University of Strathclyde Engineering

Evaluating the robustness of an active network management function in an operational environment

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Introduction

Incentives to renewable sources of energy are causing an increase of the number of generators connected to distribution networks.

The cost of the network reinforcement are very high and utilities are interested in active network management solutions in order to manage the generator connection to the net, reducing to the minimum the network reinforcement.

So, automatic control systems, based on software tools, are becoming more desirable in distribution power systems.

Primarily, such schemes are expected to manage system voltage fluctuations, network power flows and fault levels.

Functionalities include also power balancing, system frequency control and management of demand side resources for the primary system constraints.

Introduction

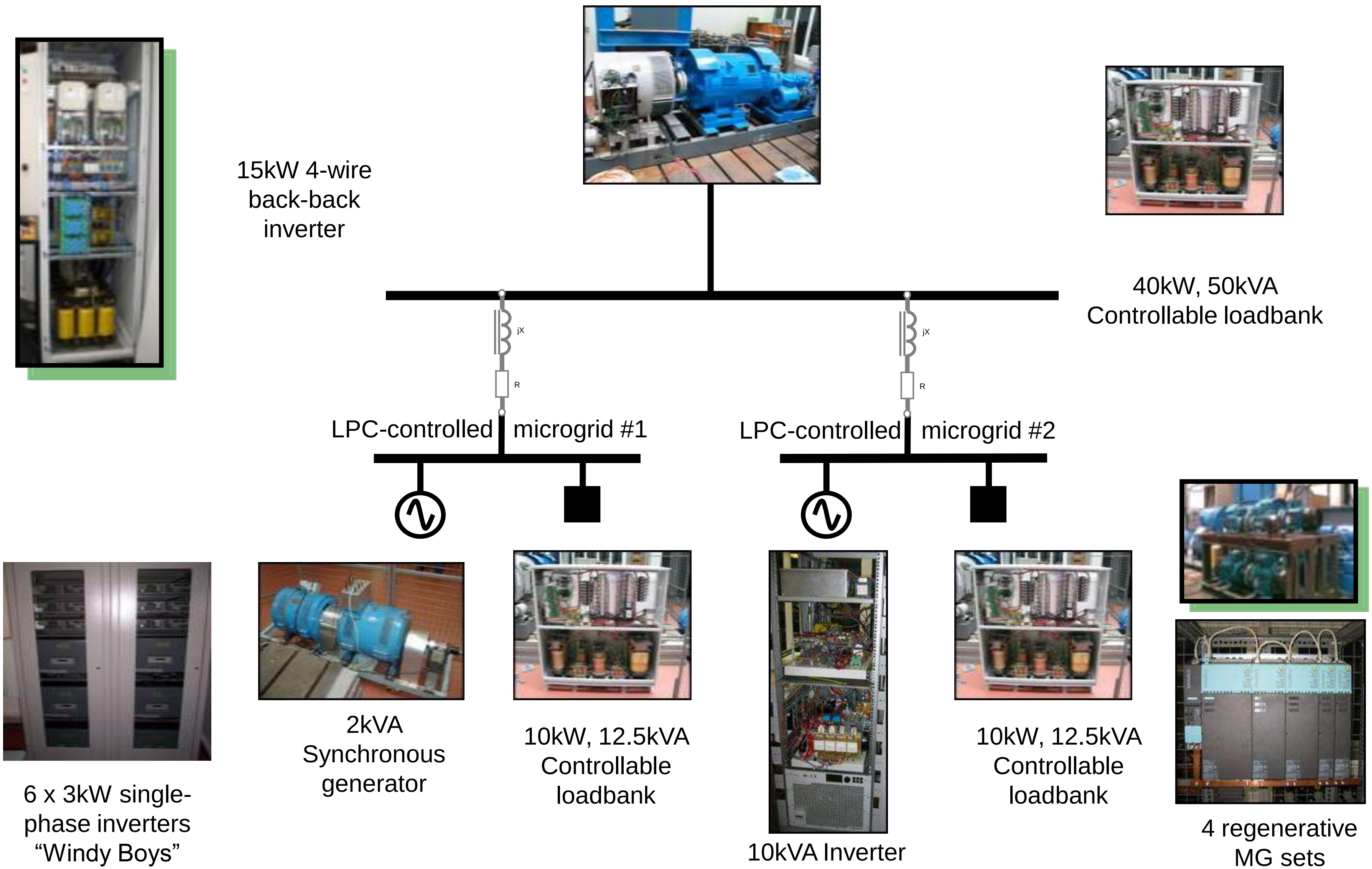
A critical concern is the robustness of online and automatic active network management (ANM) algorithms/schemes.

