Dynamic models of wind farms for power system studies – IEA Wind Annex 21

John Olav Tande

john.o.tande@sintef.no

Introduction

- Large scale wind farms may have a significant impact on grid stability.
- Numerical power system simulation tools are essential for predicting impact and pinpointing cost-effective solutions for secure operation.
- Dynamic models of wind farms for power system studies are at present not a standard feature of many software tools, but are being developed by research institutes, universities and commercial entities.
- Model development is not trivial, and model validation is essential.

- IEA Wind Annex 21 (2002-2006) is a means to aid the development through international collaboration.

- This presentation gives an overview of Annex 21 works; focus is in particular on benchmark testing of dynamic wind generation models.

IEA Wind R&D Annex 21 (2002-2006): Dynamic models of wind farms for power system studies

- Immediate objectives and activities:
  - International forum for exchanging knowledge and experience within the field of wind farm modeling for power system studies
  - Develop, describe, and validate wind farm models.
  - Set-up and operate a common database for benchmark testing of wind turbine and wind farm models as an aid for securing good-quality models.

- Partners:
  Risø (DK), VTT (FI), UCD (IE), ECN and TU Delft (NL), Chalmers (SE), UMIST (UK), NREL (USA), INETI (PT)
- Operating Agent: SINTEF Energy Research (NO)

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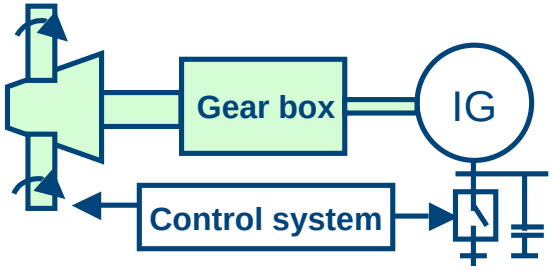
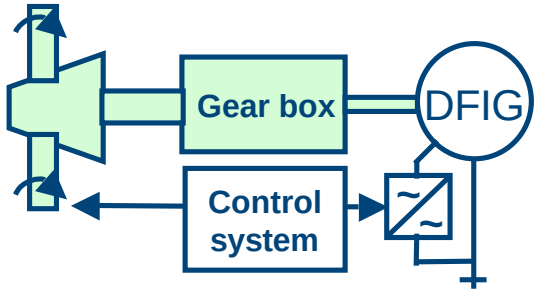
Modelling is not trivial

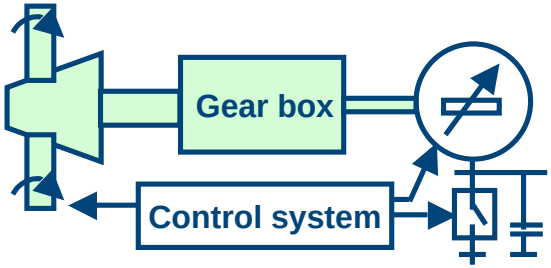
Fixed speed



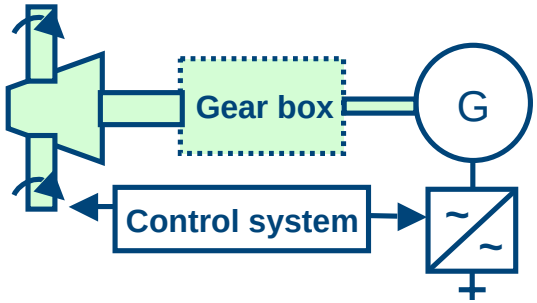
Doubly-fed IG



Variable slip



Full converter (IG/PM/SG)



Dynamic wind farm models

- Accurate simulation of wind farms relies on detailed modelling of the applied wind turbine technology, e.g. the dynamics of a fixed speed wind turbine may differ significantly from that of a variable speed wind turbine, but there will also be manufacturer specific variations.
- Wind farm models may be built to various level of detail ranging from one-to-one modelling to full aggregation.
- The one-to-one approach is computer demanding and in many cases not practical, hence aggregated wind farm models are often applied
- The aggregation is not trivial, i.e. considering that a wind farm may consist of hundreds of wind turbines distributed over a large area
- Aggregated models must therefore be applied with care. Possibly a cluster-by-cluster aggregation may constitute a fair approach.

