Towards Holistic Testing

Development of a Microgrid Controller

Symposium on Microgrids – 2017 | Newcastle, Australia

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Newcastle | November 29-30, 2017

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1. Introduction
Holistic Testing – Motivation / Challenges

Motivation

- Pure simulations representing only simplified and user-assumed results
- Pure hardware testing is too complex and costly at innovation and research level
- Current testing capability is limited:
  - Component testing – difficulties in holistic system testing
  - Testing at rigid grid connections – no influence between device-under-test and network dynamics
  - Limitation of high power, missing components, etc.

Objectives

- Development and application of an advanced test chain for smart grid components
- Smoothen transitions between simulation, testing and validation
- Closing the gap between simulation, laboratory and field testing
2. Innovative Testing Chain

Stages of the Testing Chain

1. Simulation-only studies
   - Simulation of all required components of a new idea/approach

2. Controller Hardware-in-the-Loop
   - Real-time simulation of all required components connected to a hardware controller

3. Power Hardware-in-the-Loop
   - Replacement of simulated devices by hardware components and real-time simulation of remaining components

4. Field Test (Pure Hardware)
   - Field installations with additional monitoring tools
3. Development procedure of a Microgrid Controller

Overview

- Task:
  - Restoration of a purely inverter based Microgrid
  - Grid control and operation control in islanding operation
  - Resynchronization

- Components in the Microgrid:
  - Grid forming inverter with PV and battery (VSI),
  - Aggregated load, 100kVA
  - Commercial available battery inverter (CSI)
  - Transformers, lines, circuit breaker
3. Development procedure of a Microgrid Controller (MGC)

**Modelling**

- **Modelling Plant and MGC**
- **Offline-Test (SiL)**
- **Online-Test I (Controller-HiL)**
- **Online-Test II (Power-HiL)**
- **Demonstration (Lab test)**

**MGC**
- Initiation, coordination and monitoring of restoration
- Generator management
- Load management
- PV-curtailment
- Consideration of forecast data
- Adaptive protection coordination

Diagram:

- Read measurement data
- Write control values
3. Development procedure of a Microgrid Controller (MGC)

**Offline-Test / Software-in-the-Loop**

- **Modelling** Plant and MGC
- **Offline-Test (SiL)**
- **Online-Test I** (Controller-HiL)
- **Online-Test II** (Power-HiL)
- **Demonstration (Lab test)**

**Simulation Domain**

Benefits:
- Implementation of all required components and control strategies
- Fast execution of various investigations (short-/long-term aspects)
- Flexibility of investigations and scenarios
3. Development procedure of a Microgrid Controller (MGC)

**Offline-Test / Software-in-the-Loop**

- **Modelling** Plant and MGC
- **Offline-Test** (SiL)
- **Online-Test I** (Controller-HiL)
- **Online-Test II** (Power-HiL)
- **Demonstration** (Lab test)

Simulation results (sunny day, summer load)
3. Development procedure of a Microgrid Controller (MGC)

**Online-Test / Controller Hardware-in-the-Loop**

- **Modelling**
  - Plant and MGC

- **Offline-Test (SiL)**

- **Online-Test I**
  - (Controller-HiL)

- **Online-Test II**
  - (Power-HiL)

- **Demonstration**
  - (Lab test)

**Benefits:**

- Transfer of the Microgrid Controller as Device-under-Test (DuT) onto real hardware
- Consideration of all dynamics and interfaces of the DuT
- Testing of controller performance and communication
- Comparative results for stage 1
3. Development procedure of a Microgrid Controller (MGC)

**Online-Test / Controller Hardware-in-the-Loop**

- **Modelling**
  Plant and MGC

- **Offline-Test (SiL)**

- **Online-Test I (Controller-HiL)**

- **Online-Test II (Power-HiL)**

- **Demonstration (Lab test)**

*Plant simulation in real time on OPAL RT and host PC*

*MGC as application on BACHMANN SPS and host PC*
3. Development procedure of a Microgrid Controller (MGC)

Online-Test / Controller Hardware-in-the-Loop

Comparison simulation (sim) and Controller-Hil (rt)

- Modelling Plant and MGC
- Offline-Test (SiL)
- Online-Test I (Controller-HiL)
- Online-Test II (Power-HiL)
- Demonstration (Lab test)
3. Development procedure of a Microgrid Controller (MGC)

**Online-Test / Power Hardware-in-the-Loop**

- **Modelling Plant and MGC**
- **Offline-Test (SiL)**
- **Online-Test I (Controller-HiL)**
- **Online-Test II (Power-HiL)**
- **Demonstration (Lab test)**

**Benefits:**
- Partial replacement of simulated models by hardware
- Verification of communication, DuT and power hardware operation and harmonized performance
- Investigation of different scenarios
3. Development procedure of a Microgrid Controller (MGC)

**Online-Test / Power Hardware-in-the-Loop**

- Modelling Plant and MGC
- Offline-Test (SiL)
- Online-Test I (Controller-HiL)
- Online-Test II (Power-HiL)
- Demonstration (Lab test)

Control room with LAN access to all components
3. Development procedure of a Microgrid Controller (MGC)

*Online-Test / Power Hardware-in-the-Loop*

- Modelling Plant and MGC
- Offline-Test (SiL)
- Online-Test I (Controller-HiL)
- Online-Test II (Power-HiL)
- Demonstration (Lab test)

RTDS system with power amplifiers
3. Development procedure of a Microgrid Controller (MGC)

Online-Test / Power Hardware-in-the-Loop

- Modelling Plant and MGC
- Offline-Test (SiL)
- Online-Test I (Controller-HiL)
- Online-Test II (Power-HiL)
- Demonstration (Lab test)

Battery inverter with transformer station and battery container
3. Development procedure of a Microgrid Controller (MGC)

**Demonstration / Field Test**

- **Modelling Plant and MGC**
- **Offline-Test (SiL)**
- **Online-Test I (Controller-HiL)**
- **Online-Test II (Power-HiL)**
- **Demonstration (Lab test)**
4. Summary of Performed Investigations

Conclusions and Overview

- New testing technologies support the validation of current and prospective research
  - Integrates realistic power system conditions in lab testing
  - Enables holistic testing of prototypes and innovative methods and technologies

- Proof of Concept
  - Support during the design of a Microgrid Controller
  - Step by step testing for controller development
  - Validation of the idea/approach by iterative replacement of simulation models by real hardware

Innovate testing chains de-risk field tests by enabling reality-close testing in controllable/safe laboratory environments
Thanks for your attention!

Acknowledgement
We acknowledge the support of our work by the German Federal Ministry for Economic Affairs and Energy (BMWi) and the Projekträger Jülich within the project “NETZ.KRAFT: Netzwiederaufbau unter Berücksichtigung zukünftiger Kraftwerkstrukturen” (FKZ 0325776A).

Acknowledgement
We acknowledge the support by the European Community’s Horizon 2020 Program (H2020/2014-2020) under project “ERIGrid: European Research Infrastructure supporting Smart Grid Systems Technology Development, Validation and Roll Out” (Grant Agreement No. 654113).

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