDS

GTAO

Freq, current and voltage (analog)

GTDI

Relay (digital)

Smartbox
### Table 1: Test Scenarios

<table>
<thead>
<tr>
<th>Contingency Type</th>
<th>Ratio of Demand Change</th>
<th>DFR penetration level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand increase</td>
<td>5%</td>
<td>0%</td>
</tr>
<tr>
<td>Demand decrease</td>
<td>5%</td>
<td>0%</td>
</tr>
</tbody>
</table>
HIL Test

(a)

(b)
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Conclusions

• The DFR technology has been developed to utilize the demand side resources to provide fast reserves needed in the future renewable based power system.
• The DFR technology has been tested by offline simulations in the previous work.
• The real time HIL tests were conducted to verify the effectiveness of the DFR technology.
• The HIL test results show that the DFR technology can successfully arrest the system frequency and illustrate the efficacy of the SmartBox.
Thank you for your attention