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The role of accurate measurements within smartgrids

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SMART GRID METROLOGY

Smart Grid Metrology, European research project

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Introduction

The necessity of developing alternatives to fossil combustibles as energy sources is increasingly leading towards non-conventional, renewable and distributed generation systems.

To manage the transition from the present centralized grid to the future active systems consisting of multiple bi-directional energy clients it is necessary to extend the measurement systems to LV grids.

Currently limited instrumentation is installed in the medium-voltage (MV) and low-voltage (LV) distribution levels of most networks.

Introduction

Better observability of the power network at the distribution level will be required to understand the power flows in the grid.

The necessity of reducing not only the installation cost of new monitoring and metering but also the amount of data to handle and to interpret, leads to a desire to optimize the amount, type and placement of monitoring equipment

Using measurements taken from the 100-kVA micro-grid installed at Strathclyde University and software simulations, this paper will report the sensitivity of these simulations to different amounts, placements, types and accuracy of monitoring instrumentation, and the resulting impact on the accuracy of the state estimator technique applied.

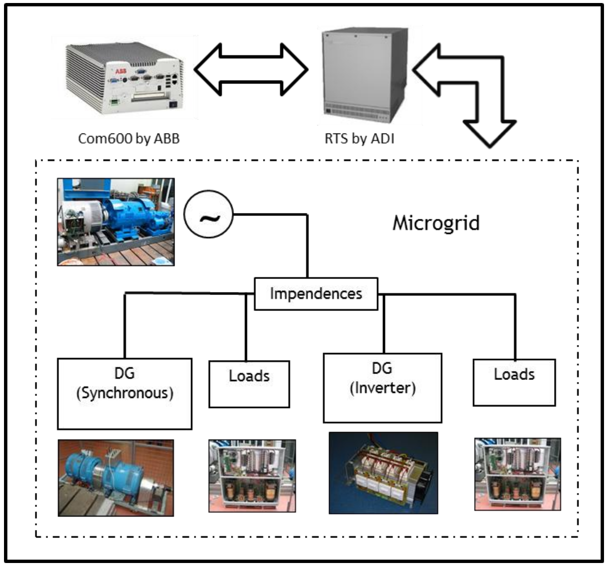
Distribution State Estimators

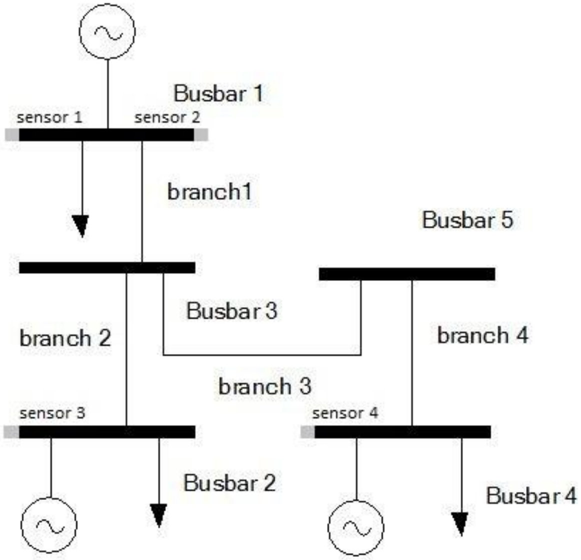
Distribution state estimation techniques are different with respect to transmission state estimation techniques: the former ones have been developed to make up for the lack of measured data at LV level, while the latter ones to reduce the uncertainty of the redundant measurements available at HV

The state estimators will be populated with real measured data from the microgrid, using sparse measurements as well as prior information (such as nominal values for line parameters).

The results of the state estimators will be compared with real measurements from the smartgrid and the flow analysis results.

Strathclyde Experimental Microgrid





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 to identify a strategy to optimize the location, number and accuracy of the measurement points to enable effective network control

Sensitivity Analysis

Suppose the state estimation problem is given as

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

Where:
x are the parameters to be estimated
H is a (linearized) observation matrix
E is a constraint matrix
z and **y** are vectors storing measured data values

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

And the variance matrix is:
(**z** and **y** supposed uncorrelated)

$$V_{\mathbf{x}} = S_{\mathbf{z}} V_{\mathbf{z}} S_{z}^{\mathrm{T}} + S_{\mathbf{y}} V_{\mathbf{y}} S_{\mathbf{y}}^{\mathrm{T}}$$

Sensitivity Analysis

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

The residual vector is:

$$\mathbf{r} = \mathbf{z} - H\mathbf{x} = f(\mathbf{z}, \mathbf{y}, H, E)$$

Applying an adequate transformation to **z** and **y** so that their corresponding variance matrices are identity matrices, with the hypothesis of accurate constraint data **y**, it can be shown that, said $u^2(r_i)$ the variance associated with the i_{th} residual:

$0 \leq u(r_i) \leq 1 = u(z_i)$

Sensitivity Analysis

$0 \leq u(r_i) \leq 1$

if $u(r_i) = 0$ the i_{th} model prediction must match the i_{th} observation z_i exactly.
z_i is pivotal and removing that data point would lead to rank deficiency. if the measured value was an outlier due to sensor malfunction, for example, there would be no way of detecting that was defective

if $u(r_i) = 1$ the i_{th} observation plays no part in determining the i_{th} model prediction

Experimental Work

Power flow analysis provides missing information because the micro-grid is not yet fully instrumented.