Numerical simulation tools

- Model platform depends on scope of study

- PSS/E: power system simulation tool, used by TSOs, phasor models, good for analysis of large power systems
- SIMPOW and DIgSILENT: power system simulation tool, both phasor and instantaneous value models
- PSCAD (EMTDC): power system simulation tool, detailed instantaneous value models
- Matlab/Simulink: general simulation tool, mostly for research, models can be built to any level of detail

IEA Annex 21 measurement data base

- WT500 (Denmark); 500 kW wind turbine (fixed speed, stall controlled), measurements during normal operation.
- Alsvik (Sweden); 4x180 kW wind farm (fixed speed, stall controlled), measurements during normal operation and response to voltage dip.
- Olos (Finland); 5x600 kW wind farm (fixed speed, stall controlled), measurements during normal operation and response to voltage dip.
- Azores (Portugal); 4x100 + 1x150 kW wind farm (fixed speed, stall controlled), measurements during normal operation.
- DFIG850 (Sweden); 850 kW DFIG wind turbine (variable speed, pitch) measurements during normal operation and response to voltage dip.
- SimWT (Denmark); simulated response of fixed speed wind turbine on voltage dip (simulations in EMTDC and DIgSILENT).
- Smøla (Norway); 20x2 MW wind farm (fixed speed, active stall), measurements during normal operation and voltage dip.
- CART (USA) 600 kW full converter wind turbine (variable speed, pitch), measurements during normal operation and voltage dip.

IEA Annex 21 benchmark test procedures

Dynamic operation during normal conditions:

- Input:
  - Wind speed time series (and optionally voltage time series)
- Output:
  - Time series plot of active power output, reactive power, and voltage (optionally)
  - Power spectral density of active power output
  - Short-term flicker emission
  - Optionally plots of Q(U) and Q(P)

Response to voltage dip:

- Input:
  - Voltage time series and constant aerodynamic torque (or optionally wind speed time series)
- Output:
  - Time series plot of active and reactive power output
  - Time series of voltage at wind turbine terminals

