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

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Overview

- The D-NAP Facility
- Power Hardware-In-The-Loop Capability
- Case studies
  - Testing demand side management algorithm
  - Evaluating power line carrier technologies
  - State estimation algorithm validation
  - Dynamic modelling
- Benefits of microgrid scale demonstration
- Conclusions

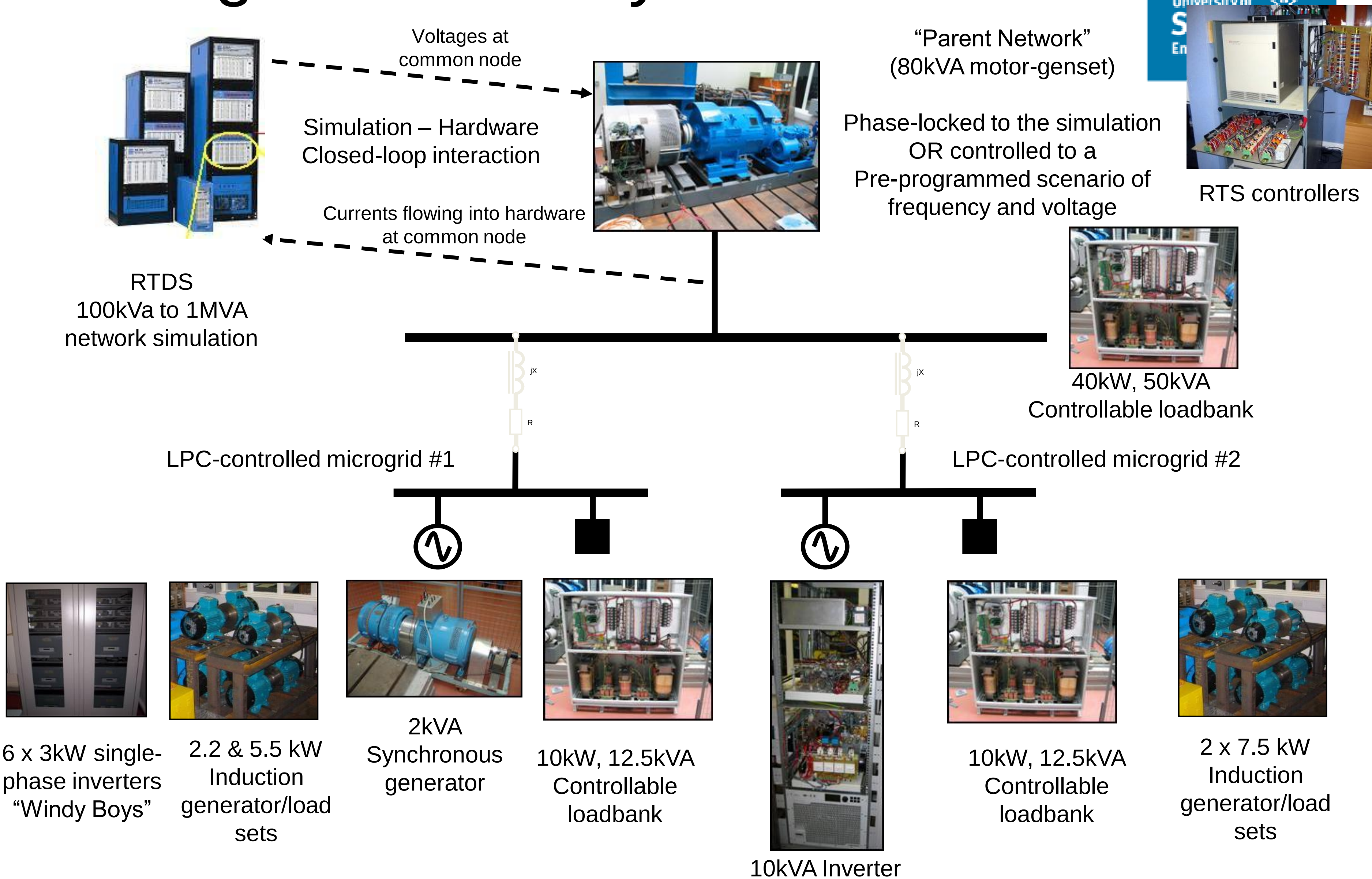
The D-NAP Facility

(Distribution Network, Automation and Protection)

