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WILMAR

WP5: System stability analysis

Results concerning system stability, secondary control and activation of balancing power

Ian Norheim, Kjetil Uhlen
SINTEF Energy Research

Objectives of WP5

- The specific objectives of WP5 has been to
  - Identify and quantify specific potential stability problems in particular related to large-scale integration of intermittent renewable energy generation into the power system
  - Identify and evaluate various solutions to eliminate / reduce problems

Description of work

- **Identification of evaluation criteria:**
  - Identify and describe relevant problems and possible solutions of power system stability when large amounts of wind power is introduced into the Northern European power system.
  - Selection of evaluation criteria based on and reflecting the general requirements for grid standards.
- **Selection of case studies:**
  - In close relation to WP6 a number of case studies are selected.
  - The case studies have to reflect the range of problems already realised or foreseen within the area.
- **Analysing problems of system stability:**
  - Analyses of the selected cases related to short-term instabilities or operational problems using the set of criteria (above).
  - Evaluation of different solutions to cope with problems of system stability.
  - The work will be carried out using dedicated power system simulation tools.

System stability impacts for different stakeholders

- From a system operator (or network owner) point of view:
  - How much Wind Energy can the system cope with?
  - Secondary control and protection issues
  - Congestion managemenet
  - How to deal with reserves?
  - System stability (Voltage stability, Angle stability)

- From the generation owner point of view:
  - Assessments regarding choice of technology (control systems, protections, etc.)
  - Additional costs (or reduced income) due to network constraints