For the experimental work four different scenarios have been considered: “machine”, “load”, “BUS2”, “BUS4”.

The variance of the residual, $u^2(r_i)$, was calculated for each input and indicates the importance of the input parameter to the observability of the solution.

By eliminating the elements with a high value of this index, the network still remains observable and the difference between the estimated values and the real ones remains low.

Experimental Work: Load Scenario

The SE was first run with a complete set of information to determine $u^2(r_i)$ for each input parameter.

A 1 % uncertainty was assigned to each data point, such that the measurements were given equal weighting by the SE.

Bus/branch index	P_F (kW)	P_T (kW)	P_G (kW)	V_a (°)	Q_F (kW)	Q_T (kW)	Q_G (kW)	V_m (V)
1	13.9300	-13.9136	23.2286	0.000	0.0339	-0.0324	-0.0008	428.82
2	6.5394	-6.4798		-0.502	-0.0315	0.0873		424.45
3	7.3742	-7.3696		-0.006	0.0638	-0.0634		428.32
4	7.3696	-7.2939		-0.562	0.0634	0.0076		423.64
5				-0.010				428.05

Experimental Work: Load Scenario

The SE was first run with a complete set of information to determine $u^2(r_i)$ for each input parameter.

A 1 % uncertainty was assigned to each data point, such that the measurements were given equal weighting by the SE.

Bus/branch index	P_F	P_T	P_G	V_a	Q_F	Q_T	Q_G	V_m
1	0.5762	0.5772	0.8467	1.0000	0.6153	0.6060	0.7785	1.0000
2	0.5509	0.5593		1.0000	0.2938	0.5961		1.0000
3	0.4997	0.5003		1.0000	0.5014	0.4986		1.0000
4	0.6032	0.6115		1.0000	0.5479	0.2375		1.0000
5				1.0000				1.0000

Experimental Work: Load Scenario

Voltage measurements, reactive and reactive generator power, P_G and Q_G, and reactive power Q_F, were removed and the analysis was repeated.

The minimum number of measurements for observability is eight, but if either of the input measurements P_F1 or P_F3 are removed, the system is not observable.

Bus/branch index	P_F	P_T	P_G	V_a	Q_F	Q_T	Q_G	V_m
1	0.0003	0.5058				0.4939		
2	0.1999	0.2642				0.5359		
3	0.0000	0.5014				0.4986		
4	0.3559	0.4494				0.1948		
5								

Experimental Work: Load Scenario

Now nine measurements are provided for the SE.
The sensitivity analysis shows that only certain measurements can be removed: P_T4, Q_F4 or Q_T4 while still retaining observability.

Removing any of the other data points leads to the system being unobservable.

Bus/branch index	P_F	P_T	P_G	V_a	Q_F	Q_T	Q_G	V_m
1		0.0000				0.0000		
2		0.0000			0.0000			
3		0.0000				0.0000		
4		0.3559			0.4494	0.1948		
5								

Experimental Work: Machine Scenario

The SE was first run with a complete set of information to determine $u^2(r_i)$ for each input parameter.

A 1 % uncertainty was assigned to each data point, such that the measurements were given equal weighting by the SE.

Bus/branch index	P_F	P_T	P_G	V_a	Q_F	Q_T	Q_G	V_m
1	0.6666	0.6668	0.6666	1.0000	0.6667	0.6667	0.6667	1.0000
2	0.5007	0.4993		0.9999	0.4991	0.5010		0.9999
3	0.4998	0.5002		1.0000	0.5000	0.5000		1.0000
4	0.4973	0.5031		0.9998	0.5028	0.4972		0.9998
5				1.0000				1.0000

Experimental Work: Machine Scenario

The voltage magnitudes and angles are shown to have little impact on the solution

At least two measurements in each branch are required.

Bus/branch index	P_F	P_T	P_G	V_a	Q_F	Q_T	Q_G	V_m
1			0.0000				0.0000	
2	0.5007	0.4993			0.4991	0.5010		
3	0.4998	0.5002			0.5000	0.5000		
4	0.4972	0.5030			0.5027	0.4971		
5								

Conclusion

A model of the Strathclyde experimental microgrid has been developed and is now being studied and utilised to investigate optimal strategies for reliable grid state observation

A sensitivity analysis was applied to a SE using four different network load scenarios; the results were used to rank the input measurements in order of importance to the state estimate.

These rankings were shown to be reliable indicators of the importance of the measurements to the observability of the solution

Future work

A more objective rigorous procedure to select the optimum minimum set of measurements for reliable state estimation will be the object of further investigation.

Use of sensitivity analysis to assess the sensitivity of the state estimates to variations in the input measurement uncertainties.

It is hoped that the techniques developed on the micro-grid can be applied to real operating full-scale smart grids, but testing of this will require the cooperation of a DNO (distribution network operator).