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Engineering



EMRP

European Metrology Research Programme
• Programme of EURAMET
The EMRP is jointly funded by the EMRP participating countries
within EURAMET and the European Union



Sensitivity Analysis of Sensor Networks for Distribution Grids

Paul Clarkson, Alberto Venturi, Alistair Forbes, Xin-She
Yang, Paul Wright, Andrew Roscoe, Graeme Burt

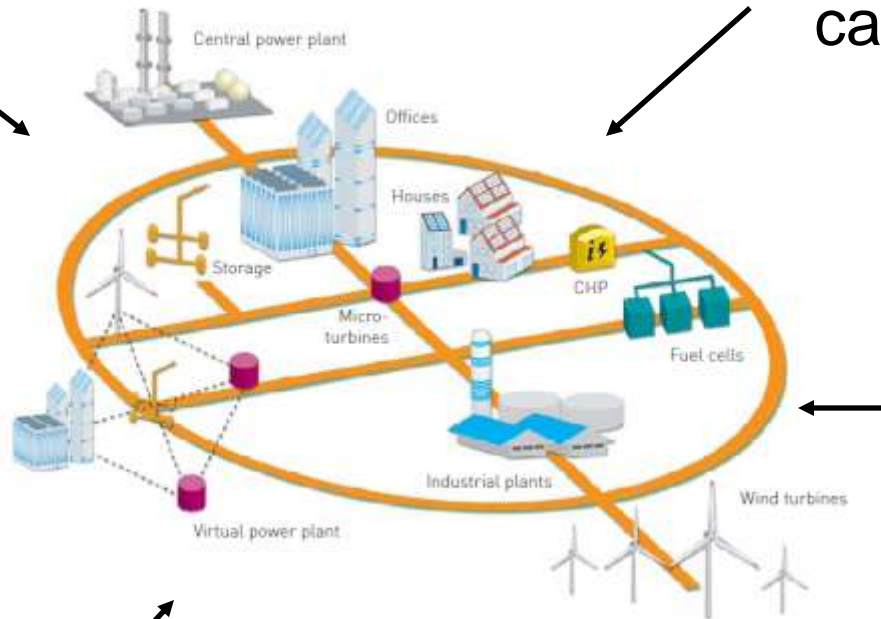
26 June, 2013

Sensor Coverage in Electricity Networks

How to handle
Too much data ?

Which sensors
can be removed ?

How many
Sensors are
Needed ?



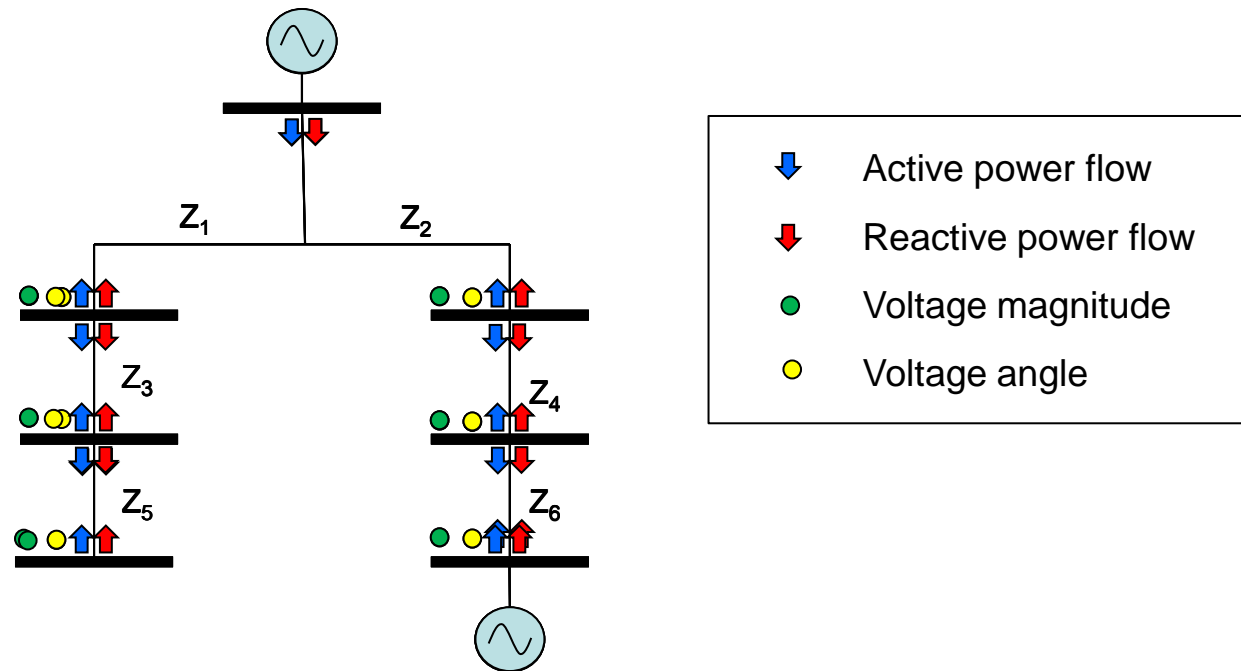
What
happens
when a given
sensor fails ?

Estimate unknown
Cable impedances

How accurate
Should a given
Sensor be ?

State estimation

- From limited power flow and voltage measurements derive voltage magnitudes and angles at each bus
- Derive power flow at every node in the network from estimated impedances and calculated voltages.



Sensitivity Analysis



Suppose the state estimation problem is given as

$$\min_{\mathbf{x}} (\mathbf{z} - H\mathbf{x})^T (\mathbf{z} - H\mathbf{x}) \quad \text{Subject to: } E\mathbf{x} = \mathbf{y}$$

Where:

\mathbf{x} are the parameters to be estimated

H is a (linearized) observation matrix

E is a constraint matrix

\mathbf{z} and \mathbf{y} are vectors storing measured data values

The solution depends linearly on \mathbf{y} and \mathbf{z} : $\mathbf{x} = S_z \mathbf{z} + S_y \mathbf{y}$

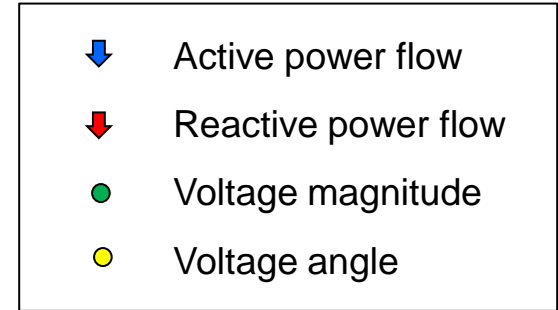
And the variance matrix is:

$$V_{\mathbf{x}} = S_z V_z S_z^T + S_y V_y S_y^T$$

(\mathbf{z} and \mathbf{y} supposed uncorrelated)