Interaction between WP5 and WP6

WP6

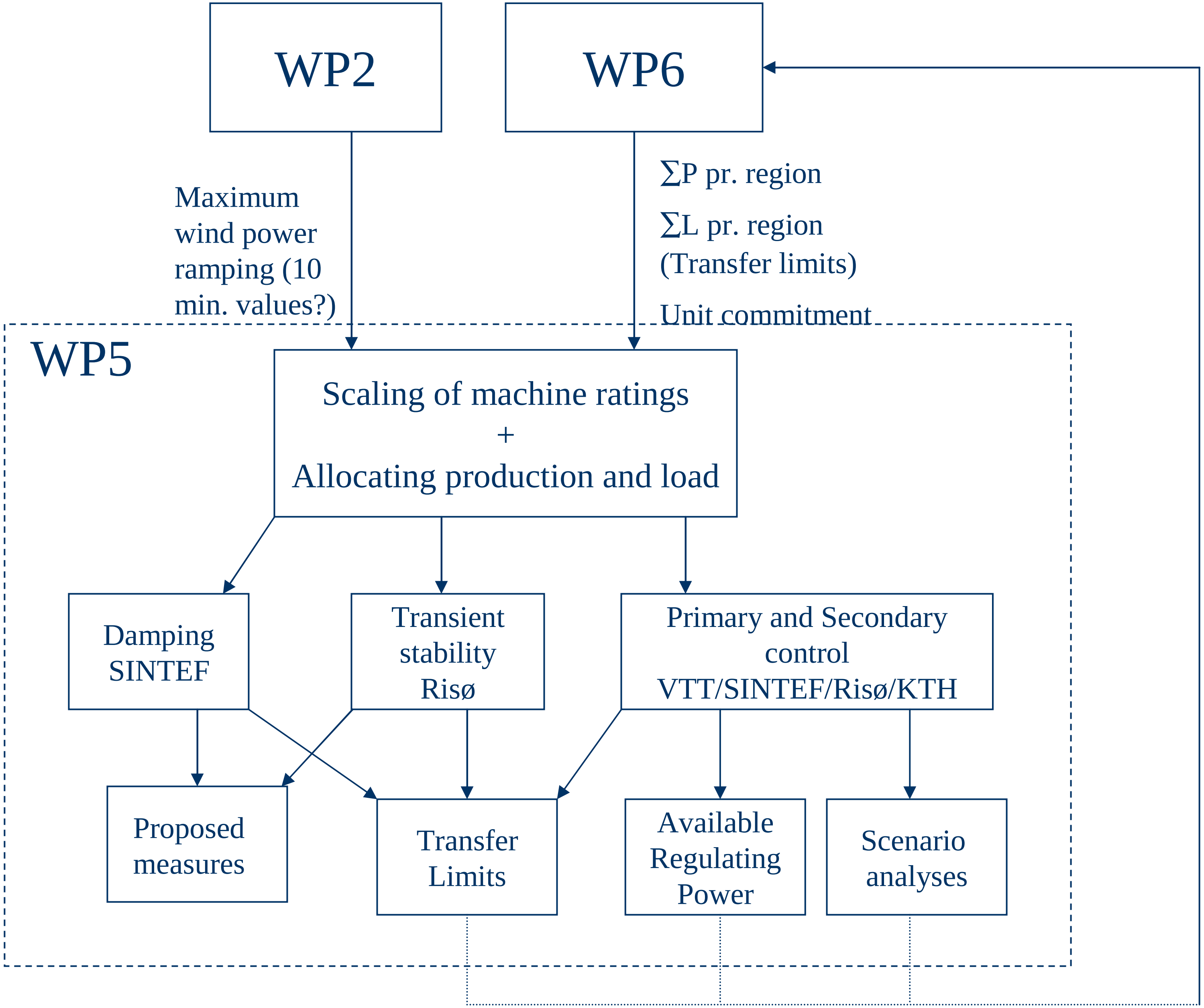
WP5

- Long-term planning
  - Future demand and system expansion
  - Future prices
  - Optimisation of resources
- Network planning
  - How much wind energy can be integrated
  - Secondary control and protection
  - Congestion managemenet, reserves, etc.
- System stability and primary control
  - Voltage stability
  - Angle stability
    - Transient stability
    - Damping