University of Strathclyde Engineering

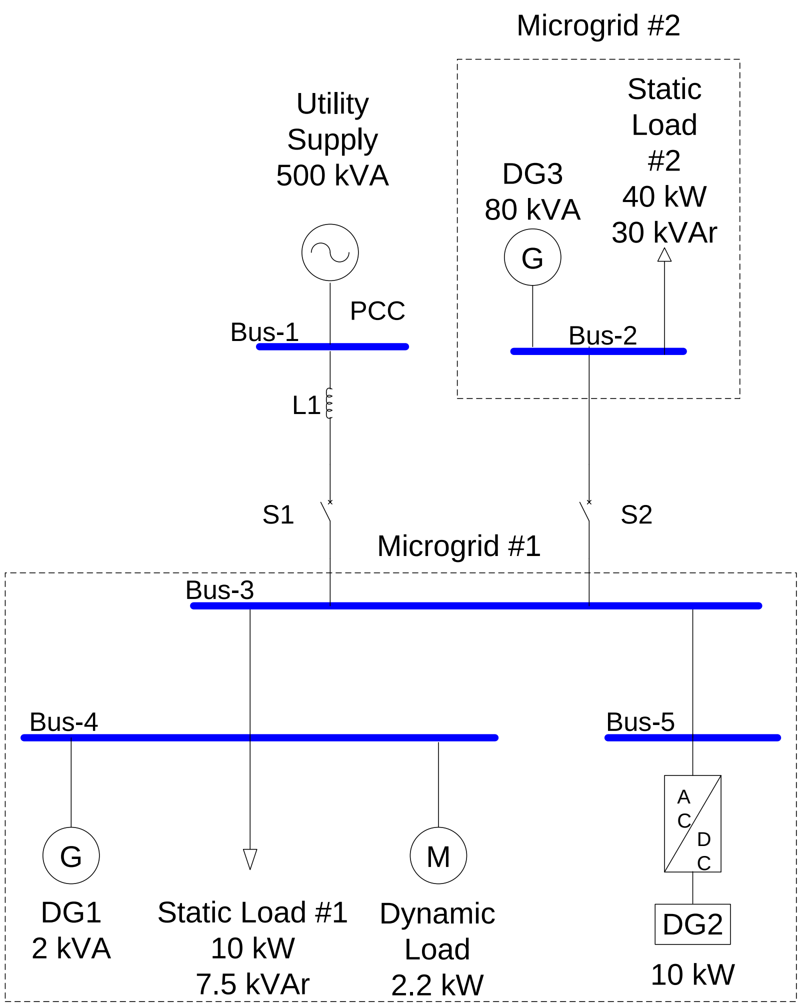
- 100kVA low-voltage facility
- Can run islanded or grid connected
- A range of inverters, static and dynamic loads
- Motor-Generator set connected to RTDS for Real-Time Power-Hardware-In-the-Loop capability