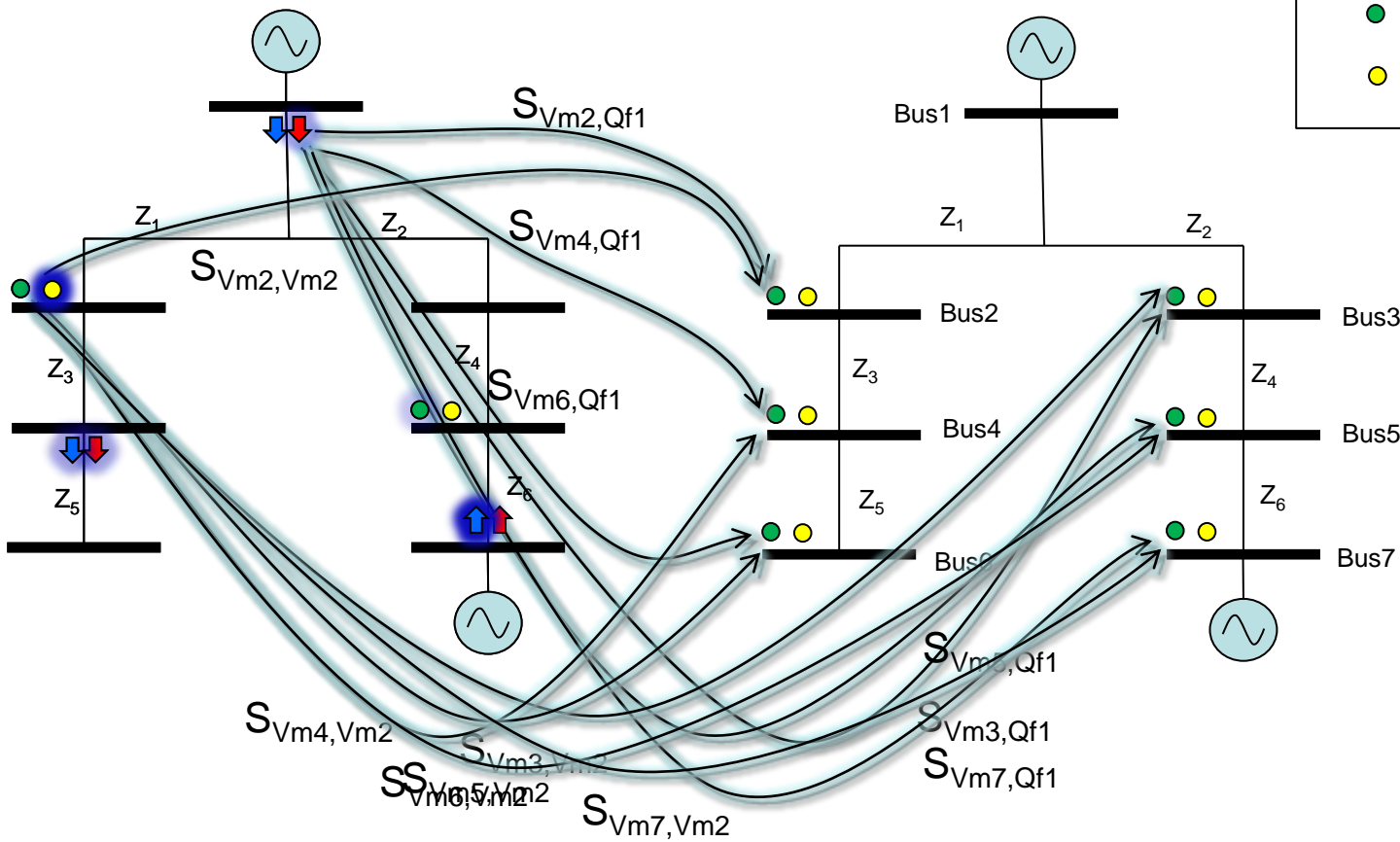
The matrices S_z and S_y show precisely how the uncertainties associated with the data vectors \mathbf{z} and \mathbf{y} contribute to the uncertainties associated with the parameter estimates \mathbf{x} .