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.

The work presented evaluates power flow management (PFM) functionality based on the Constraint Satisfaction Problem (CSP) in an operational environment.

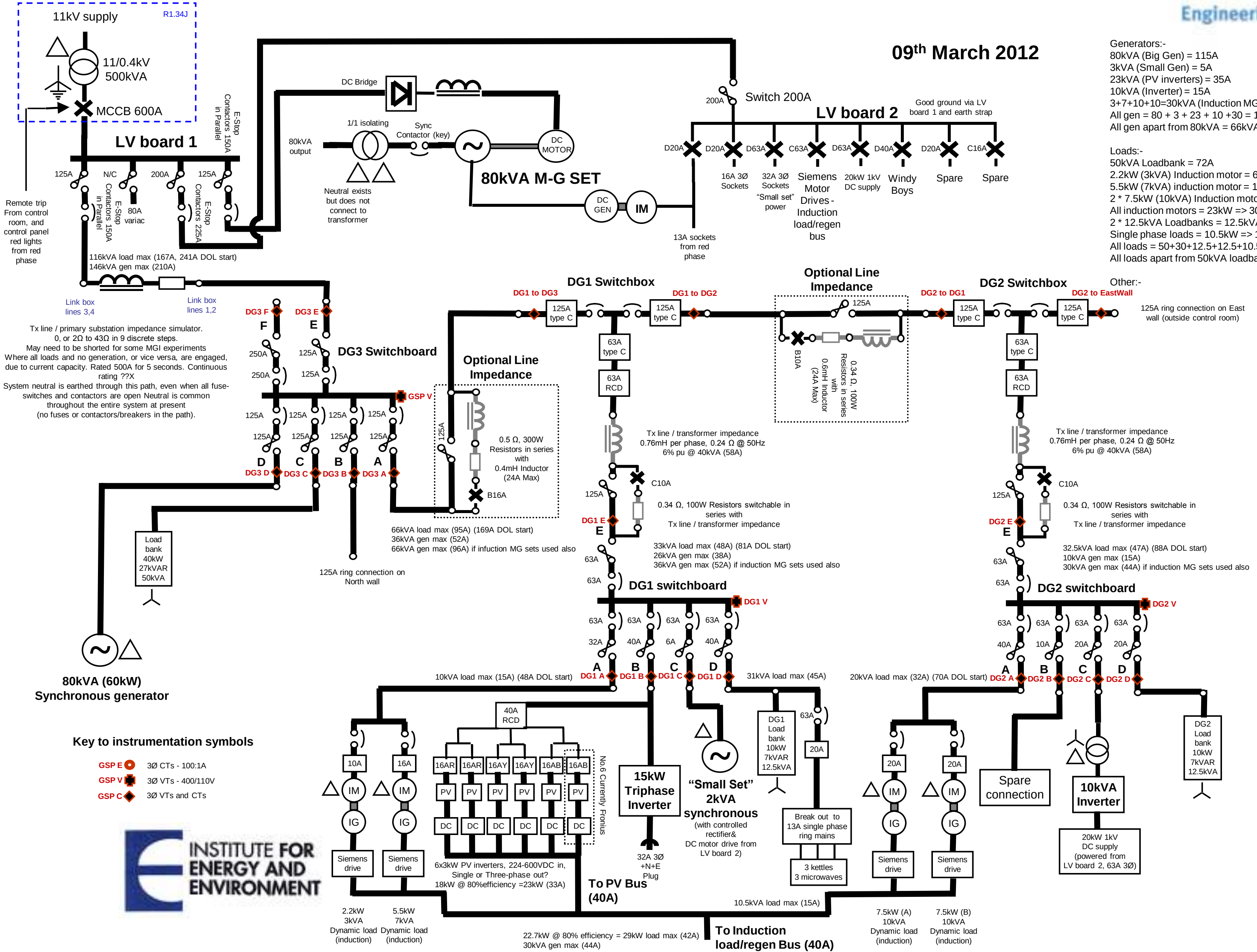
The objective is to assess performances when subjected to different levels of data uncertainty and verify the introduction of a state estimator (SE) in the ANM architecture to mitigate the data uncertainty effects on the control action.