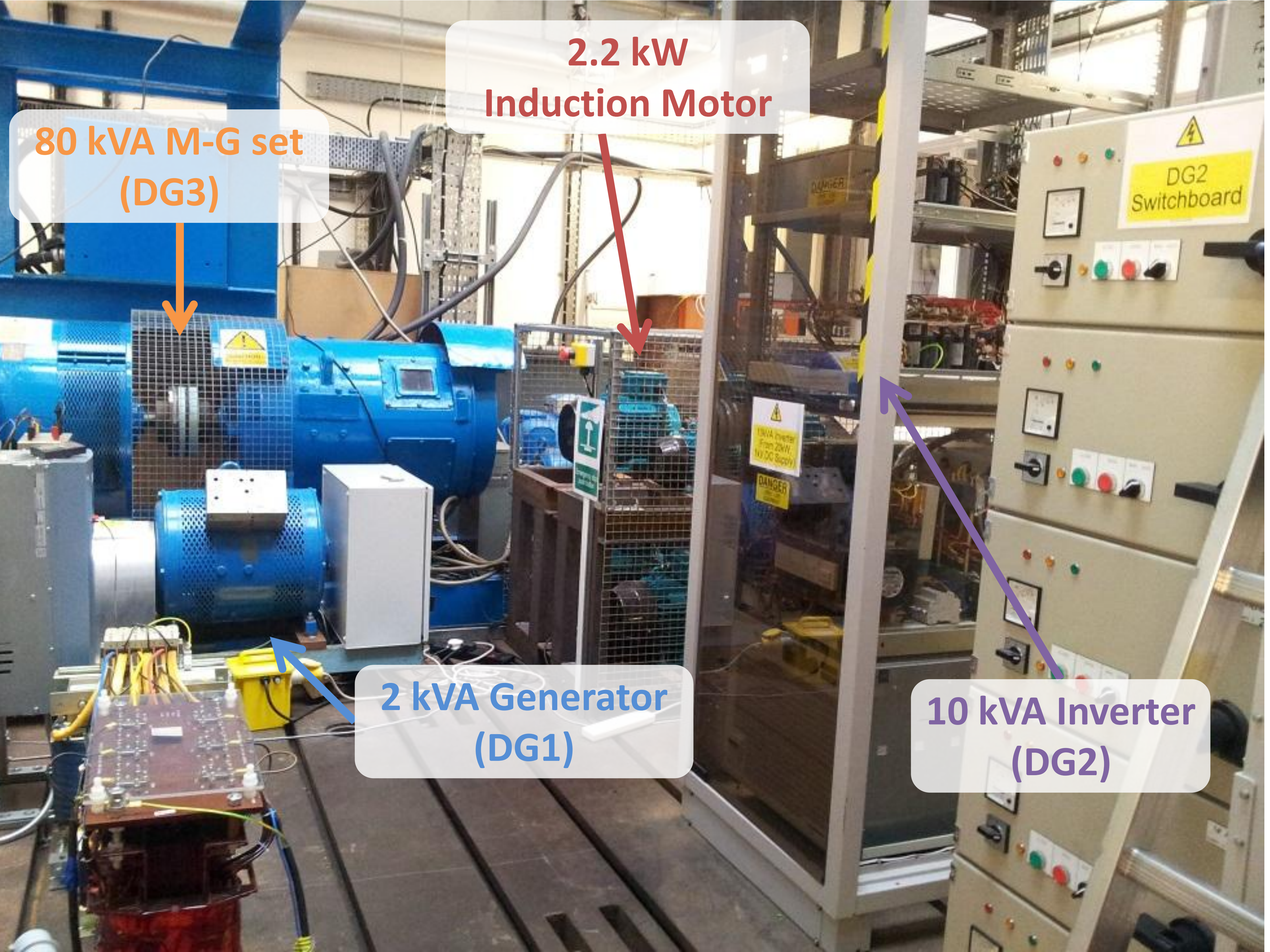
Microgrid laboratory



Laboratory configuration

- 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

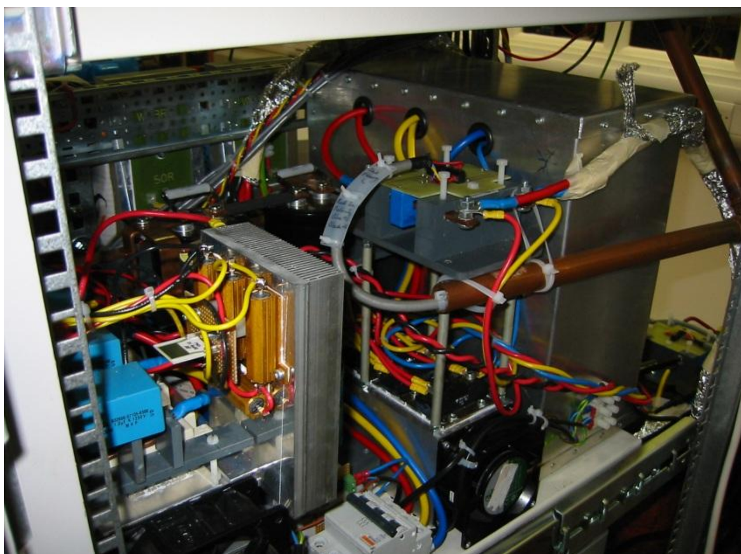


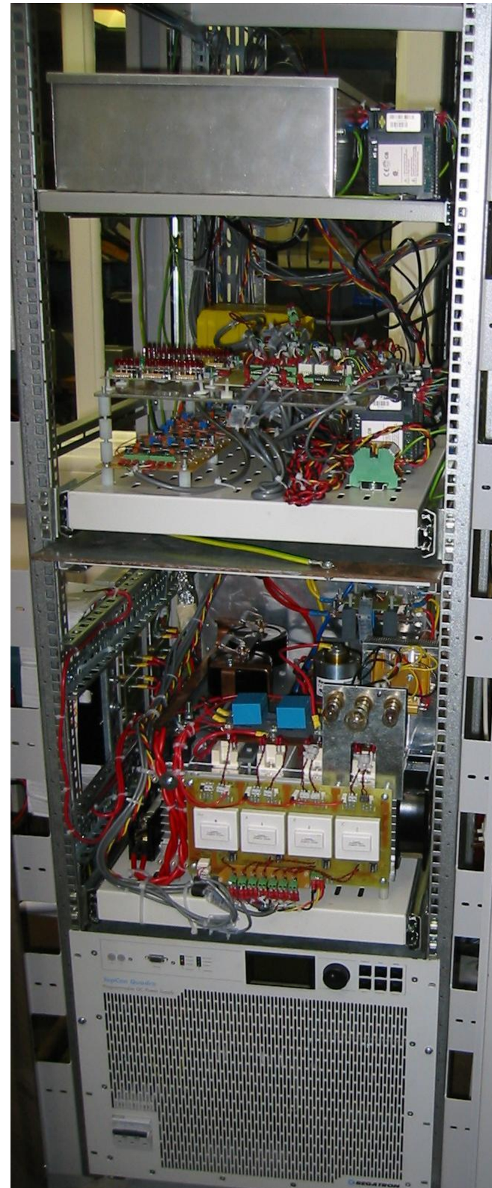


80 kVA M-G set
(DG3)
2.2 kW
Induction Motor
DG2
Switchboard
2 kVA Generator
(DG1)
10 kVA Inverter
(DG2)

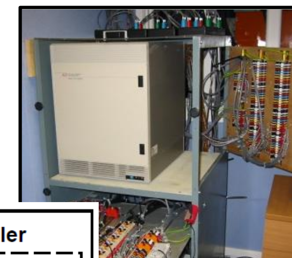
10kVA inverter – Built and tested at the University of Strathclyde