Sensitivity analysis



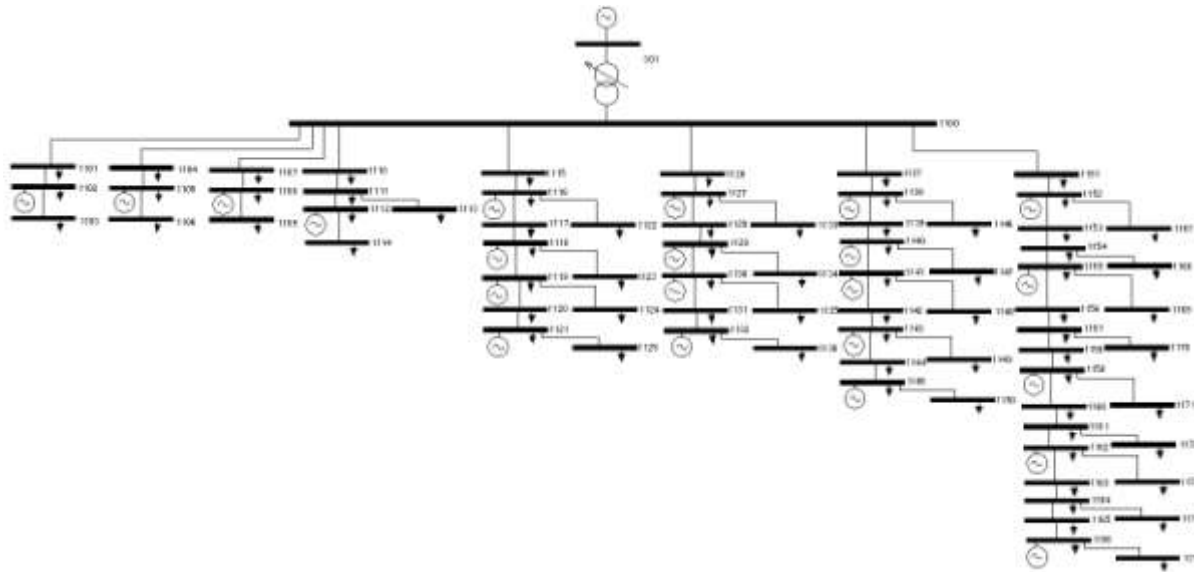
Measurements

Estimates

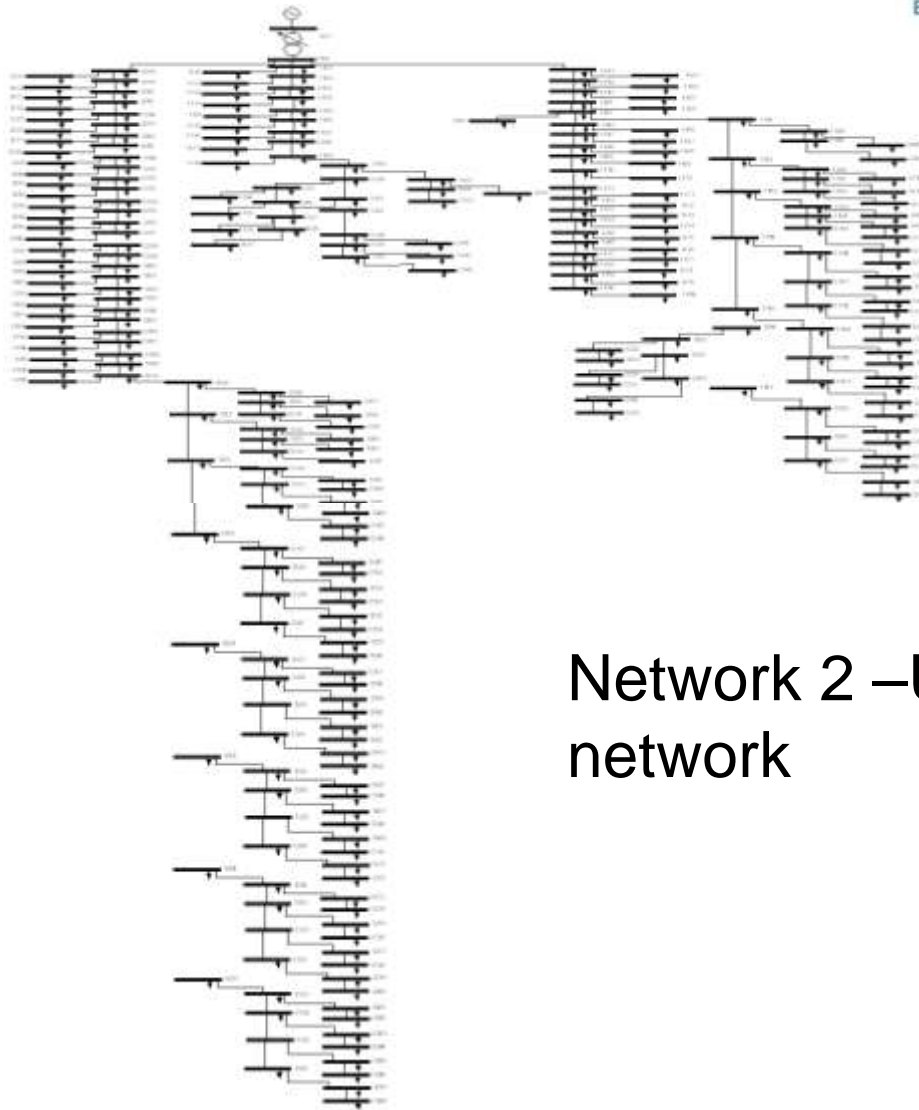


Example simulated networks

Network 1 – United Kingdom Generic Distribution System (UKGDS) 77 bus network



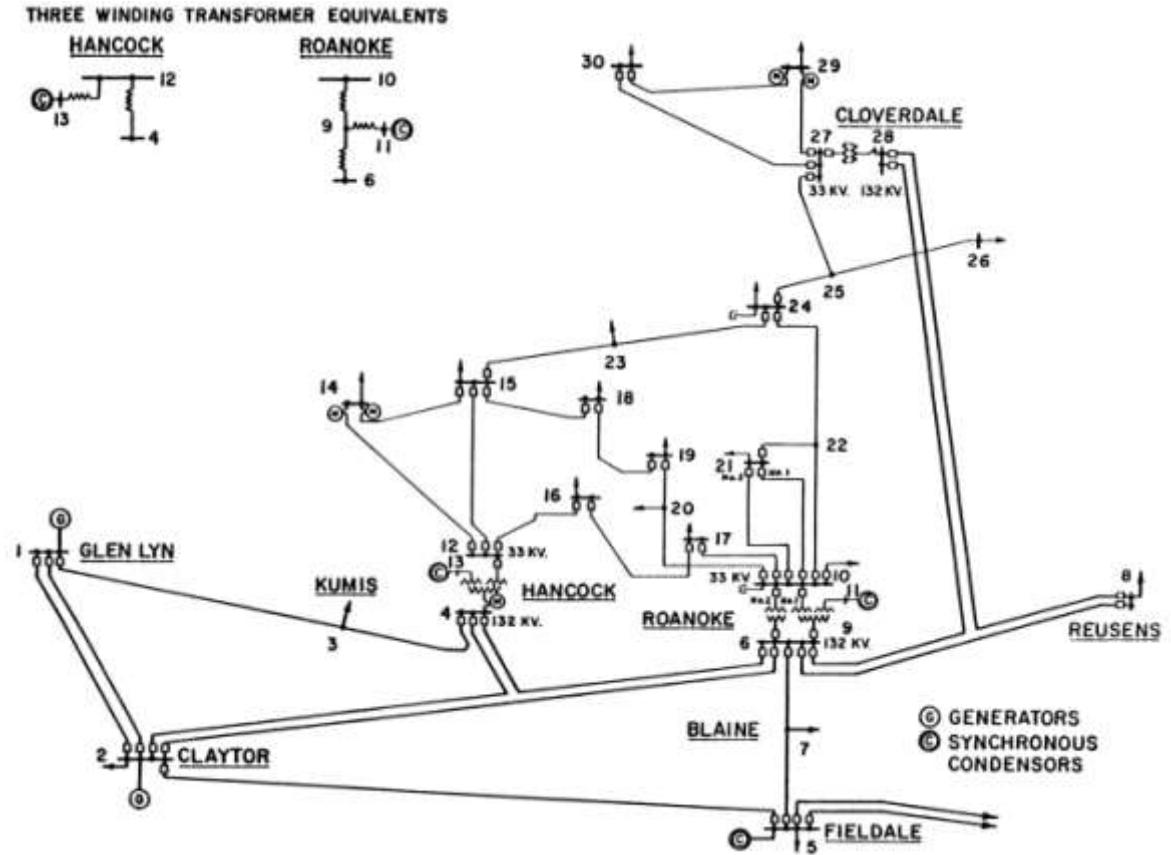
Example simulated networks



Network 2 –UKGDS 290 bus network

Example simulated networks

Network 3 – IEEE
30 bus system



Example simulated networks

Network 4 – IEEE 300 bus system

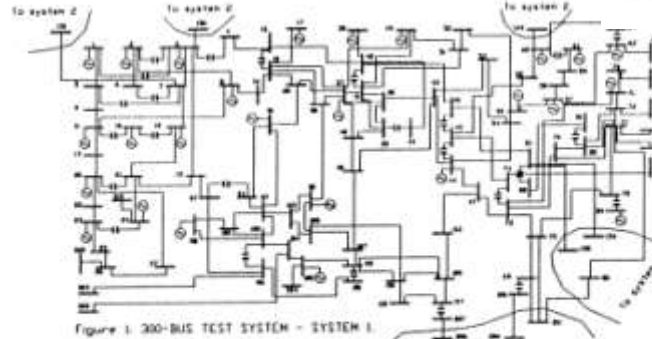


Figure 1. 300-BUS TEST SYSTEM - SYSTEM 1.