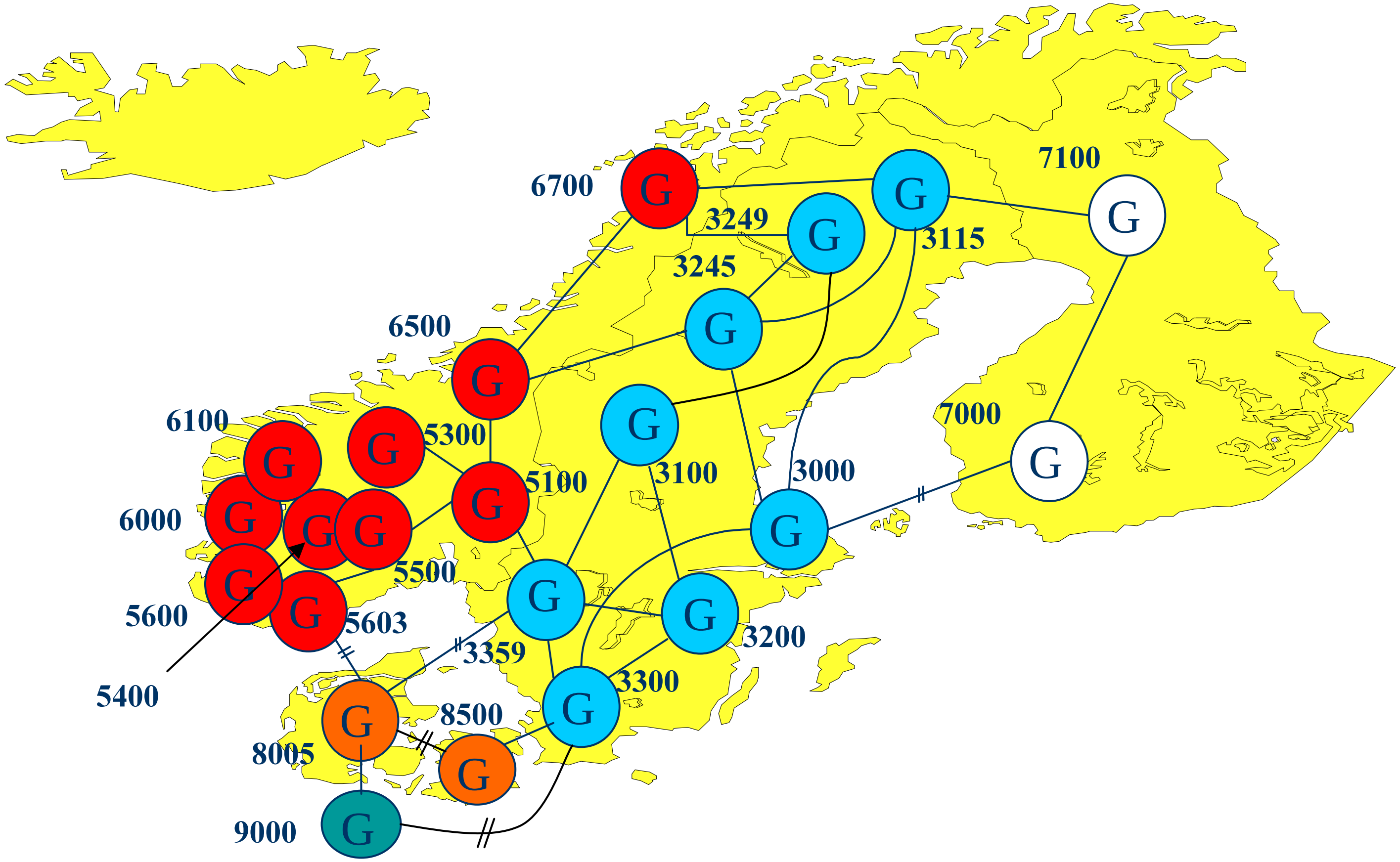
Status for WP 5

1. Identification of evaluation criteria

- Transient and voltage stability
- Small signal stability – Power oscillation damping
- Frequency control and spinning reserves (primary control)
- Balancing control fast reserves (secondary control)
  - Stepwise Powerflow


WP2
WP6
Maximum wind power ramping (10 min. values?)
ΣP pr. region
ΣL pr. region
(Transfer limits)
Unit commitment
WP5
Scaling of machine ratings + Allocating production and load
Damping SINTEF
Transient stability Risø
Primary and Secondary control VTT/SINTEF/Risø/KTH
Proposed measures
Transfer Limits
Available Regulating Power
Scenario analyses

WP5 model of the Northern European system (23 generator model)



Frequency stability

- The main activity in WP5
- Case studies based on WP6 results
- Studies focused on how the frequency varies from minute to minute within a simulated hour in WP6
- The studies also reveal the power flow between the regions. This way one can verify if the WP6 results are reasonable when including the network impedances
- A conversion program has been made to convert WP6 output data to WP5 input format
  - Load, production, wind power, balancing power bid list, HVDC-flow, forecast errors in wind are made readable for WP5 simulations