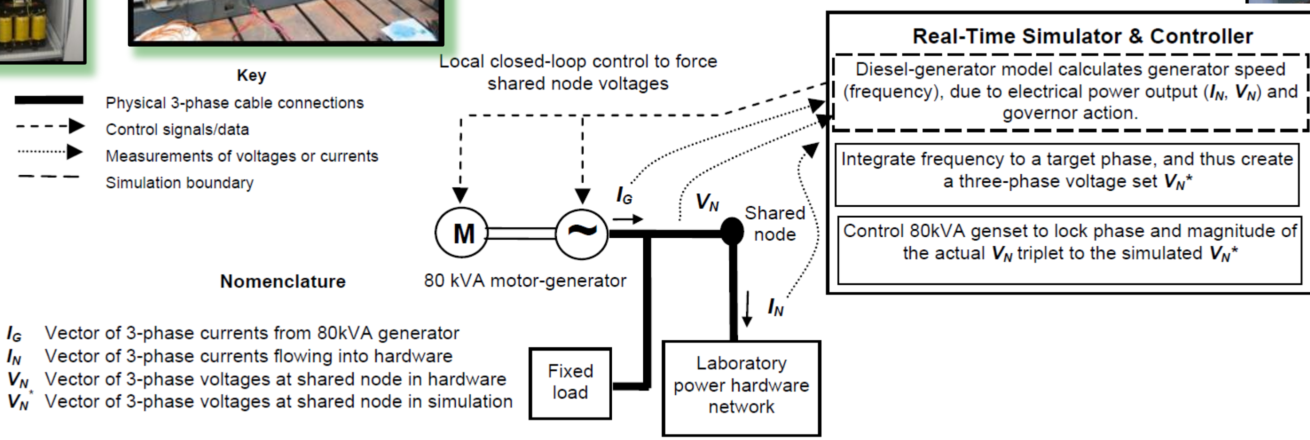
University of Strathclyde Engineering





RT-PHIL (Power Hardware in the Loop) Techniques and Capabilities



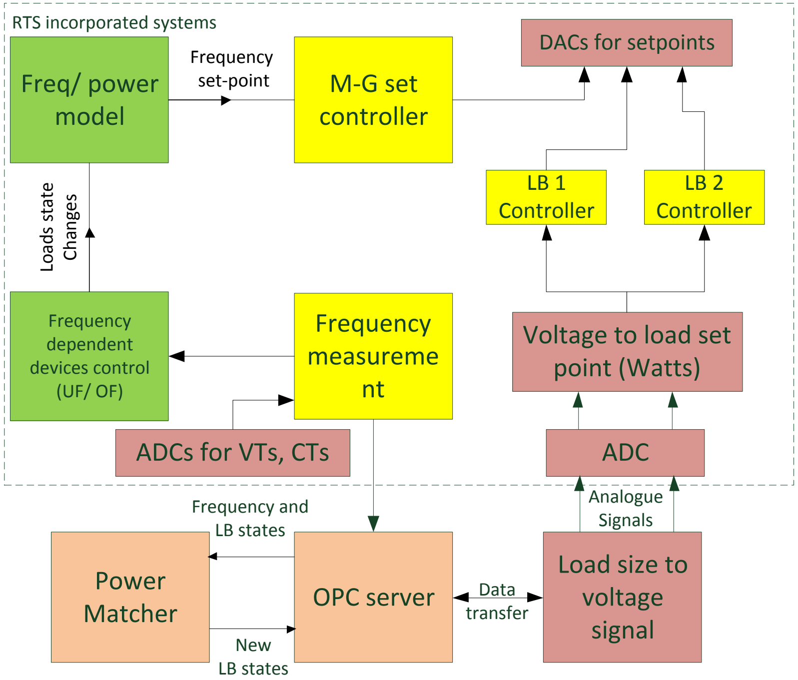


CASE STUDIES

Fast demand response in support of the active distribution network