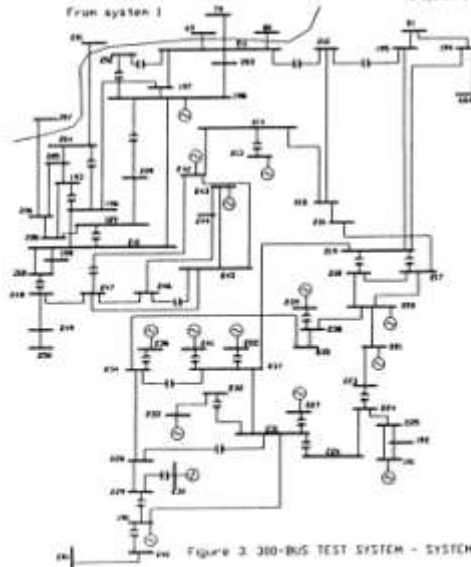


Figure 3. 300-BUS TEST SYSTEM - SYSTEM 3.

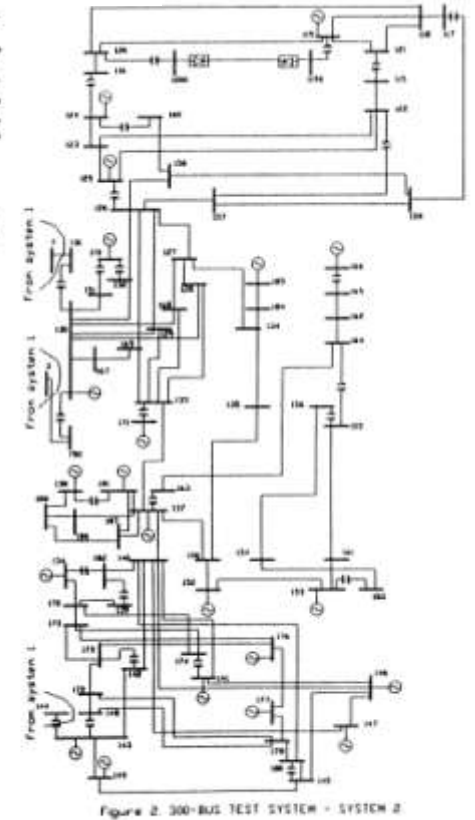
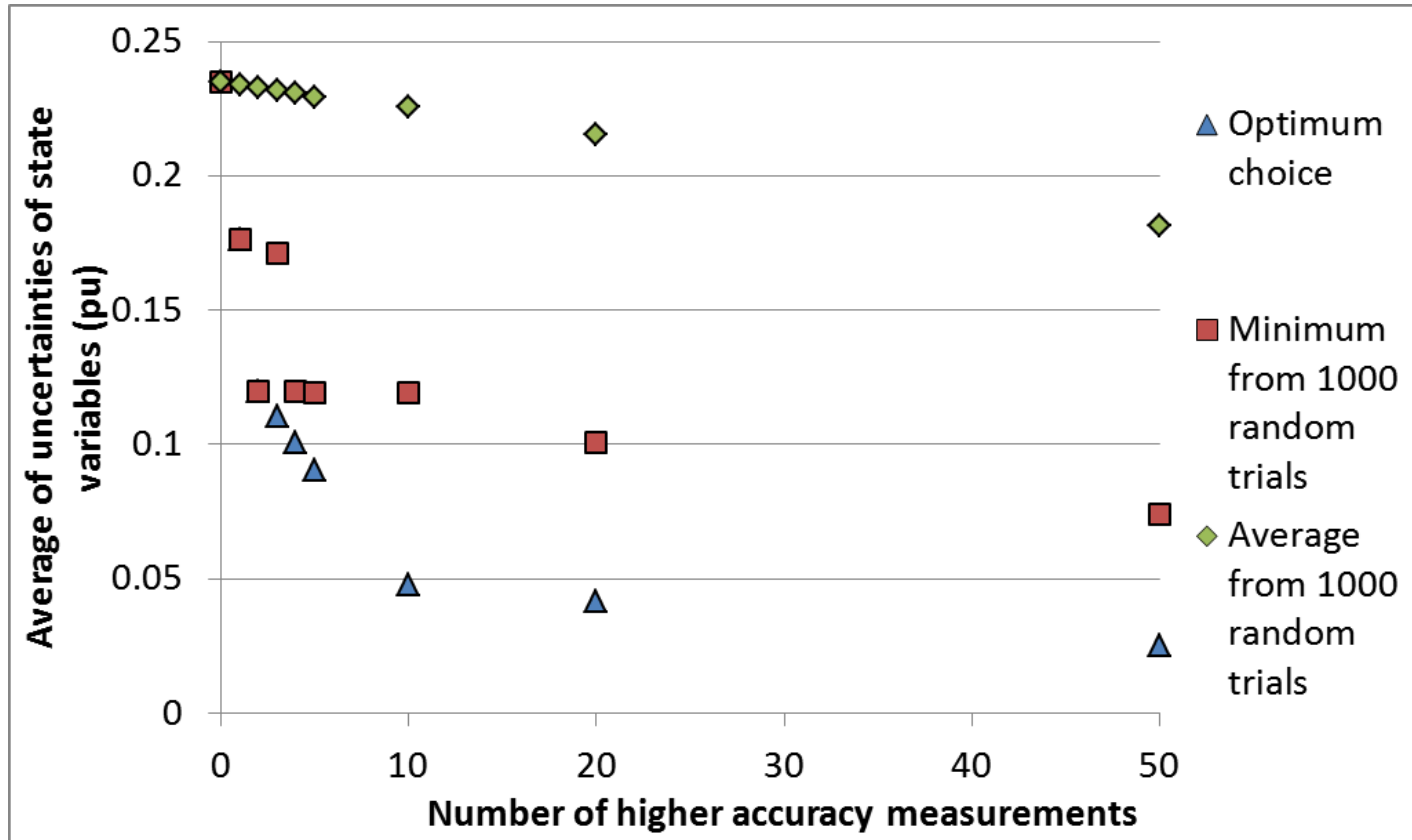


Figure 2. 300-BUS TEST SYSTEM - SYSTEM 2.