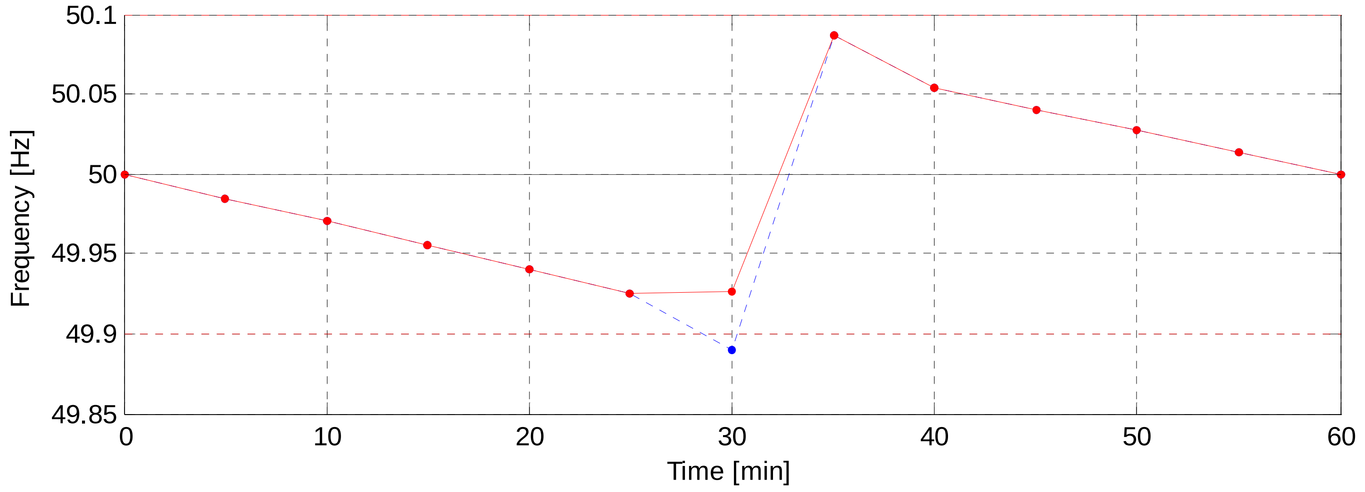
Frequency stability cont.

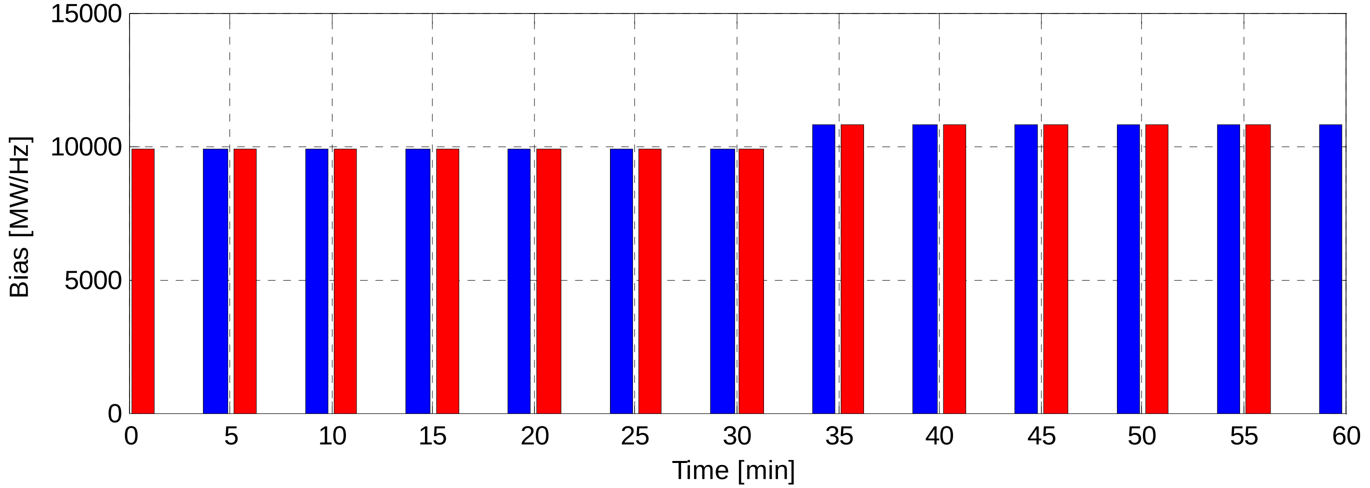
- Cases are simulated in WP5 with the tools:
  - ”Stepwise Power Flow” developed at SINTEF
  - ”LP optimisation with DC load flow” developed at KTH
  - ”PSS/E” from Siemens Power Transmission & Distribution, Inc., Power Technologies International
- The results from the different tools are compared and commented

Case 2001 (January 5, hour 7-8)

- The case was used as a test case, and for comparison of the different simulation tools used for frequency control studies in WP5
- Total production in the Nordel system: 48358 MW (hour 7)
- HVDC ramps from 25 minutes to 40 minutes
- Wind power production is 232 MW and decreases to 225 MW during the hour
- Forecast errors are only 41 MW within the whole hour and are neglected

