Grid Code Compliance of Wind Energy Systems

Dr Sigrid M. Bolik

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Day's Agenda

10:15	*Introduction to grid code* **Sigrid Bolik** An overview of what grid code is, the history of development, its relevance to wind power, the process for change or review of existing grid code, the process for proving compliance
11:00	*Further grid code developments* **Sigrid Bolik** Comparisons with overseas markets, comparing requirements and the international transmission impacts, application of grid code offshore
11:45	*Discussion and questions*
12:00	*Lunch*
13:00	*Grid in Scotland* **Keith Maclean** An update on latest developments regarding grid issues in Scotland and in particular the grid queue and the Beauly-Denny public enquiry.
13:20	*Grid in Wales* **Peter Roper (Glasgow)** **Graeme Cooper (London)** An update on latest developments regarding grid in Wales and in particular the TAN 8 impact and lack of Grid in Wales.
Developments and technical challenges to grid code	
13:40	*Technical challenges to grid code compliance* **Sigrid Bolik** Wind farm control, compensation, fault ride through, generic modelling, validation/measurements/monitoring Implications for other renewable generation

Technical Challenges to Grid Code Compliance

Dr Sigrid M. Bolik

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Agenda

1. Control challenges
2. Wind Turbine modelling
3. Wind Farm modelling
4. Validation

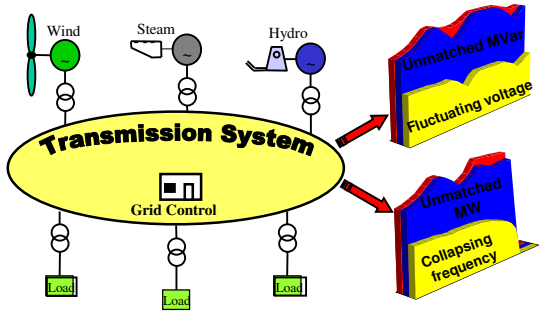
power system modelling

Wind Power today

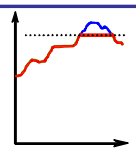
- The power system changed from central controlled & decentralized controlled
- WT become a considerable part of the network, needs to support
  - Voltage
  - Frequency
  - Stability
- When WT connected to weak grids – wind turbine performance is very important

- new focus
  - models of wind turbines and wind farms for network operation & planning

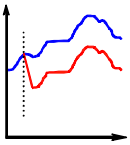
Grid Code / control need



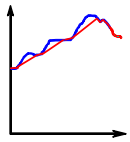
Frequency control of WF



1.Absolute Power Constraint control
2.Balance Control



Delta Control

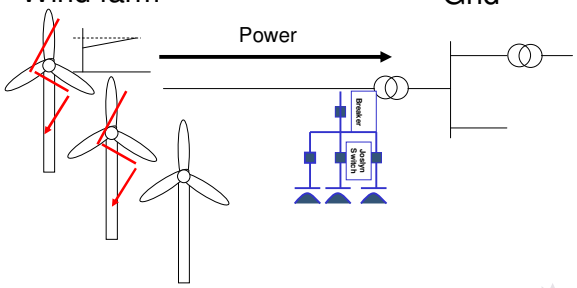


Power Rate Limitation control approach.

voltage control

Wind farm

Grid



LVFRT 275kV/ 400kV

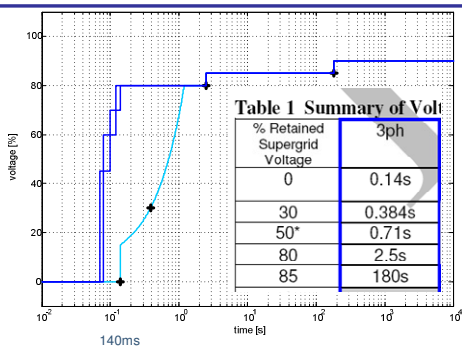


Table 1 Summary of Volt

% Retained Supergrid Voltage	3ph
0	0.14s
30	0.384s
50*	0.71s
80	2.5s
85	180s

140ms

History

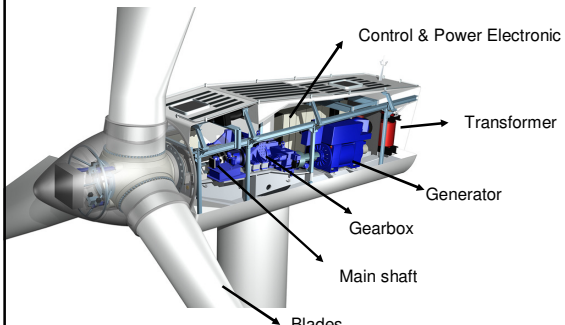
Grid requirements

Power quality focus::