Test Environment



Test Environment

09th March 2012



Generators:-
80kVA (Big Gen) = 115A
3kVA (Small Gen) = 5A
23kVA (PV inverters) = 35A
10kVA (Inverter) = 15A
3+7+10+10=30kVA (Induction MG sets in gen mode) = 44A
All gen = 80 + 3 + 23 + 10 +30 = 146kVA = 210A
All gen apart from 80kVA = 66kVA = 96A

Loads:-
50kVA Loadbank = 72A
2.2kW (3kVA) Induction motor = 6A (16A DOL start)
5.5kW (7kVA) induction motor = 12A (32A DOL start)
2 * 7.5kW (10kVA) Induction motor = 16A (35A DOL start)
All induction motors = 23kW => 30kVA, 50A, (118A DOL start)
2 * 12.5kVA Loadbanks = 12.5kVA, 18A
Single phase loads = 10.5kW => 10.5kVA, 15A.
All loads = 50+30+12.5+12.5+10.5 = 115.5kVA, 166A (241A DOL start)
All loads apart from 50kVA loadbank = 66kVA = 95A (169A DOL start)

Other:-

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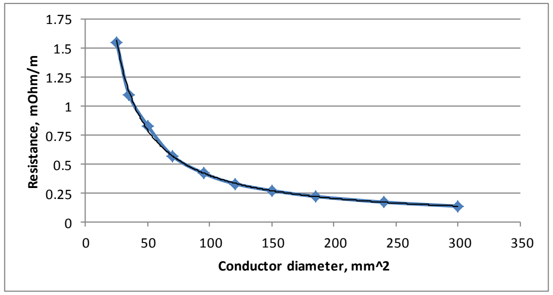
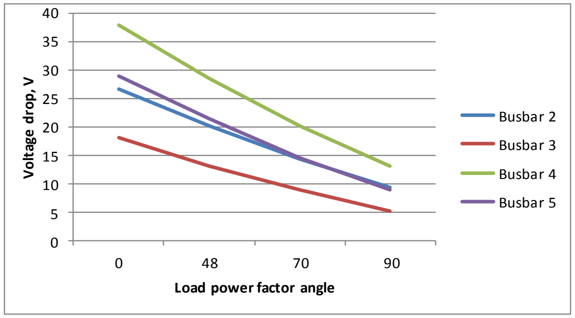
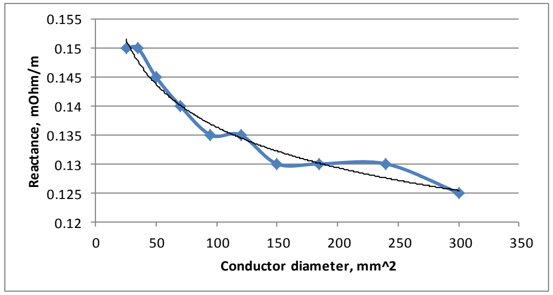
Test Environment





The impedance of the cables has been estimated using values available in literature.

The effect of the addition of extra impedances has been evaluated and new impedances have been added to the branches of the grid.