Case 2001, Stepwise Power Flow results



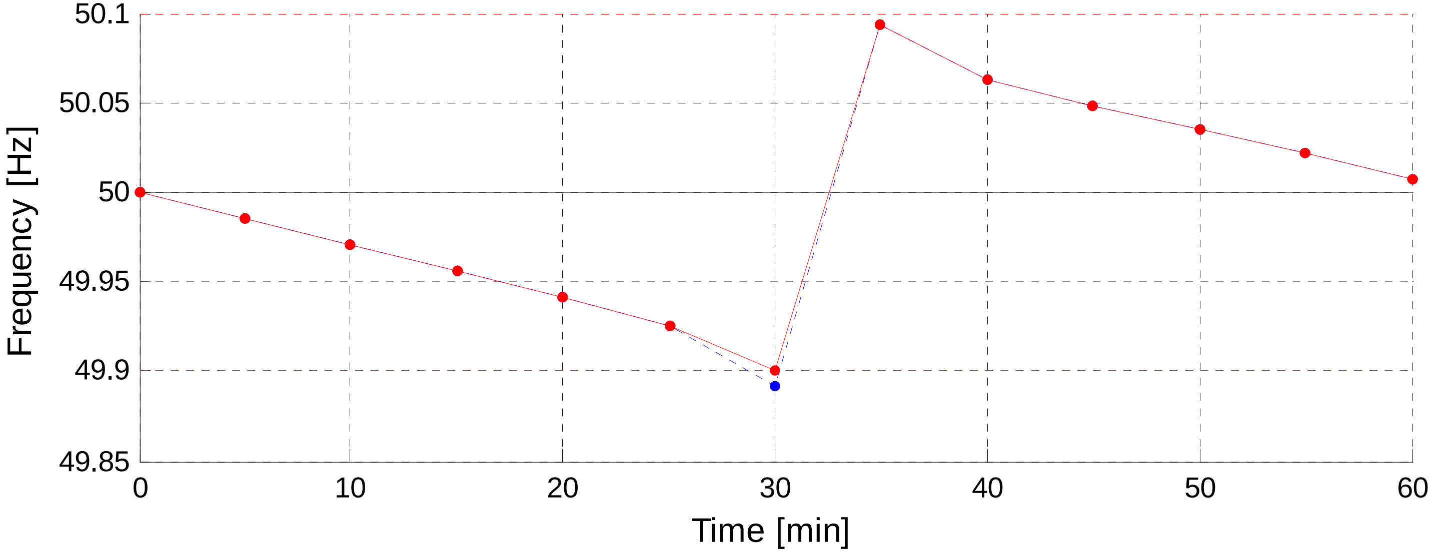


Case 2001, Stepwise Power Flow results

Table 5.3 Actual and maximum allowed flow in the corridors between the WP6 price areas

Corridor		Maximum Flow (MVA)	Maximum allowed flow (MW)	
Area A	**Area B**	**Area A – Area B**	**Area A- Area B**	**Area B – Area A**
NO_N	NO_M	331.7	600	600
NO_N	SE_N	590.2	600	700
NO_M	SE_N	288.1	600	500
NO_M	NO_S	88.7	300	300
NO_S	SE_M	185.3	2050	1850
NO_S	DK1	1008.7	1040	1040
SE_N	FI	934.4	1600	1200
SE_N	SE_M	3253.9	7000	7000
SE_M	FI	0	550	550
SE_M	DK1	734.8	670	630
SE_M	SE_S	824.5	4000	4000
SE_S	GER	371.3	600	600
SE_S	DK2	1169.1	1775	1700
DK2	DK1	0	600	600
DK1	GER	825.9	1200	1200