Choosing optimum measurement locations using sensitivity analysis

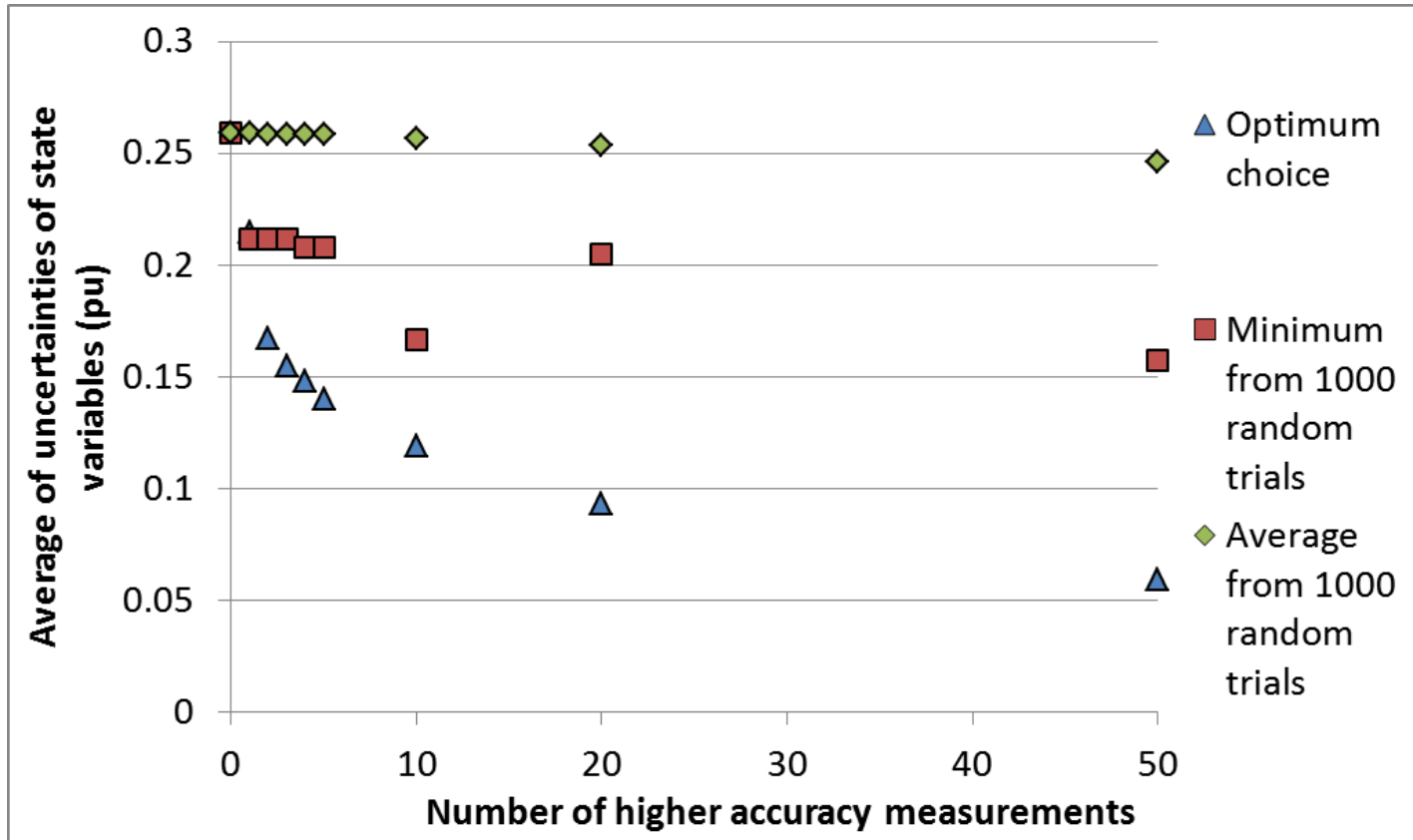
Network 1



Choose positions of high accuracy “real” measurements and low accuracy “pseudo” measurements