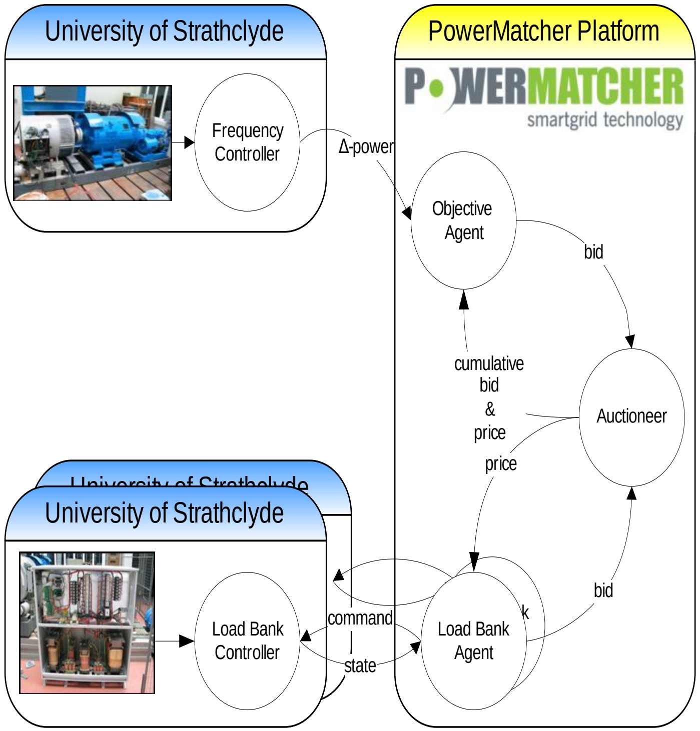
– *with TNO Netherlands*

- 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

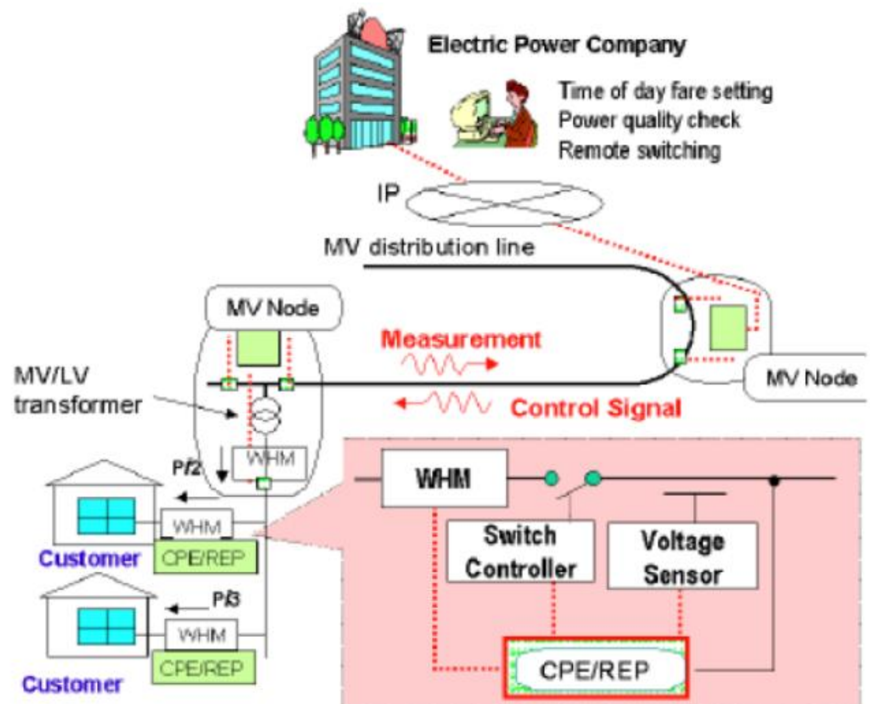


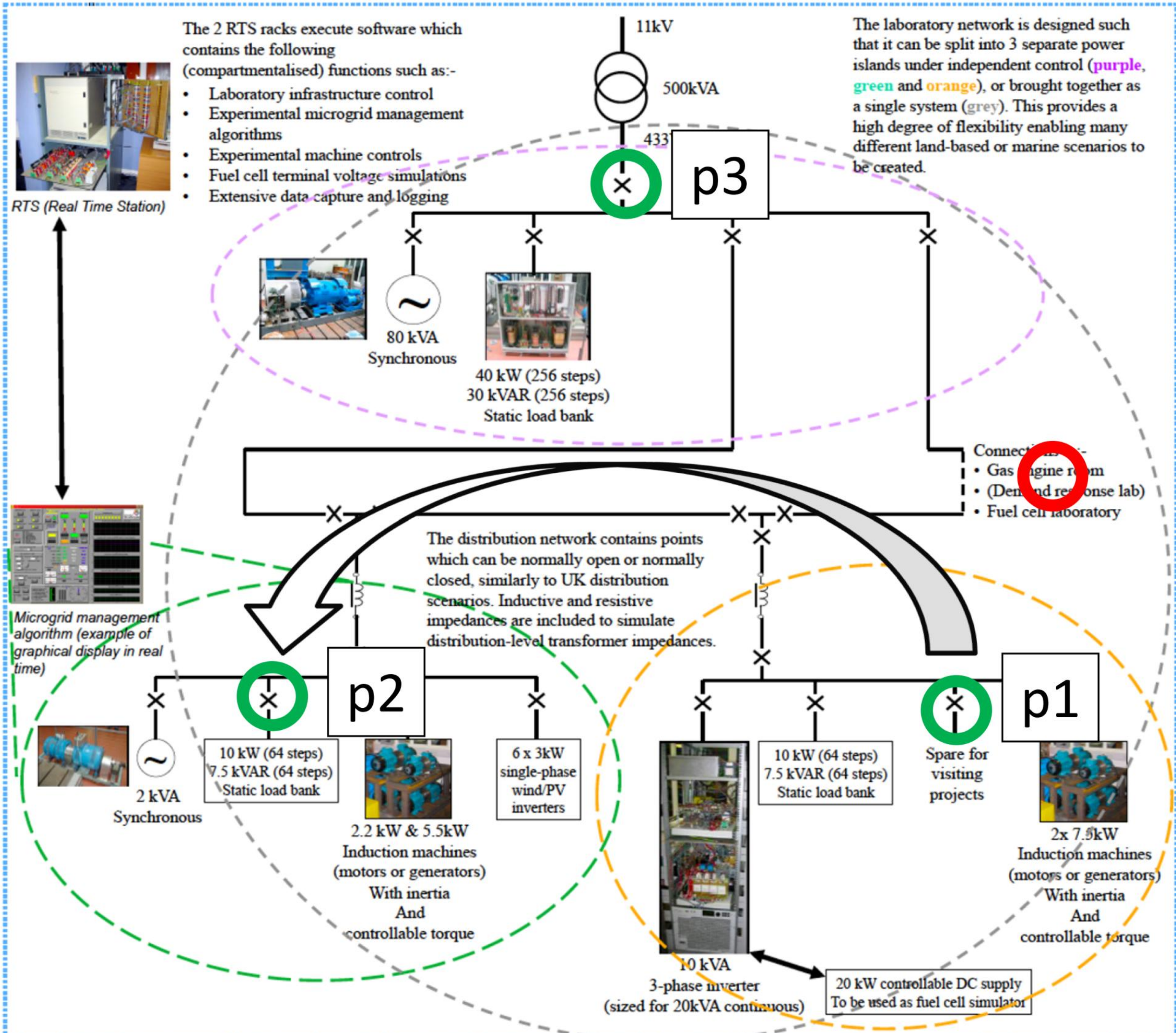
Evaluating smart grid communication in an industrial microgrid environment