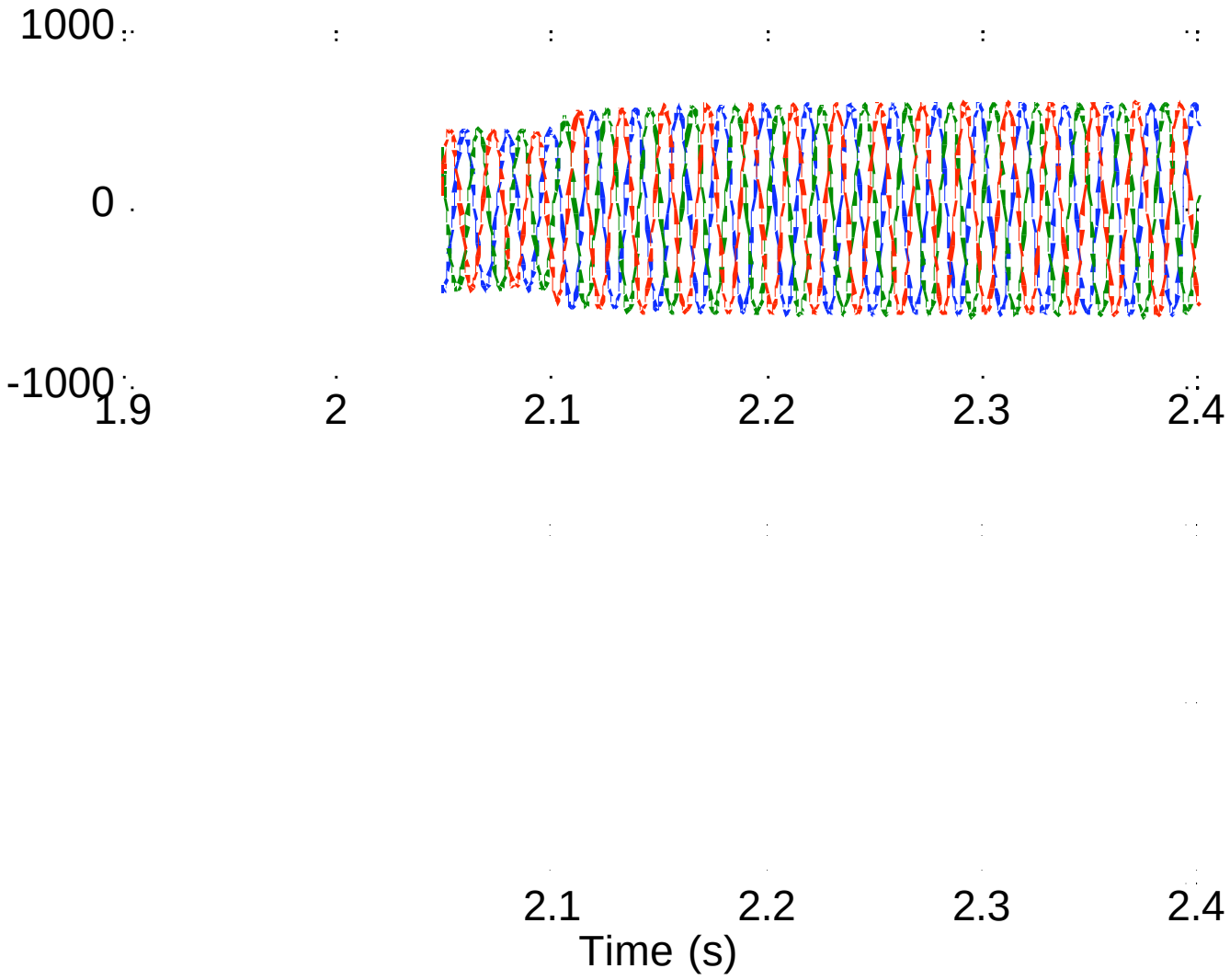
IEA Annex 21 benchmark test procedures

Transformation of measurement data:

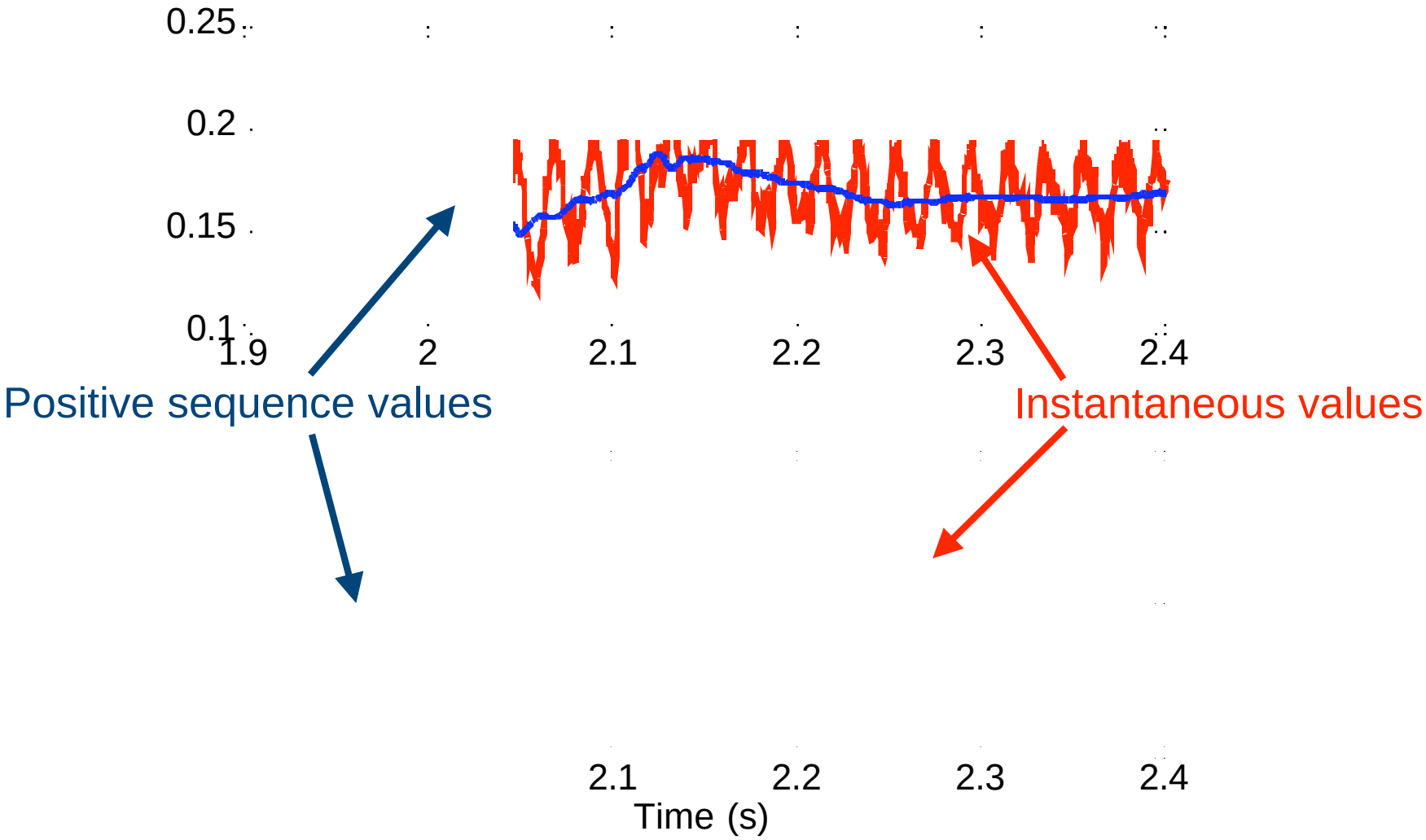
- The test data include three-phase measurements of instantaneous voltages and currents at the wind turbine or wind farm terminals.
- The benchmark test procedure includes transforming these measurements to fundamental positive sequence voltage and current phasors, and from these calculate the active and reactive power for comparison with simulation results.