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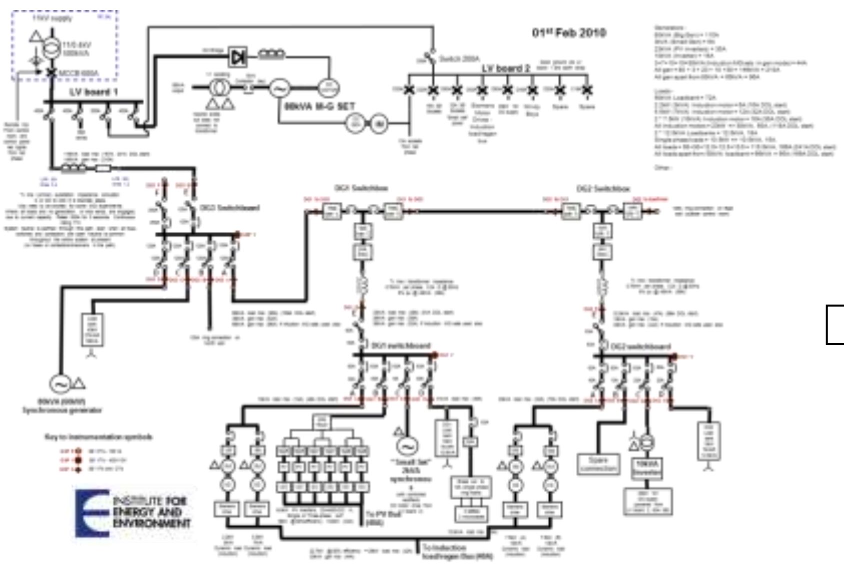
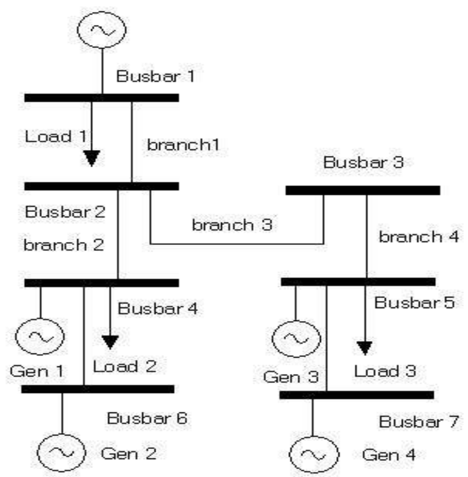


Part of the microgrid available at Strathclyde University has been configured to allow the integration and testing process of an ANM function.



Busbar 1 includes a variable load bank. Load banks are also connected to two other busbars (4 and 5). Induction machines, which can also act as generators, are connected to buses 4, 5, 6 and 7. These units have a maximum real power output of 2.2kW, 5.5kW, 7.5kW and 7.5 kW.

PFM using a CSP approach

Modelling the PFM problem as a constraint satisfaction problem entails expressing the problem as a set of variables with finite discrete domains and a set of constraints.

For PFM, the problem to be solved is concerned with deciding what control actions to take, on the Distributed Generation (DG) units, in order to maintain the network within the thermal limits (i.e. power constraints) and maximize DG access.

The variables of the CSP are the controllable generating plant power output set-points and the domains are the discrete values that the generators' set-points can assume.

$V := \{gen_1, gen_2, \ldots, gen_n\}$

$D_{gen1} := \{control_1, \ldots, control_n\}$

PFM using a CSP approach

These values are the maximum values that a generator can output. However, the intermittent nature of most renewable generating plants means that DG output is such that its output is continuous up to this discrete set-point value.

In addition to variables and their domains we have to set the constraints on the solution:

- Power flow constraints: no thermal overloads
- Contractual constraints: generators access rights
- Preference constraints.

PFM using a CSP approach

$$(V_{gens}, D_{Control\ Signal}, C) \qquad (1)$$

Where:

$V_{gens} = \{Gen_1, Gen_2 \ldots Gen_n\}$ (2)

$D_{Control\ Signal}$ is:

$D_{Gen1}=\{1,\ldots,0\}$, $D_{Gen2}=\{1,\ldots,0\}$, $D_{Genn}=\{v_1,\ldots,v_n\}$ (3)

C is the constraint applied to the sets of variables:

$$C_{Power\ Flow} = \{ |S_{ij}| \leq S_{ij}^{\max} \} \qquad (4)$$

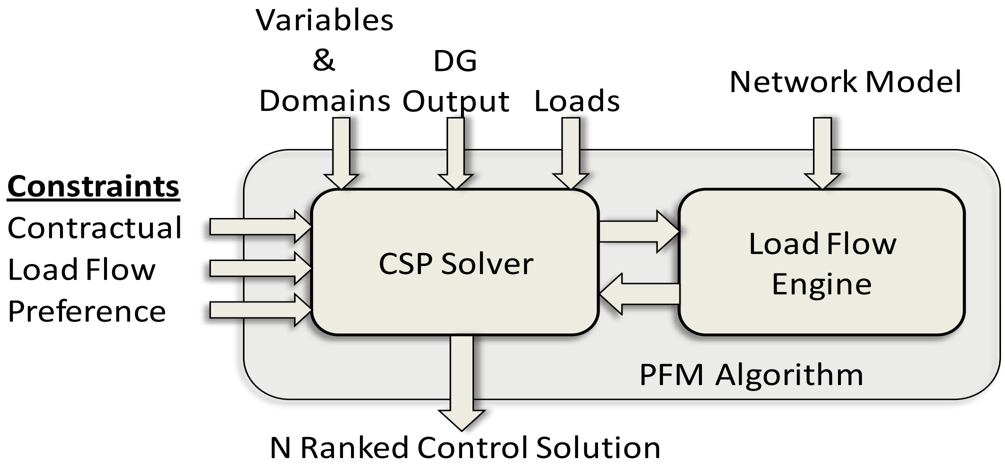
$$C_{Contractual} = \{k, l, m\} \qquad (5)$$

$$C_{MaxDG} = \left\{ \max \sum_{n=1}^{N} P_{Gi} \right\} \qquad (6)$$

PFM using a CSP approach

Modelling PFM, in this way, relies upon a load flow engine to evaluate the power flows within the network to determine any control actions that are required.

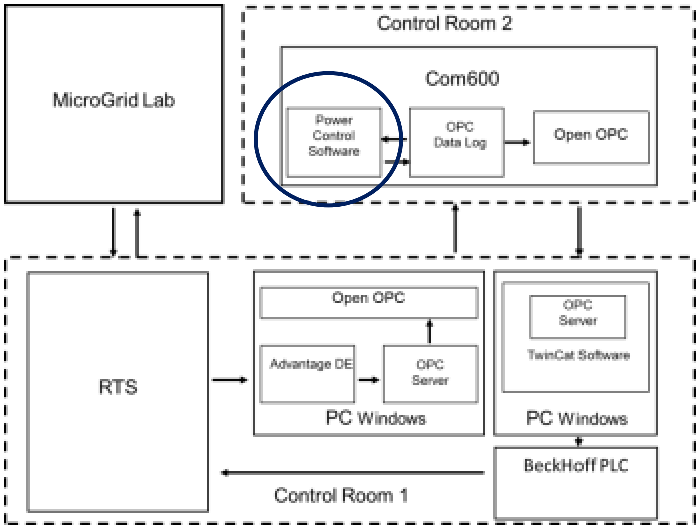
The generators have been ordered in a last-in, first off (LIFO) manner to replicate the current connection regime used in the UK.



M. J. Dolan, E.M.Davidson., G. W. Ault, K.R.W. Bell, S. D. J. McArthur, *Distribution Power Flow Management Utilizing an Online Constraint Programming Method.* Smart Grids, IEEE Transaction on.

Integration of the ANM and the Microgrid

The PFM algorithm, presented above, was chosen as the ANM control approach and installed initially on a COM600 (Windows XP embedded industrial PC).



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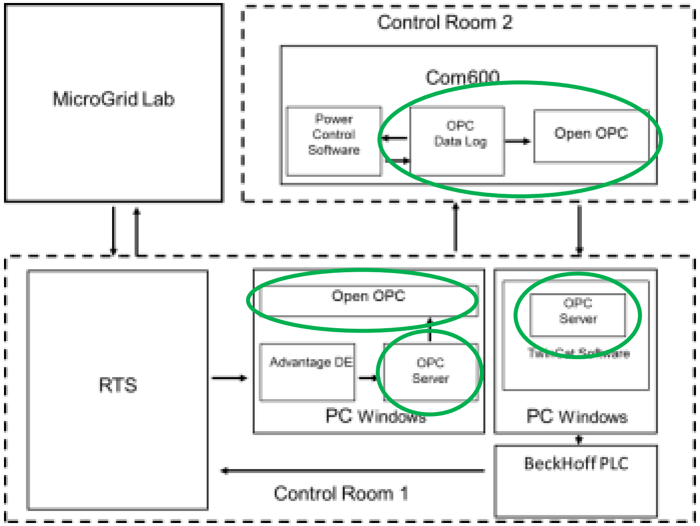
The communication system among the PCs of the Microgrid created some problems and different solutions has been tested. The solution chosen at the end is based on the OPC server/client architecture, with the integration of the OpenOPC functionalities.