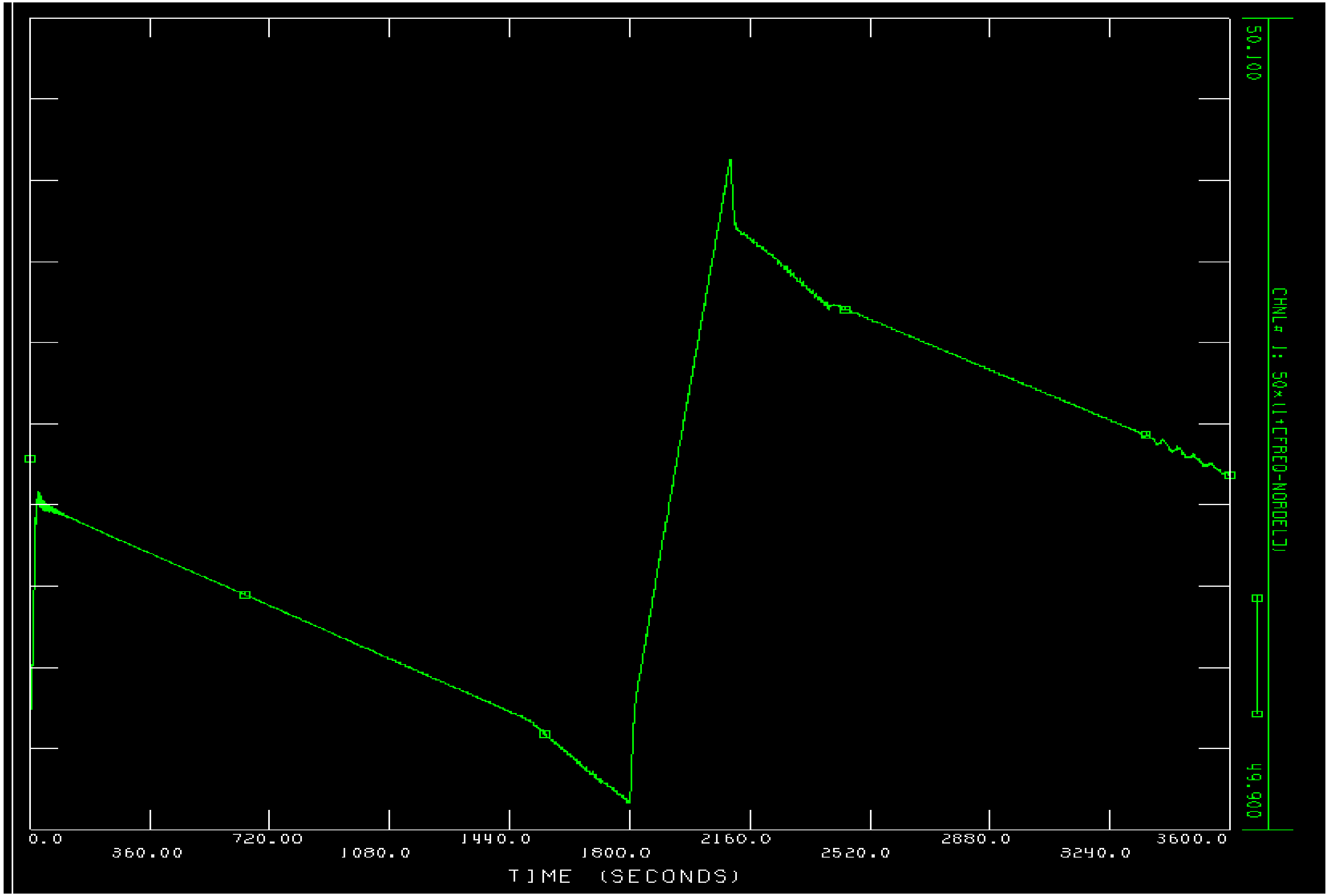
Case 2001, LP optimisation results



- Line flows only differs a few percent with SPF
- Activated Balancing power is here 78 MW against 370.7 MW with SPF

  This is reasonable as SPF lifts the frequency higher after 30 minutes (49.925 Hz against 49.9 Hz), and SPF only increases the rating of the generators according to the bid list while LP optimisation increases the actual active production according to the bid list.
- *All in all: the correspondance between LP optimisation and SPF is good*

