Experiences of a microgrid research laboratory and lessons learned for future smart grids

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Santiago 2013 Symposium on Microgrids
11 & 12 September 2013
Overview

1. The D-NAP Facility
2. Power Hardware-In-The-Loop Capability
3. Case studies
   - Testing demand-side management algorithm
   - Evaluating power line carrier technologies
   - Dynamic modelling
   - Real-time grid emulator: wind turbine control design
4. Benefits of microgrid scale demonstration
5. Conclusions and lessons learned
The D-NAP Facility
(Distribution Network, Automation and Protection)

- This is a 3-phase, 400V, 100kVA microgrid – can be split into 3 smaller microgrids
- 1.21 p.u. inductance is available to emulate stiff/weak topologies
- Grid connection or islanded using M-G set
- M-G set connected to an RTDS to extend simulation capabilities of power systems
Microgrid laboratory (D-NAP)

RTDS 100kVA to 1MVA network simulation

Simulation – Hardware Closed-loop interaction

Voltsages at common node

Currents flowing into hardware at common node

“Parent Network” (80kVA motor-genset)

Phase-locked to the simulation OR controlled to a Pre-programmed scenario of frequency and voltage

RTS controllers

LPC-controlled microgrid #1

LPC-controlled microgrid #2

6 x 3kW single-phase inverters “Windy Boys”

2.2 & 5.5 kW Induction generator/load sets

2kVA Synchronous generator

10kW, 12.5kVA Controllable loadbank

10kVA Inverter

40kW, 50kVA Controllable loadbank

2 x 7.5 kW Induction generator/load sets

10kW, 12.5kVA Controllable loadbank
80 kVA M-G set (DG3)

2 kVA Generator (DG1)

2.2 kW Induction Motor

10 kVA Inverter (DG2)
10kVA inverter – Built and tested at the University of Strathclyde
RT-PHIL (Power Hardware in the Loop) Techniques and Capabilities
CASE STUDIES
Fast demand response in support of the active distribution network
— with TNO Netherlands

- Observe demand response’s potential to contribute to frequency control of the power system
- Test this potential against a real frequency excursion event using an integrated laboratory test environment
**PowerMatcher** as part of RT-PHIL

- PowerMatcher integrated within D-NAP laboratory to control loads as part of a real-time power hardware-in-the-loop experiment (RT-PHIL)
- Simulation based on a real event – 2008 UK frequency excursion
- Real-time market based control using the PowerMatcher
Evaluating smart grid communication in an industrial microgrid environment

- with University of Udine

- Characterisation of power line carrier (PLC) channels within a controllable, electrically noisy, LV network

- Investigation of the possibility of using PLC in a laboratory for control

- Identification of noise sources for deployment of PLC for smart grid technologies
Dynamic performance of a low voltage microgrid with droop controlled distributed generation

- with Aristotle University of Thessaloniki

- Using experimental measurements of a microgrid’s (MG) characteristics to validate a dynamic black-box model

- **Focusing on small-signal dynamics** (challenging task when large number of ac/dc – dc/ac interfaces are involved)

- Investigate the interactions between rotating and inverter interfaced DG units

- MG examined in grid-connected and islanded mode
Summary of microgrid projects

- **DERRI Transnational Access**
  - DISCOSE (*Testing PowerMatcher in RT-PHII environment*)
  - POLSAR (*Investigating PLC in a microgrid*)
  - MoDERN and MoreModern (*Dynamic modelling in a microgrid*)
  - DERManagement (*New energy management technology*)
  - PV-APLC (*detecting and adjusting unbalance and harmonics*)

- **EURAMET** (*state estimation modelling and validation*)
SOME LESSONS LEARNED AND POSSIBLE SOLUTIONS
Low Voltage Branch Grid Impedance

- The impedances of the grid branches at low voltage level very often are not well known.

- For this reason the grid models at low voltage level are afflicted by an important uncertainty.

- Measurements in the lab and estimations, based on values available in literature, have been done in order to better evaluate these impedances.

- It is still open the problem to find an optimal way to evaluate the grid impedances on the real field.
Sensitivity Analysis

• Distribution networks present a large number of nodal points.

• The installation of monitoring and metering is expensive particularly at MV and LV where the installation of new VTs and CTs may be necessary.

• It is not possible to measure at every node and branch.

• It is crucial identifying a strategy to optimize the location, the number of the measurement point is important for effective network control; in order to do this, a technique based on sensitivity analysis has been developed successfully.
Active Network Management

- A critical concern is the robustness of online and automatic active network management (ANM) algorithms/schemes.

- The ANM scheme’s functionality depends on convergence to a solution when faced with uncertainty and its reliability can be reduced by data skew and errors.

- It is important to assess ANM performances when subjected to different levels of data uncertainty and verify the introduction of a state estimator (SE) in the ANM architecture to mitigate the data uncertainty effects on the control action.
Lack of facilities with capacity to test in a holistic manner full-scale grid-connected wind turbines in a controlled environment

Some have the turbine but not the grid

Some have the generator and grid (LV) – but not the turbine
Objectives

1. Design a Grid Emulator test rig (structure and components) that will allow to perform endurance testing and power quality validation for wind turbines based on the requirements of:
   - International Grid Codes
   - Standard (e.g. IEC, etc.)
   - Guidelines (e.g. IEEE, GL, etc.)

2. Turbine control performance assessment (may assist understanding and addressing scalability issues)

3. Portability (‘bring’ the grid where needed!)
RT-Grid Emulator at NAREC

Specifications:

- Rated at 10MW, 11kV both ends
- Ability to perform electrical Hardware in the loop operation

Capabilities:

- Asymmetrical/unbalanced condition
- Grid fault level condition
- Harmonic distortion conditions

**Will require power electronic interfaces for power conditioning/**
Benefits to using a Microgrid test bed

- Flexible configurations in a fully instrumented network
- No customers to accidently disconnect (saves $)
- Can run devices through scenarios rarely observed on the public grid, e.g. frequency dips.
- Devices can be installed within a controlled environment and constantly monitored
- New technologies can be evaluated for multiple stakeholders
Conclusions

• Microgrid test labs are capable of more than just demonstrating microgrid technologies

• Useful platforms for validation and prototyping of novel technologies

• Can be a route for smart grid technologies into private microgrids and the public grid.