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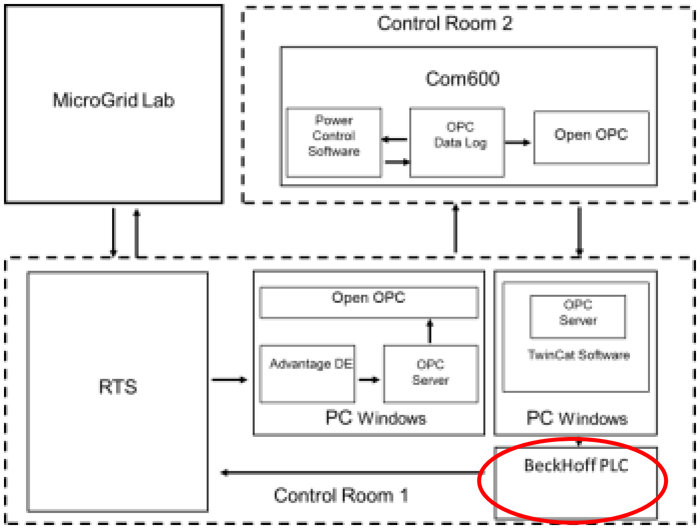
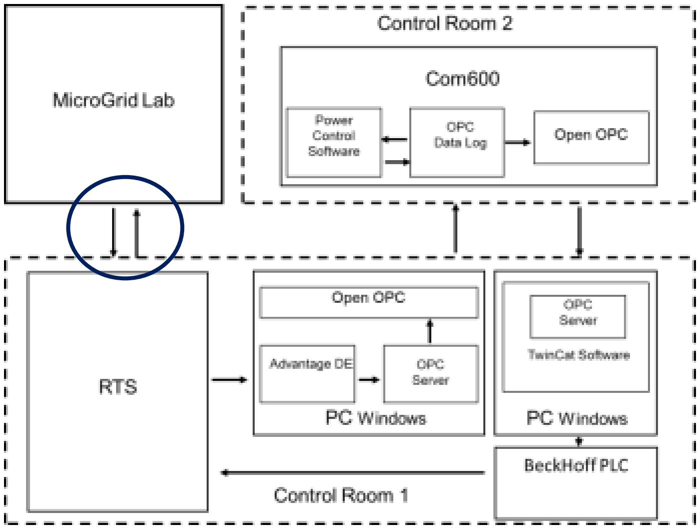
In order to send the data to the RTS analogue inputs, a Beckhoff CX5010 Embedded PC with Intel® Atom™ processor has been used. The Beckhoff software presents OPC functionalities and the data can be sent using the OPC standard. The Beckhoff unit can be set and controlled also via a standard pc.



Integration of the ANM and the Microgrid

The sensor measurements coming from the microgrid are collected via a real time station (RTS) computer developed by ADI. The RTS has analogue and digital input/output (I/O) interfaces, can execute programs written with Matlab and Simulink, process directly the data collected, manage the electrical machines of the grid and guarantee their safe operation.



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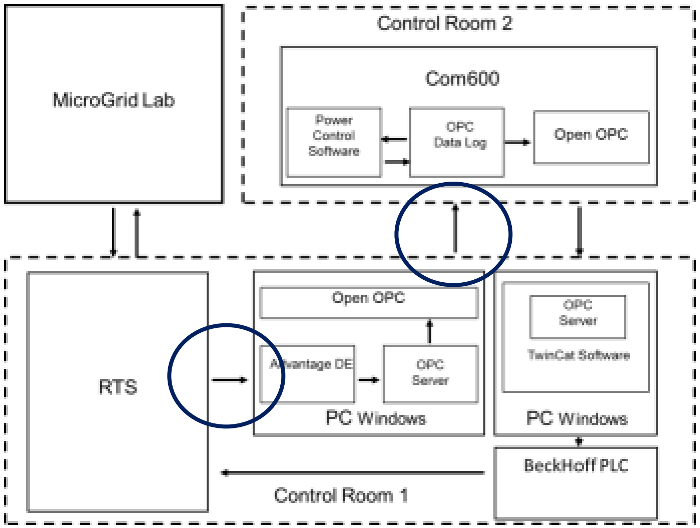
After a first elaboration, the measurements are then made available, mapped on the OPC server variables and sent from the PC, connected to the RTS, to the OPC server.