Case 2001, PSS/E simulation



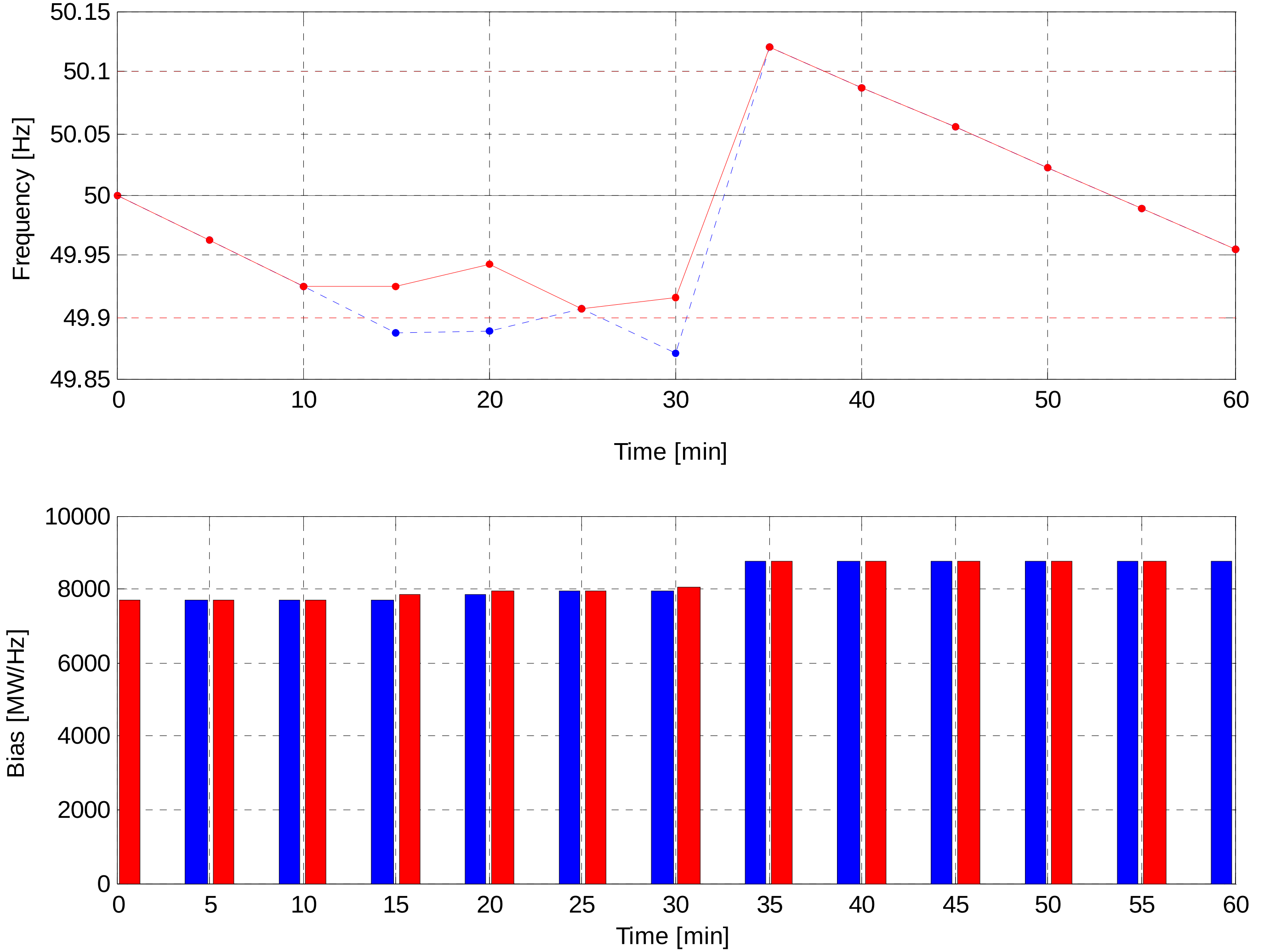
2001 Case, PSS/E simulation

- The frequency falls a bit slower than in the SPF and LP optimisation and only drops to approximately 49.1 Hz after 30 minutes
- This is probably much because of a generator on node 3359 contributed to the primary control in the PSS/E simulation and not in the SPF and LP optimisation simulations. The additional primary reserve in the PSS/E simulation was more than 400 MW (almost 17 % more primary reserves in the PSS/E simulation)