- *with University of Udine*

Objectives

- 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

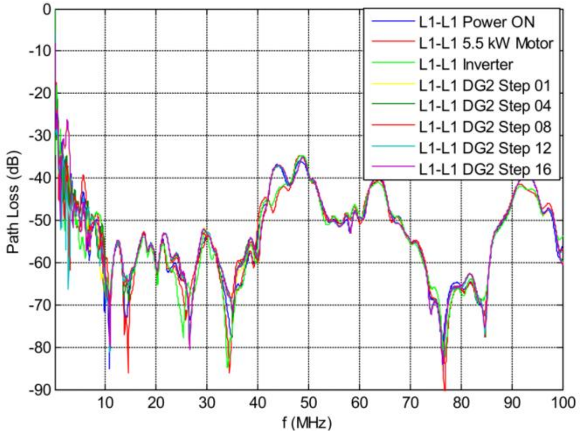


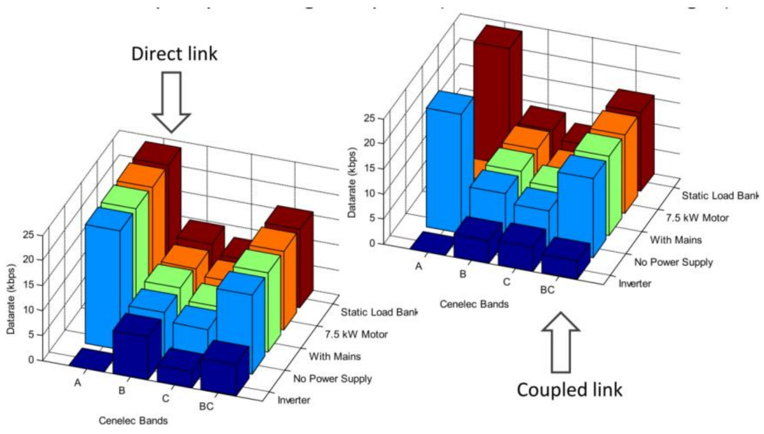


The 2 RTS racks execute software which contains the following (compartmentalised) functions such as:-
• Laboratory infrastructure control
• Experimental microgrid management algorithms
• Experimental machine controls
• Fuel cell terminal voltage simulations
• Extensive data capture and logging
RTS (Real Time Station)
11kV
500kVA
433
p3
The laboratory network is designed such that it can be split into 3 separate power islands under independent control (purple, green and orange), or brought together as a single system (grey). This provides a high degree of flexibility enabling many different land-based or marine scenarios to be created.
80 kVA
Synchronous
40 kW (256 steps)
30 kVAR (256 steps)
Static load bank
Connections to:-
• Gas engine room
• (Demand response lab)
• Fuel cell laboratory
Microgrid management algorithm (example of graphical display in real time)
The distribution network contains points which can be normally open or normally closed, similarly to UK distribution scenarios. Inductive and resistive impedances are included to simulate distribution-level transformer impedances.
p2
p1
2 kVA
Synchronous
10 kW (64 steps)
7.5 kVAR (64 steps)
Static load bank
2.2 kW & 5.5kW
Induction machines
(motors or generators)
With inertia
And
controllable torque
6 x 3kW
single-phase
wind/PV
inverters
10 kVA
3-phase inverter
(sized for 20kVA continuous)
10 kW (64 steps)
7.5 kVAR (64 steps)
Static load bank
Spare for
visiting
projects
2x 7.5kW
Induction machines
(motors or generators)
With inertia
And
controllable torque
20 kW controllable DC supply
To be used as fuel cell simulator

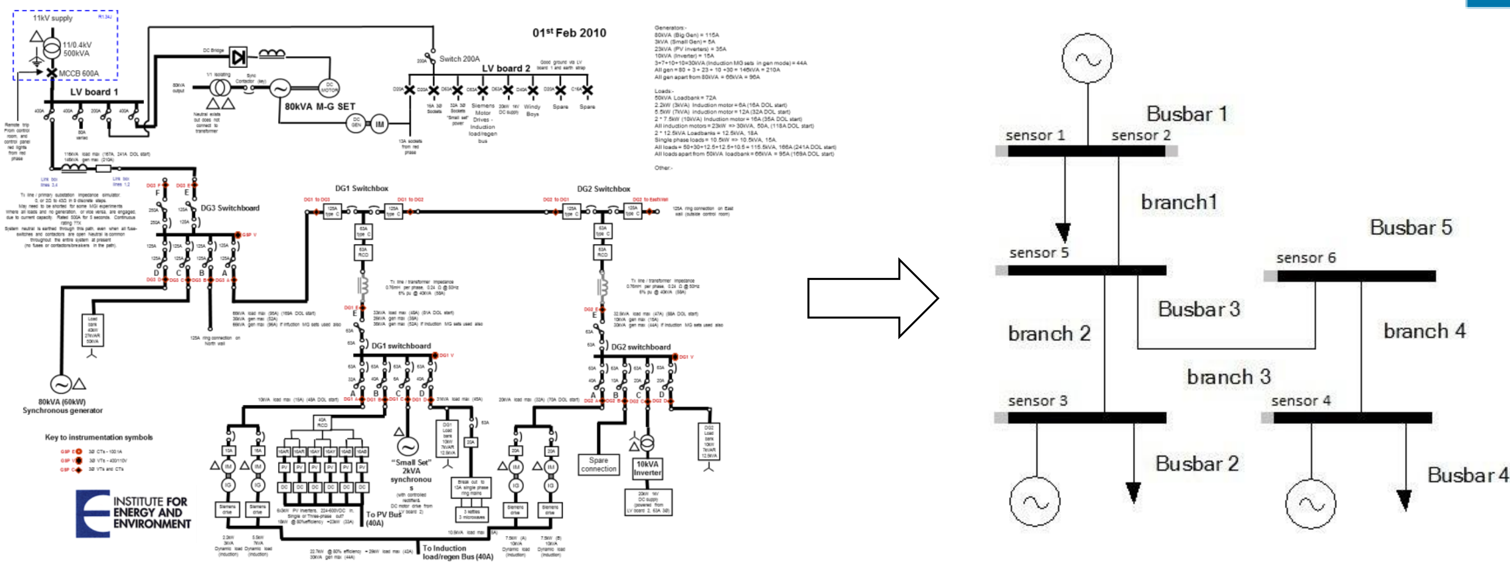
Main Achievements

- Tested the use of commercially available modems
- Tested in CENELEC A, B, C and BC bands
- Devices tested in the presence of known loads and generation sources – allowing evaluation of performance which is difficult when field tested