- Flicker
- Harmonic Distortion
- Cut-in
- Power Factor Correction

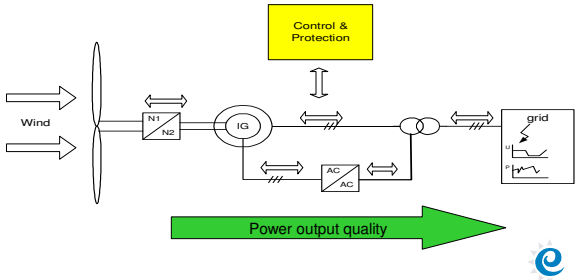
Disconnect
&
Shut down

Components

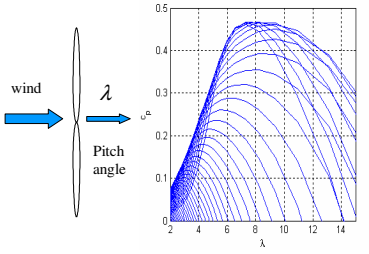


wind turbine modelling

- Wind Turbine design



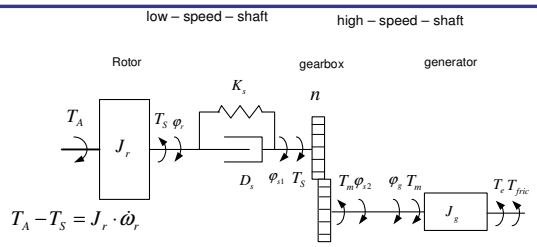
Mechanical Systems Modelling
aerodynamic, pitch model



$$P_w = \frac{1}{2}\rho \cdot A_r \cdot c_p(\lambda, \vartheta) \cdot v_w^3$$

$$T_A = \frac{P_w}{\omega_r}$$

Mechanical Systems Modelling
drive train model



$$T_A - T_S = J_r \cdot \dot{\omega}_r$$

$$T_S = K_S \cdot \Delta\varphi + D_S \cdot \Delta\dot{\varphi}$$

$$T_m = \frac{T_S}{n}$$

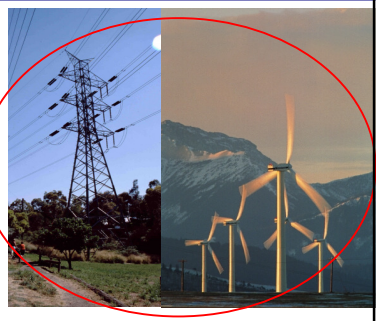
$$\Delta\dot{\varphi} = \omega_r - \frac{\omega_g}{n}$$

$$T_m - T_e - T_{fric} = J_g \cdot \dot{\omega}_g$$

Motivation
wind turbine modelling

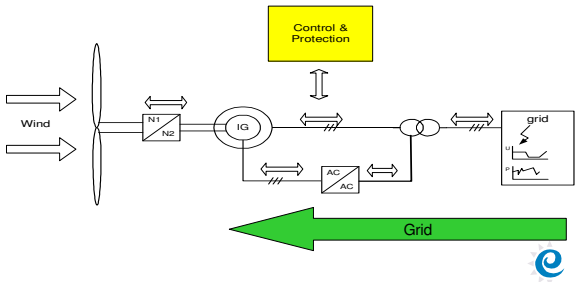
Grid integration:
- Reactive power support
- Active Power production
- Increased voltage & frequency range
- Frequency support
- Black start capability?