Choosing optimum measurement locations using sensitivity analysis

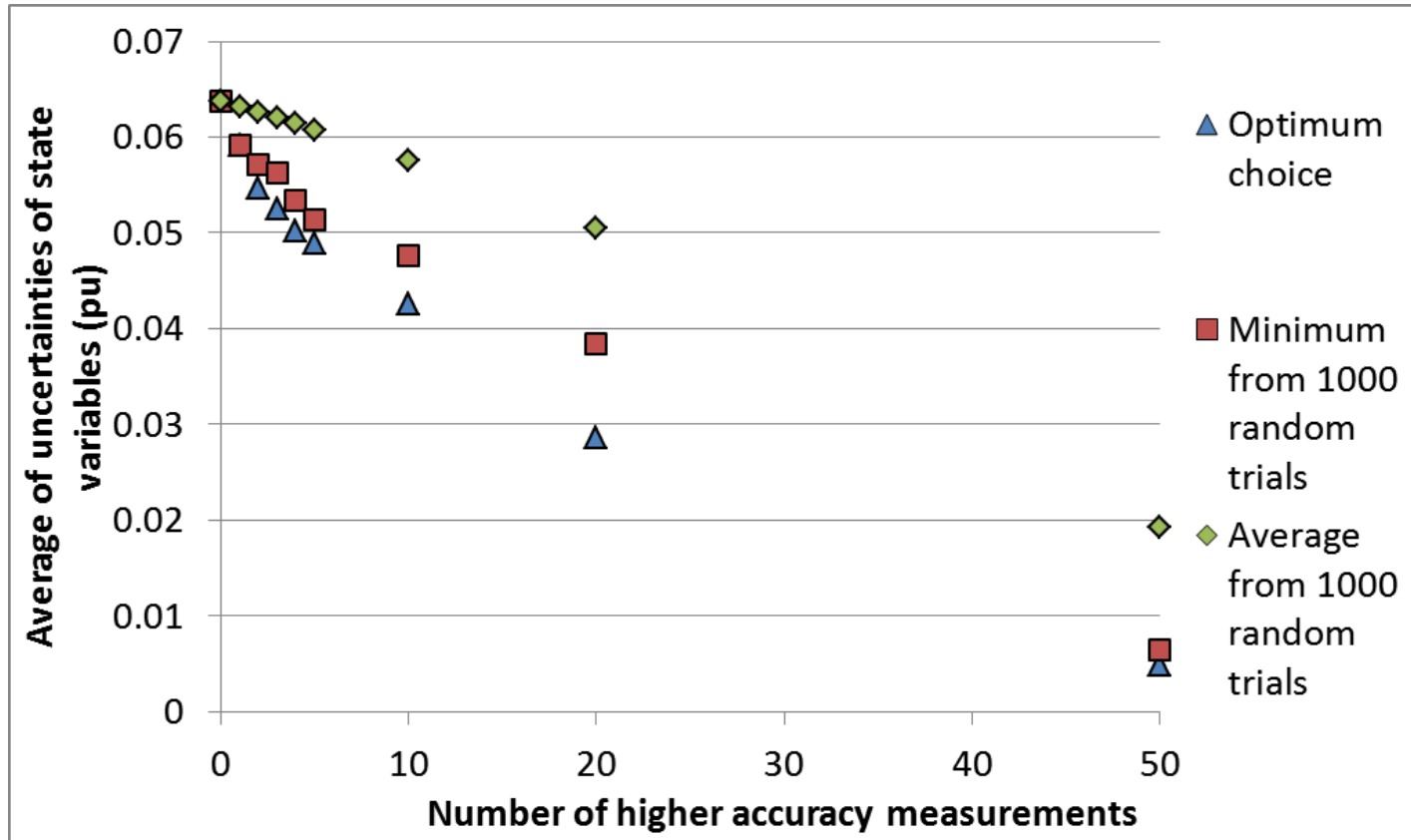
Network 2



Choose positions of high accuracy “real” measurements and low accuracy “pseudo” measurements

Choosing optimum measurement locations using sensitivity analysis

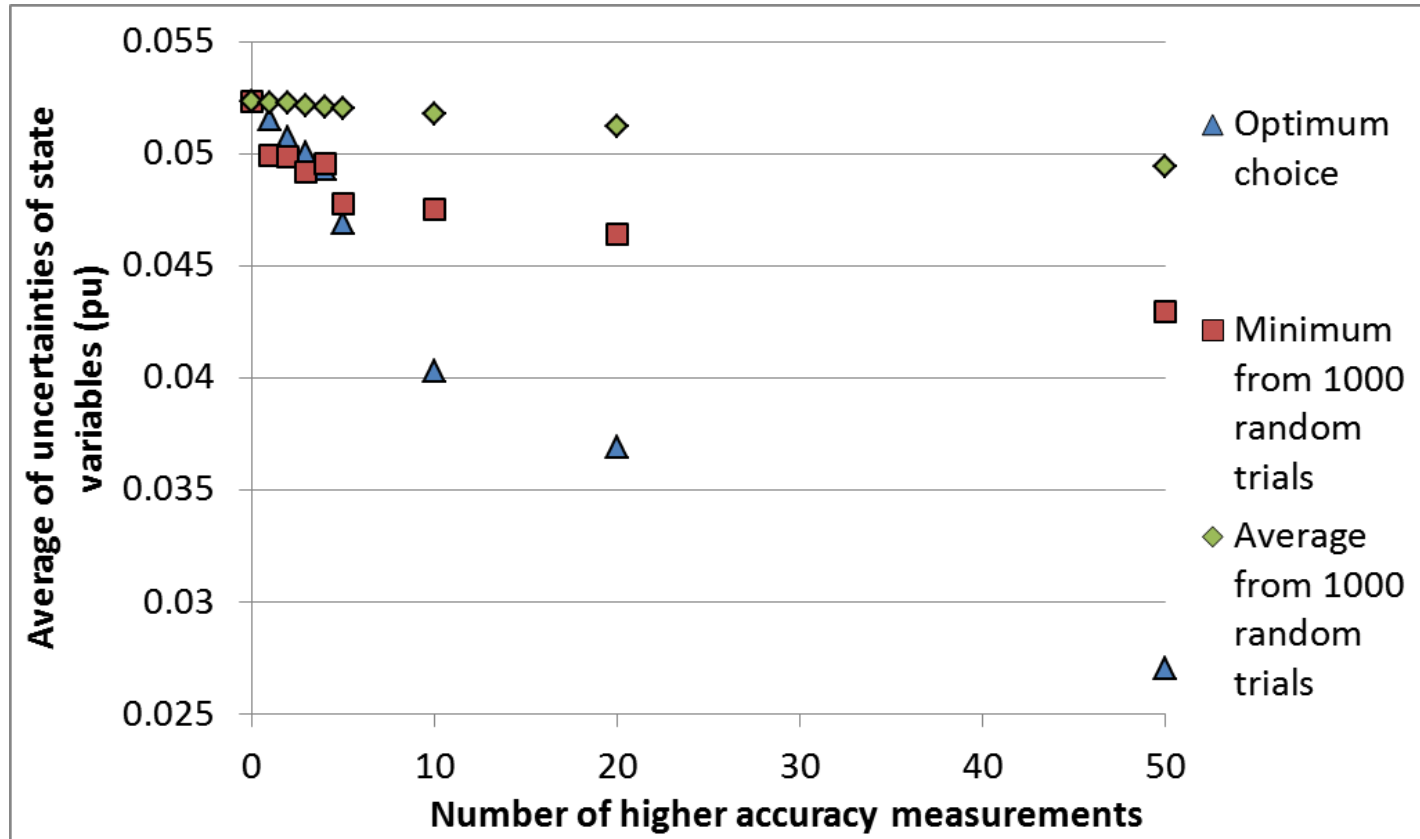
Network 3



Choose positions of high accuracy “real” measurements and low accuracy “pseudo” measurements

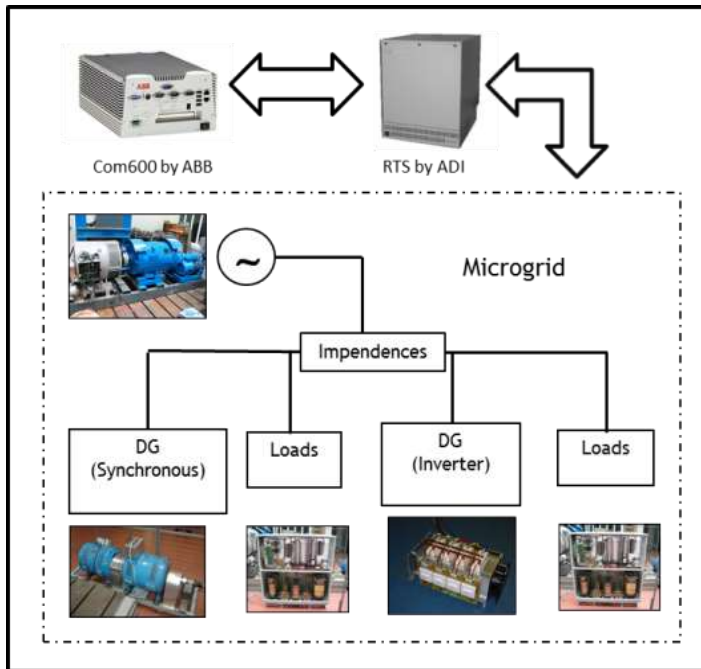
Choosing optimum measurement locations using sensitivity analysis