- The reason for using the fundamental positive sequence values is twofold.
  - Firstly, perfectly balanced conditions can not generally be assumed, and events of voltage dips are often unbalanced.
  - Secondly, most power system simulator models are phasor-type models, meaning that the electrical variables (voltages and currents) are represented as positive sequence values.

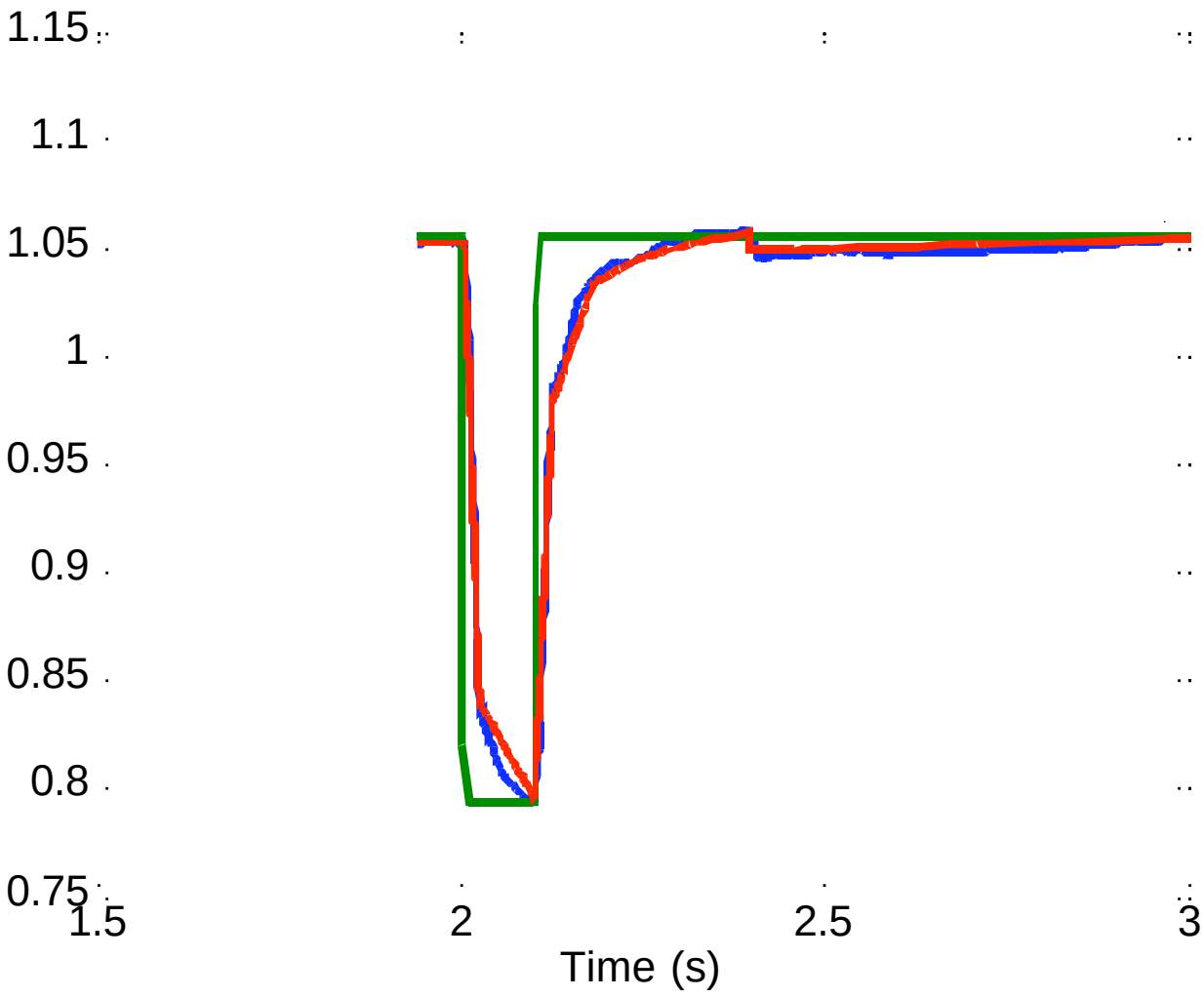
Measured voltage dip response DFIG wind turbine