Stay Connected

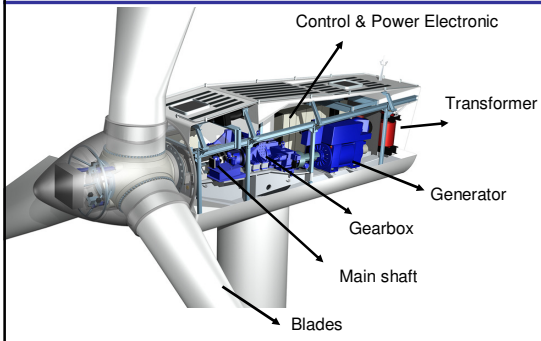


wind turbine modelling

• Wind Turbine design



Components



Modelling specification

	Power system models	**Wind turbine design**
Type of analysis	Power system stability -Steady state (load flow) -Transient dynamics (large disturbances) -Small signal stability (small disturbances) -Stability studies including short and long term dynamics (angular, frequency, voltage stability)	Wind turbine stability -Transient phenomena - dynamic analysis - Load analysis
Time scale	0…ms…10s…min	0…us…ms…s
Model type	-turbine model as wind turbine unit -> several units in wind farm	- detailed turbine model with e.g. detailed transformer model, generator model

Frequency control of WF

Model requirements

Steady state	dynamic	transient
balancing Load flow	voltage control frequency control	fault ride through

Software for WT modelling

Software packages

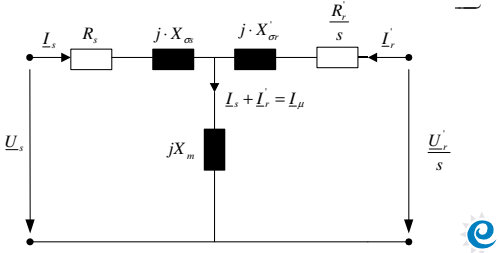
	EMT (Electromagnetic Transients)	EMD (Electromechanical dynamic analysis)	SSA (Steady State analysis)
EMTDC/PSCAD	√	√	—
SIMPOW	√	√	√
DigSilent (PowerFactory)	√	√	√
PSS/E	—	√	√

*Source: "Dynamic fault simulation of wind turbines using commercial simulation tools" Torsten Lund, Jarle Eek, Sanna Uski, Abraham Perdana

dynamic equivalent diagram

$$\underline{u}_s = R_s \cdot \underline{i}_s + j \cdot \omega_s \cdot L_{\sigma s} \cdot \underline{i}_s + j \cdot \omega_s \cdot L_m \cdot \left(\underline{i}_s + \underline{i}_r'\right)$$

$$\frac{\underline{u}_r'}{s} = \frac{R_r'}{s} \cdot \underline{i}_r' + j \cdot \omega_s \cdot L_{\sigma r}' \cdot \underline{i}_r' + j \cdot \omega_s \cdot L_m \cdot \left(\underline{i}_s + \underline{i}_r'\right)$$

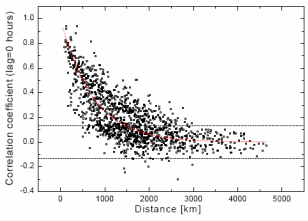


Considerations

- **Time-constant / frequency**
- Converter 100us – 1ms / 10kHz – 1kHz
- Generator transients
- Current controller 1ms – 100ms / 1kHz – 10Hz
- Power controller
- Drive train 100ms – 1s / 10Hz - 1Hz
- Pitch > 1s/ 1Hz

100ms – 1s - min Power system stability

Averaging effect



Source: Gregor Giebel (Risoe)

- **Calculate cross-correlation coefficient between every pair of stations**
- **Result: Cross-correlation decreases with distance**
- **Exponential fit has shape parameter of ca.** 700 km

Power smoothing from WF (IG,stall)

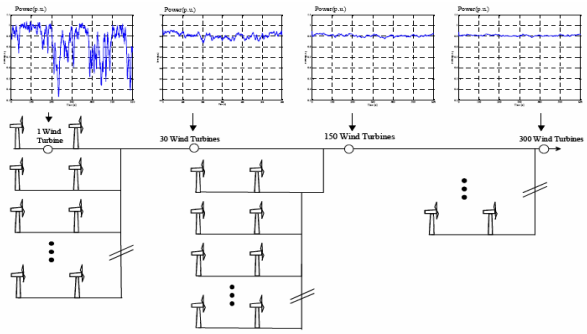
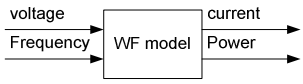


Figure 1.2 Power smoothing effect from wind farms.