Network 4

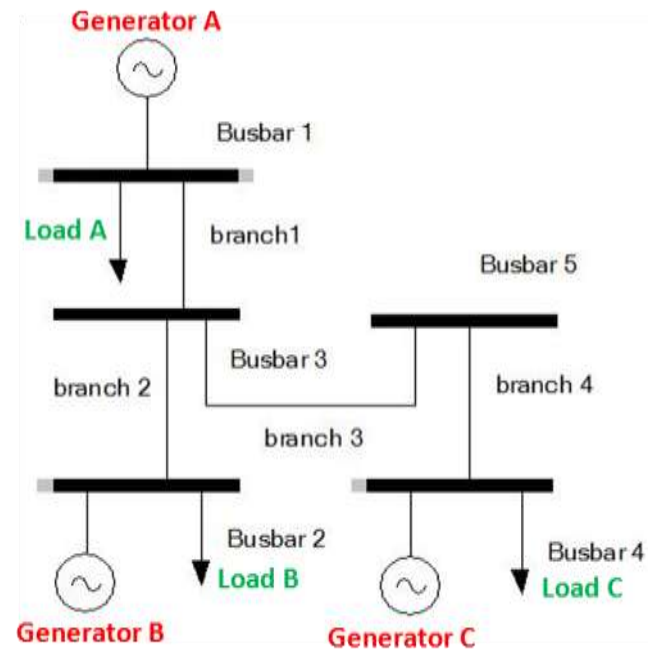


Choose positions of high accuracy “real” measurements and low accuracy “pseudo” measurements

University of Strathclyde experimental smart-grid

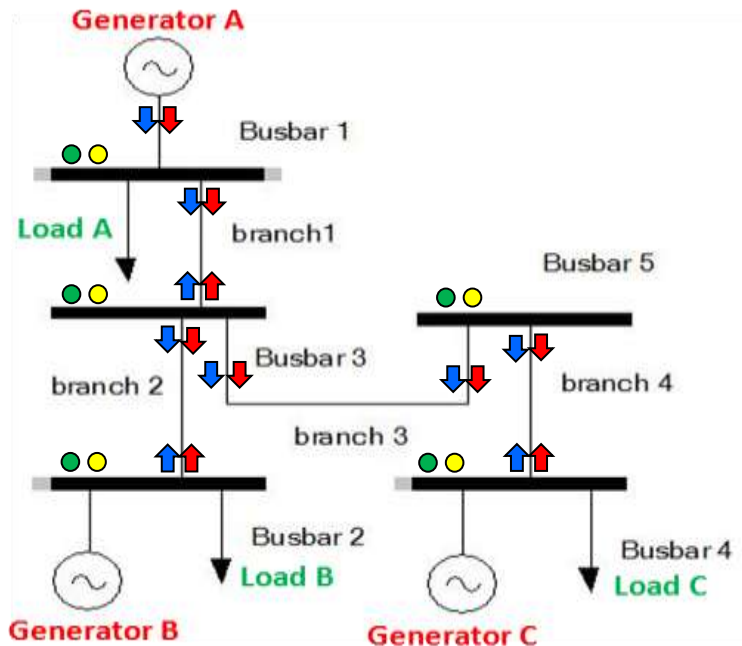


Control system



Network model

Testing on microgrid



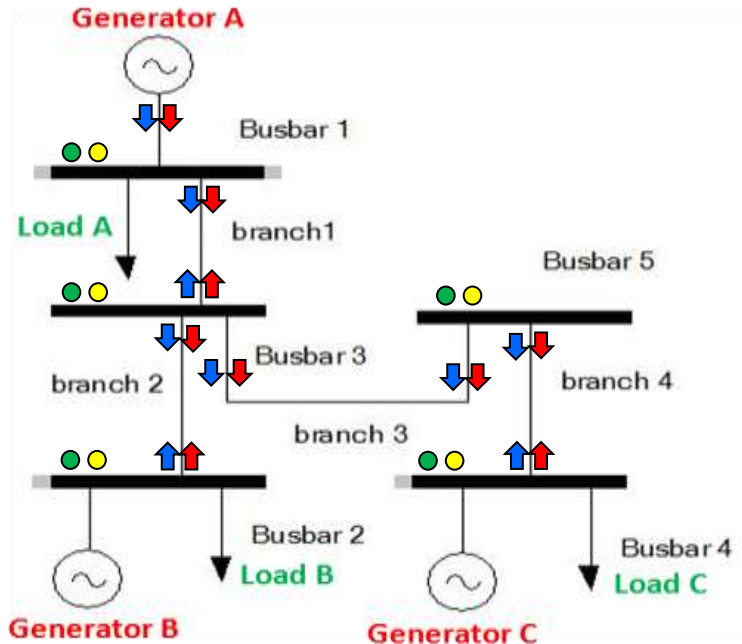
Start with fully instrumented grid

- ↓ Active power flow
- ↓ Reactive power flow
- Voltage magnitude
- Voltage angle

Apply state estimation → Measurement error

Apply sensitivity analysis → Measurement uncertainty

Testing on microgrid



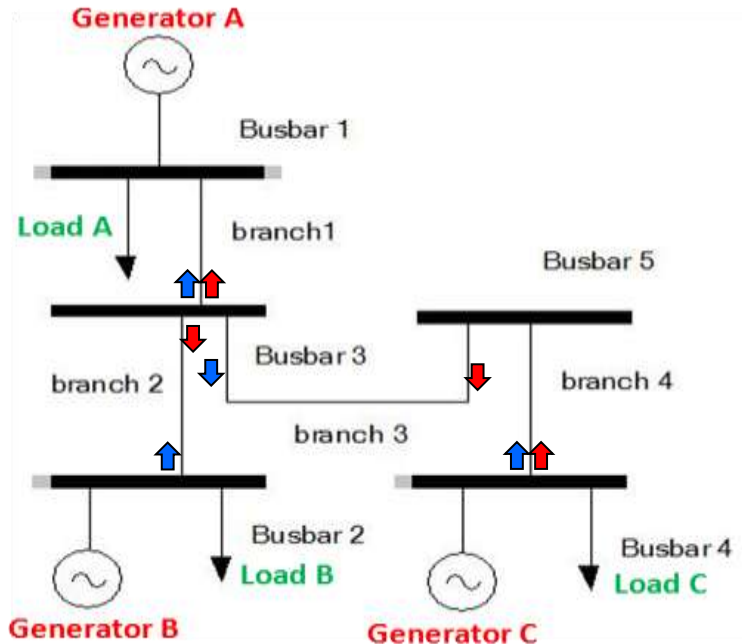
Start with fully instrumented grid

- ↓ Active power flow
- ↓ Reactive power flow
- Voltage magnitude
- Voltage angle