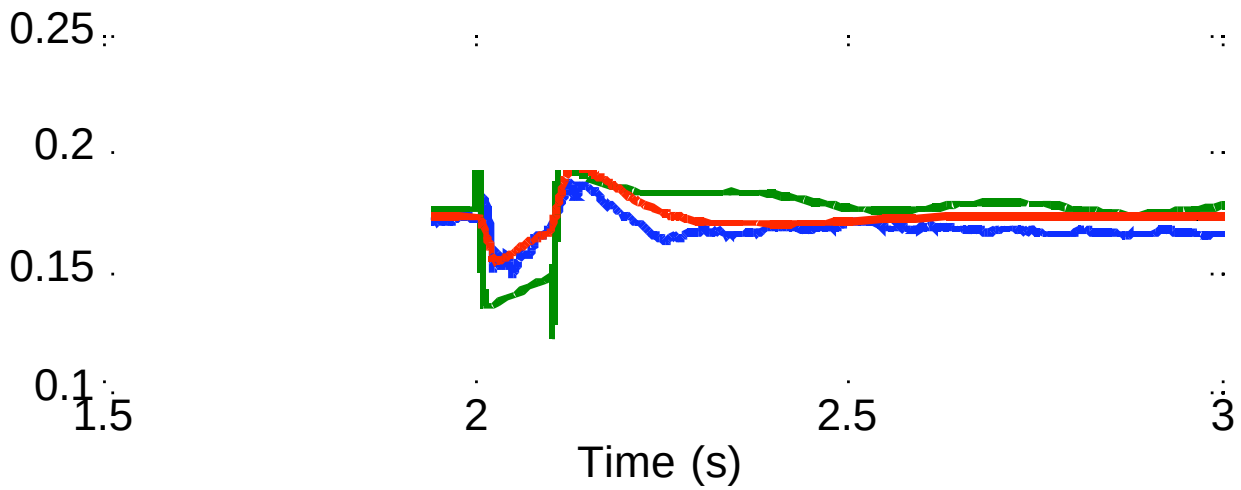
Measured voltage dip response
DFIG wind turbine



Measured (M) and simulated (I and J) voltage (pos. seq.)



Measured (M) and simulated (I and J) active and reactive power



Rounding up (1 of 2)

- In general the progress is good on model development.
- Models are available on various platforms (Matlab, PSSE etc), and the Annex participants take model validation seriously.
- The proposed benchmark test procedure and presentation of test results provide for a significant technical contribution by the Annex.
- The Annex is the first to present a systematic comparison of wind generation models (ten in total) against measurements.
- Test results give a clear indication of accuracy and usability of the models tested, and pin-point the need for both model development and testing.
- The IEA Annex 21 work will conclude by end 2006.

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Rounding up (2 of 2)

- A proposal emerging from the Annex works is to update IEC 61400-21 to specify a standardized procedure for measurements and documentation of the response of wind turbines on voltage dips.
- Hence, in the future wind turbine manufacturers may refer to standardized test results for documenting response to voltage dips, but also these test results may be used for model validations.
- A committee draft revision of IEC 61400-21 is out (March 2006).
- The IEA Annex 21 work will conclude by end 2006.

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