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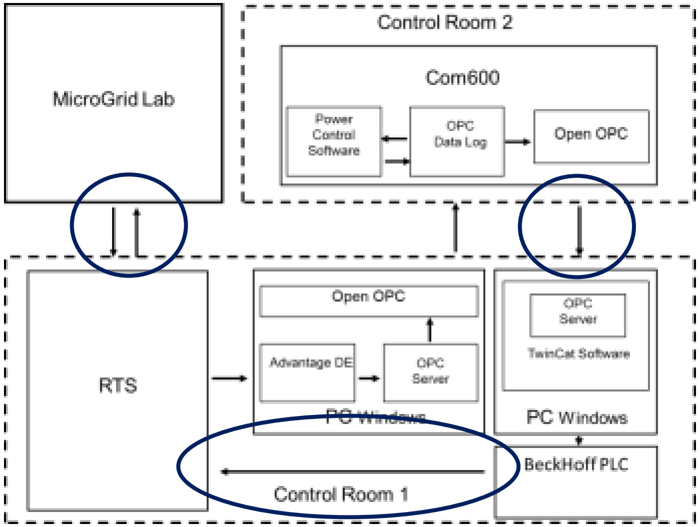
The control software reads them, through the OPC server, and sends the control signals back through the RTS.



Experimental work and results

The sensors installed on the microgrid and the data acquisition system guarantee a precision of 2.14% in the measurement of voltage and current magnitude, and consequently a precision of 4.5% in measuring the power flow. This level of precision is considered in literature enough to simulate the real operating conditions of an energy management system on a low voltage network.

In order to show the effect of the uncertainty of the data on the performance of the ANM software a series of tests were executed on the microgrid.

The induction machines located at buses 4, 5, 6 and 7 were set to compensate the load requested on the buses 4 and 5. Thermal constraints were set in the branches 1 and 3 by reducing the limits within the PFM software and microgrid network model.

Experimental work and results

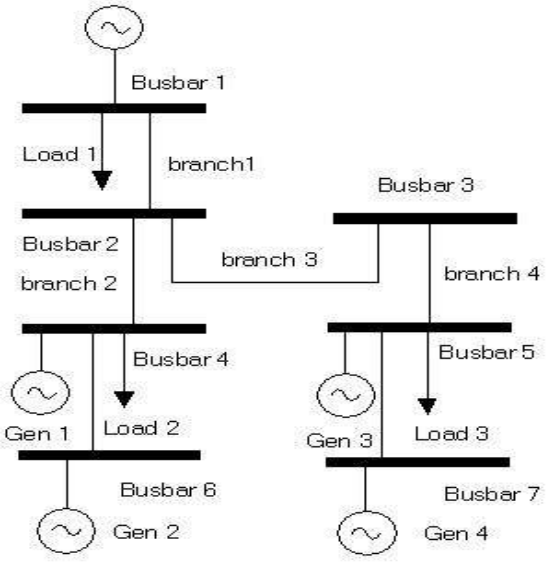
The generator access priorities were assigned to represent a LIFO connection arrangement.

Gen 1 was set to 1

Gen 3 was set to 2

Gen 2 was set to 3

Gen 4 was set to 4
(i.e. this unit would be the
first to be curtailed if a thermal breach was
detected).



Then, progressively, the loads were reduced to zero starting with the load on busbar 5.