Average measurement error of 1.7 %

Average state variable uncertainty of 0.4 %

Testing on microgrid



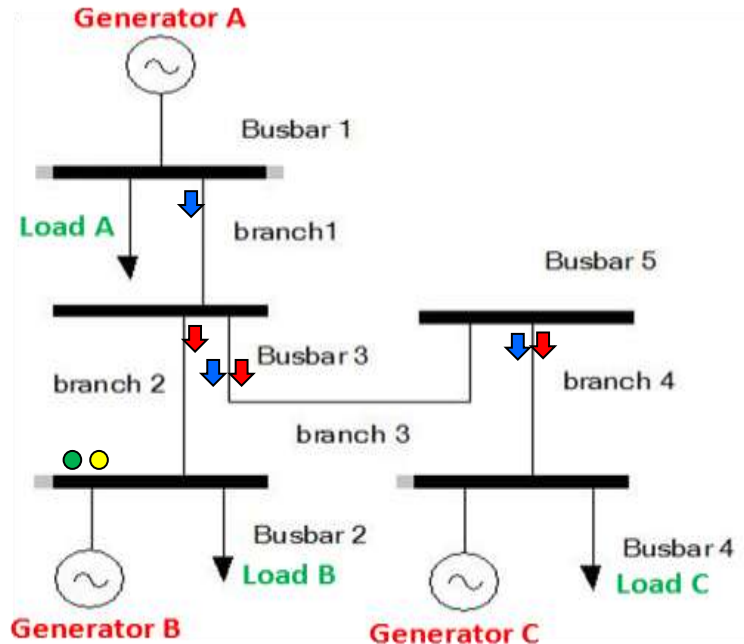
Apply algorithm to find optimum minimum measurement set

- ↓ Active power flow
- ↓ Reactive power flow
- Voltage magnitude
- Voltage angle

Average measurement error of 1.0 %

Average state variable uncertainty of 0.7 %

Testing on microgrid



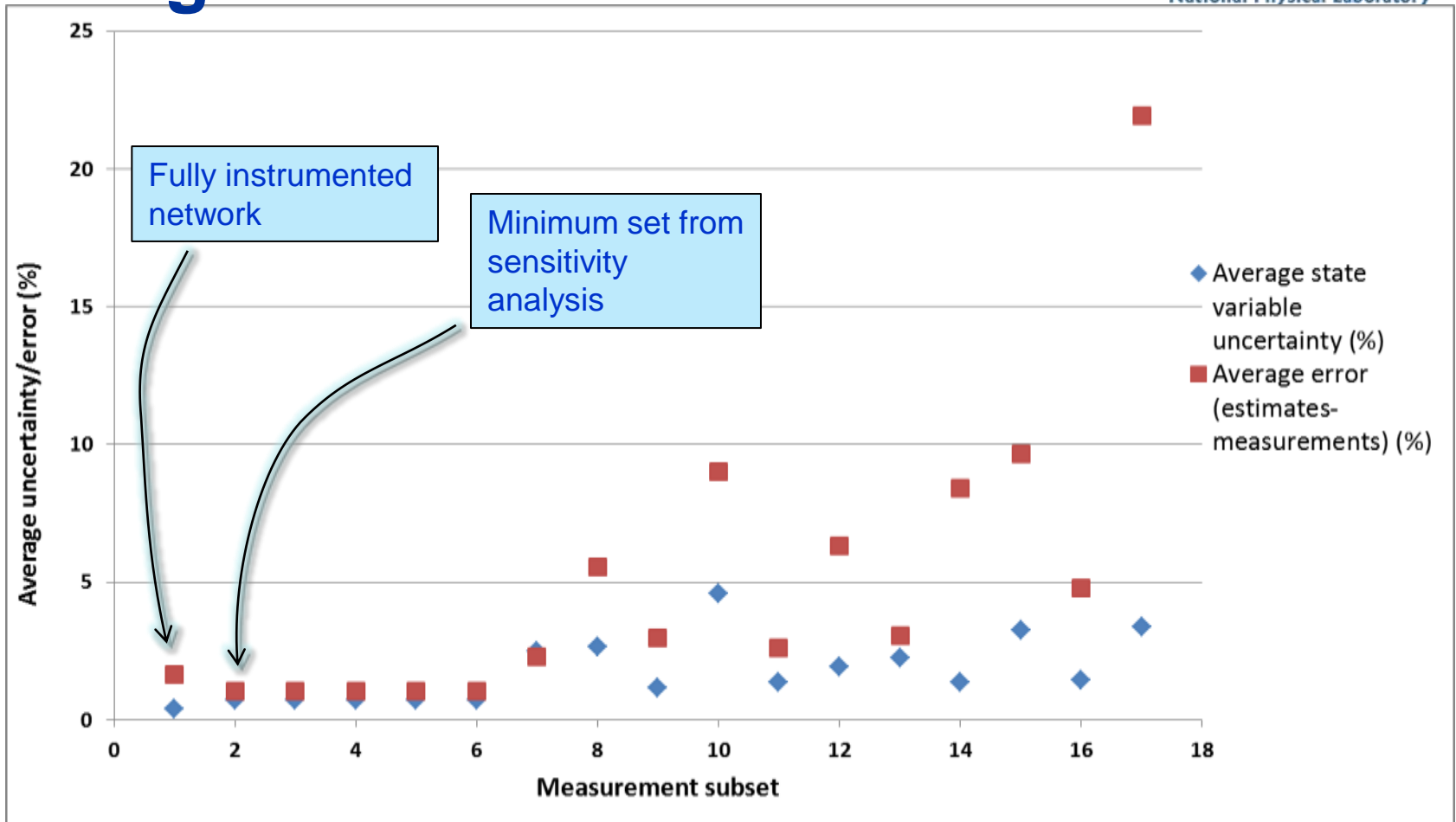
Compare with random selection of measurements

- ↓ Active power flow
- ↓ Reactive power flow
- Voltage magnitude
- Voltage angle

Average measurement error of 3.1 %

Average state variable uncertainty of 2.2 %

Microgrid measurement errors



Comparison of measurement error and state variable uncertainty

Summary



- Successfully modelled Strathclyde microgrid in MATLAB
- Applied state estimator to Strathclyde microgrid and larger simulated networks
- Verified uncertainty calculations against monte-carlo calculations
- Expanded state estimator to include uncertain impedances in the network interconnections
- Verified state variable uncertainty calculations against real measurements

Next steps

- Improve speed of optimal measurement placement algorithm
- Sensitivity analysis with cable impedances included
- Apply techniques to estimate line impedances
- Expand to include unbalanced networks
- Test with distributed generation included
- Investigate use of PMU and smart meter data.
- Try on full size real networks – need to engage with DNO