Strathclyde Experimental Microgrid

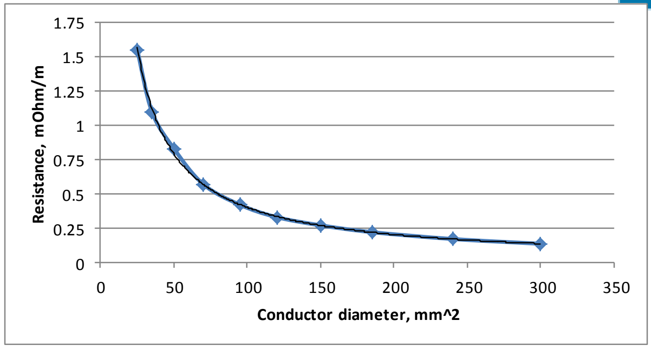


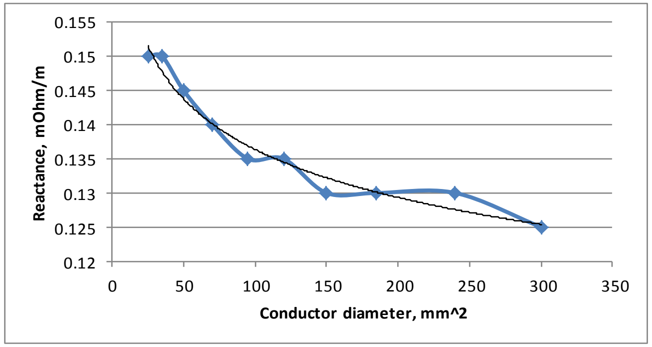
The experimental SmartGrid at Strathclyde University (100 kVA LV experimental microgrid) has been analysed and adapted in order to achieve an optimum understanding of its structure and components, to adapt a generic electrical grid model to this specific grid and simulate in an appropriate software environment

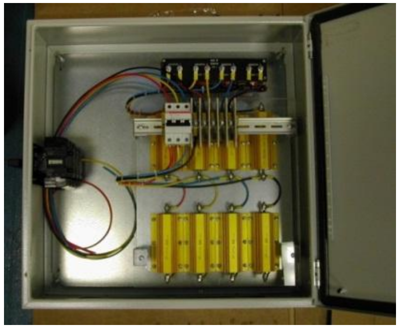
A model of the experimental SmartGrid at Strathclyde University has been made in collaboration with NPL in order to execute power flow analysis in Matlab environment using Mathpower, and with IPSA.

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.







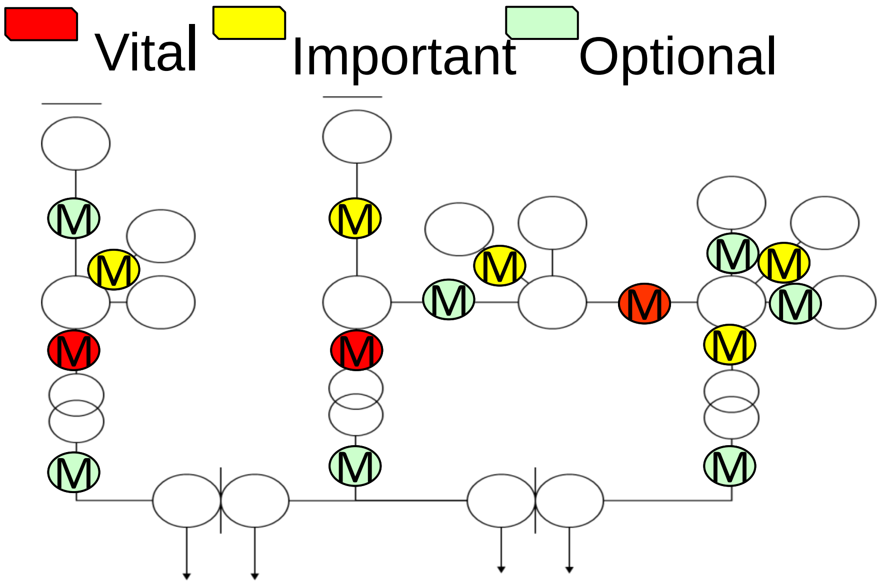
Sensitivity Analysis

- 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.