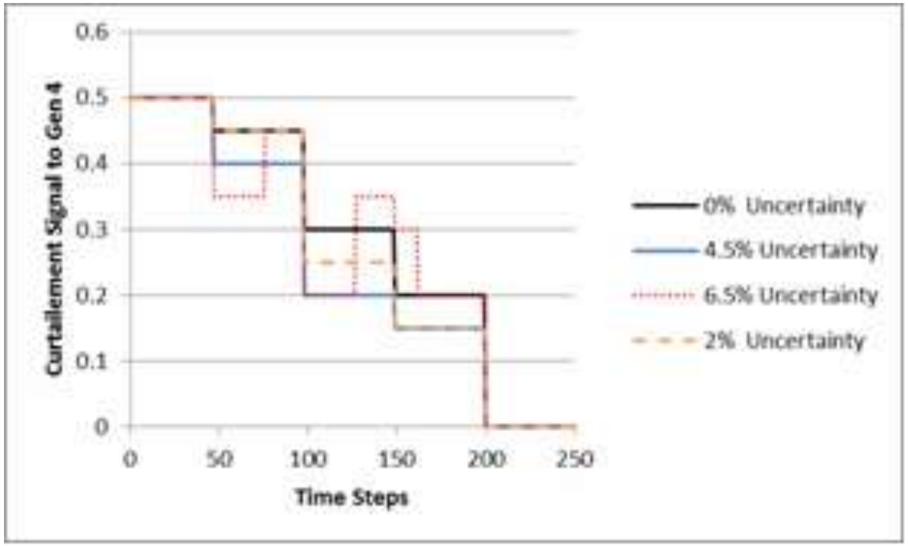
This caused a rising power flow through the branches 1 and 3, and a consequent thermal constraint violation.

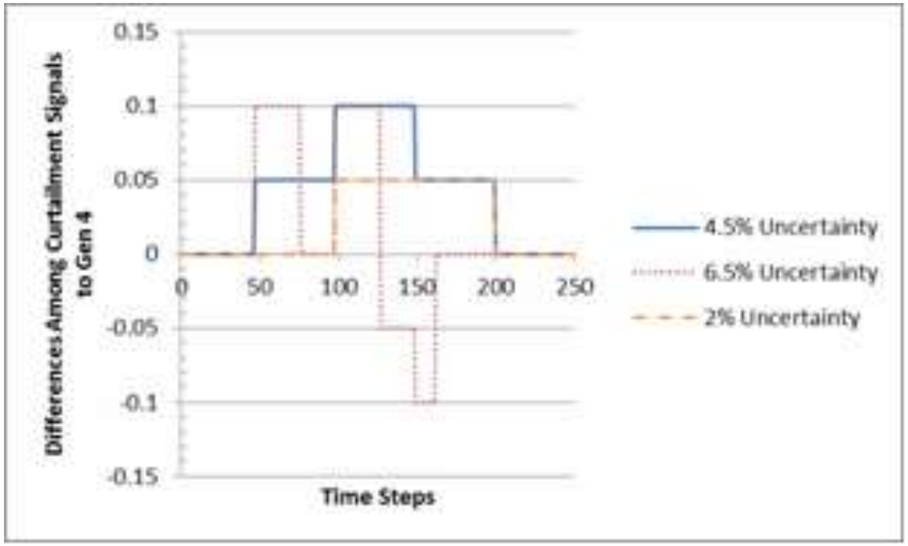
Experimental work and results

The response of the ANM function, for this scenario, was evaluated against the following data sets:

- An initial clean set of input data without any uncertainty
- A set of data as collected from the grid (with an uncertainty of 4.5%)
- A set of data in which the uncertainty of the loads and the machines power flow was artificially increased to 6%
- A set of data as calculated by a state estimator that reduces the uncertainty to 2%

Experimental work and results





The different control signals sent by the ANM to curtail the power output of the generator on busbar 7, Gen 4, in presence of different levels of uncertainty

The differences between the control signals (relative to the base case with no uncertainty) sent in presence of uncertainty

Experimental work and results

The analysis found that no divergence of the load flow engine was encountered when erroneous measurements, up to 6.5%, were presented to the ANM software.

However, with data uncertainty it can be seen that the error, in some situations, is large enough to either move the curtailment to a deeper set point (next domain value for the variable) or not curtail sufficient levels of DG.

The studies have also highlighted the importance of the reduction in uncertainty, for example through the use of a SE.

The uncertainty of the input data is reflected in the uncertainty of the final power flow calculation, so the operators taking in account of the uncertainty reduction introduced by a SE can adopt less conservative thermal detection limit to compensate for expected errors.