Wind Farm Unit Model

- aggregation for normal operation
  power quality, power output improving with nr of units



- Aggregated Wind Farm model
- Predicts active and reactive power response

modelling

Simulation Accuracy

Model Accuracy

Data Accuracy

- Table

Model Component accuracy

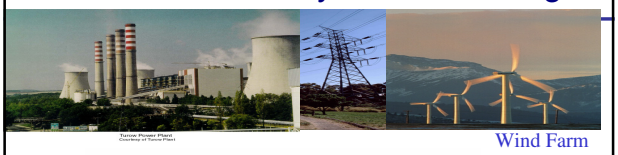
- Validity of the model
- physical level of detail

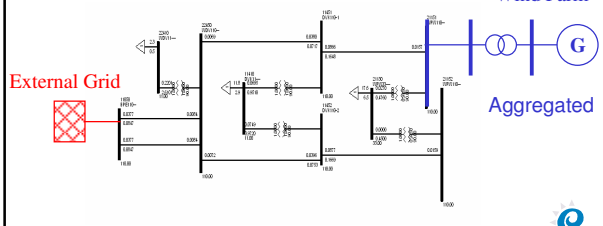
Model data accuracy

- Quality of data measuring
- estimation methods

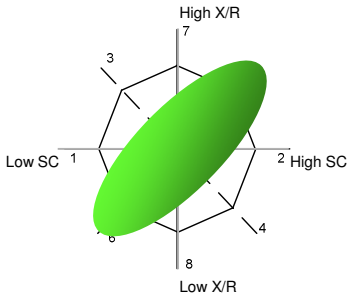
System accuracy

Power system modelling





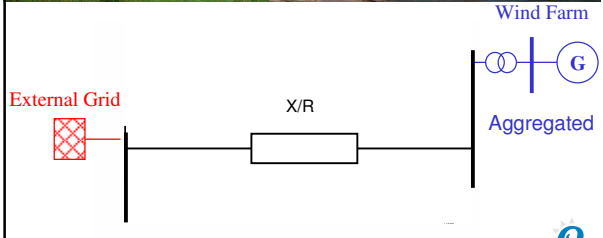
Power system Model



Operation octagon

1) weak grid,
2) strong grid,
3) full WT power ,
4) low WT power,
5) full grid load,
6) low grid load,
7) high X/R ratio,
8) low X/R ratio

Power system modelling



validation

Desktop studies according to AU requirements

- fault remote from the wind farm;
- fault at, or close to, the connection point;
- line or other plant switching or tripping;
- voltage disturbance, short or long duration (e.g. parts of network close to voltage collapse)
- frequency disturbance (e.g. part of the network is islanded)

\+ With operational octagon

42 cases

Validation

- Wind Turbine

- Type test
- Wind Farms connected to grid

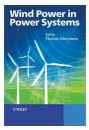
- normal operation and control
- monitoring and waiting

Conclusion

- Wind Farms connected distribution & transmission grid
- Wind Turbine Technology adjusted
- Grid codes recognising wind turbines

- Power system representation with wind farms integrated & Validation
- right model for right application & right validation

Recommended Literature



- "Wind Power in Power Systems"
- http://www.windpowerinpowersystems.info/index.html
- Fifth International Workshop on Large-Scale Integration of Wind Power and Transmission Networks for Offshore Wind Farms, 7-8 April 2005, http://www.ets.kth.se/ees/workshop/offshore/

- Risø National Laboratory www.risoe.dk
- http://www.risoe.dk/rispubl/VEA/veapdf/ris-r-1408.pdf; Dynamic Influences of Wind Power on the Power System http://www.risoe.dk/rispubl/VEA/ris-r-1331.htm; Comparison of EMTDC-PSCAD and DIgSILENT
- http://www.eltra.dk/media(15495,1030)/Afhandling_VLA_marts_2004.pdf; Analysis of Dynamic Behaviour of. Electric Power Systems with Large Amount of Wind Power

Thank you for your attention

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