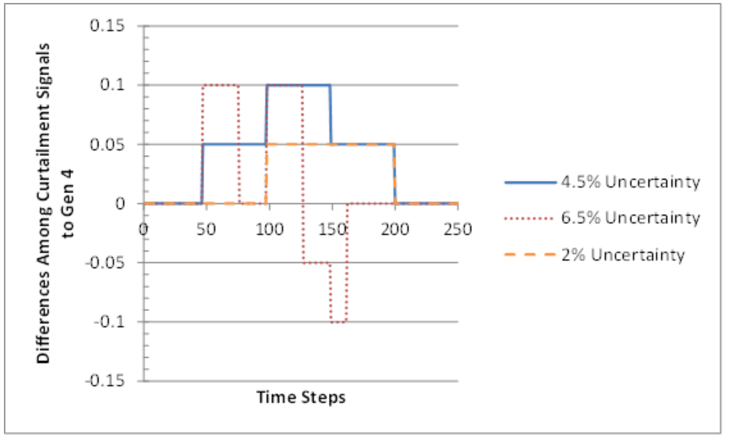


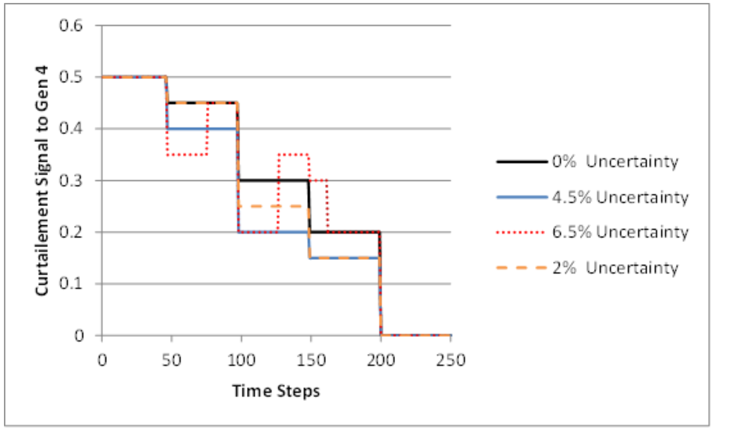
Active Network Management

- 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.





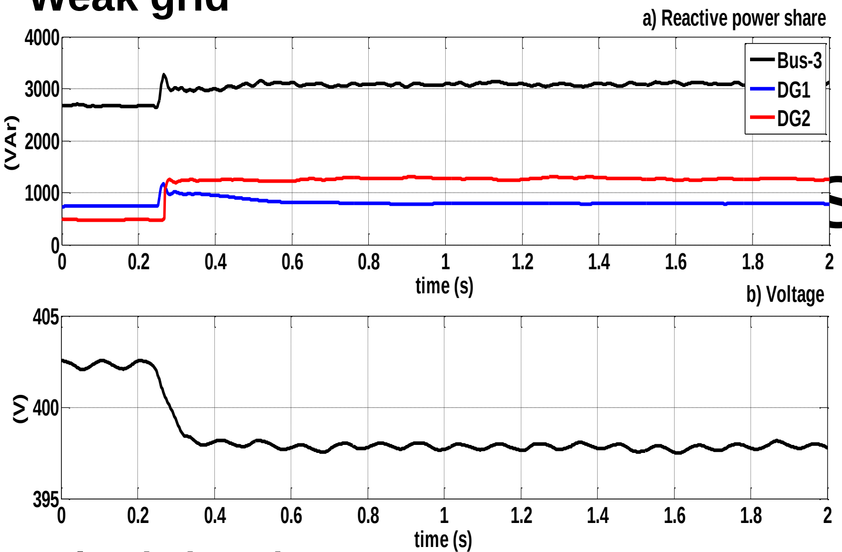
Dynamic performance of a low voltage microgrid with droop controlled distributed generation

- *with Aristotle University of Thessaloniki*

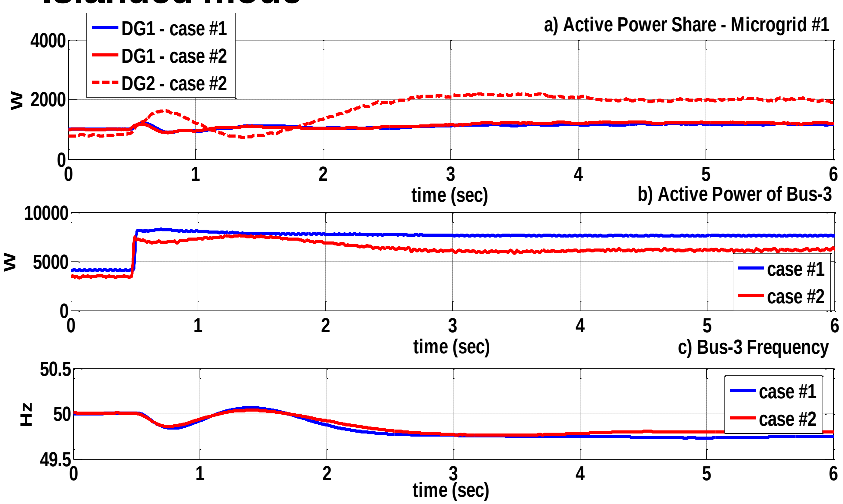
University of Strathclyde Engineering

- Using experimental measurements of a microgrid's (MG) characteristics to validate a dynamic black-box model
- Focusing on small-signal dynamics
- Emphasis on influence of small droop controlled DG unit penetration on the dynamic performance of the MG system
- Investigate the interactions between rotating and inverter interfaced DG units
- MG examined in grid-connected and islanded mode

Weak grid



Islanded mode



- Dynamic performance of a laboratory scale MG. Special emphasis on the influence of the droop controlled units
- Analysis using lab experimental results
- In grid-connected operation transients occur on the MG response in the case of weak grids
- In the islanded mode, the droop controlled inverter interfaced units significantly influence the dynamic responses of both *P* and *Q*.

Summary of microgrid projects

- DERRI Transnational Access
  - DISCOSE (*Testing PowerMatcher in RT-PHIl 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*)

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.

University of
Strathclyde
Glasgow