2010 Low load case (only SPF)

- Total production (included wind power production) in the Nordel system in 37392.54 MW in the beginning of the hour and 40045.4 MW in the end of the hour
- Wind power production is 4306.42 MW and decrease to 3916.9 MW during the hour
- Forecast errors are low in the Nordel system (only +130.4 MW within the hour), thus it will have minimum influence on the results

2010 Low load case



2010 Low load case

Table 5.5 Actual and maximum allowed flow in the corridors between the WP6 price areas

Corridor		**Maximum Flow (MVA)**	**Maximum allowed flow (MW)**	
Area A	**Area B**	**Area A – Area B**	**Area A- Area B**	**Area B – Area A**
NO_N	NO_M	256.8	600	600
NO_N	SE_N	351.6	600	700
NO_M	SE_N	1248.1 (1242.1 MW, NO_M-SE_N)	600	500
NO_M	NO_S	113	300	300
NO_S	SE_M	2147.6 (2093.6 MW NO_S-SE_M)	2050	1850
NO_S	DK1	958.2	1040	1040
SE_N	FI	2174 (2137.3 MW, SE_N-FI)	1600	1200
SE_N	SE_M	4611.4	7000	7000
SE_M	FI	470.8	550	550
SE_M	DK1	573.2	670	630
SE_M	SE_S	3126.4	4000	4000
SE_S	GER	415.8	600	600
SE_S	DK2	1607.4	1775	1700
DK2	DK1	442.6	600	600
DK1	GER	1147.9	1200	1200

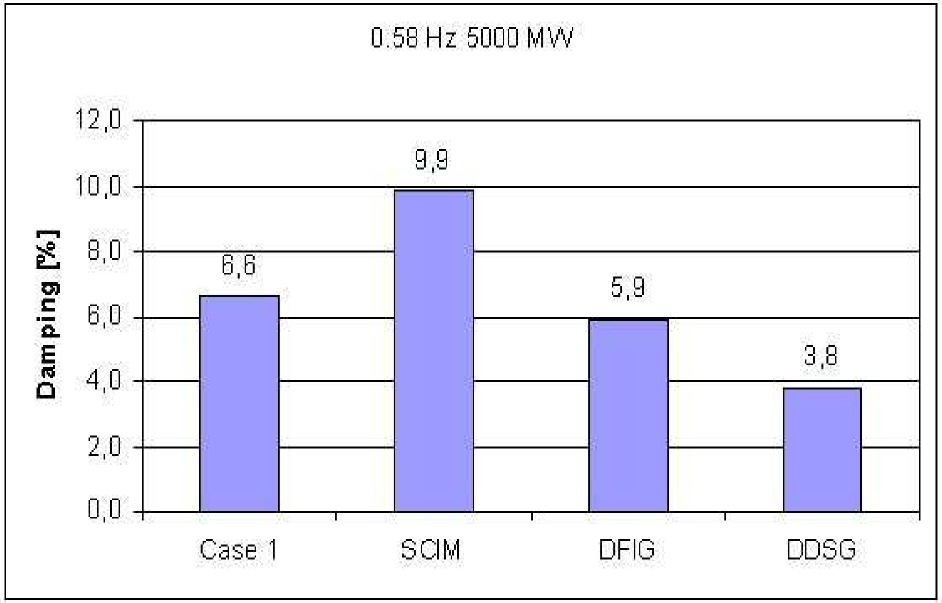
2010 Low load case

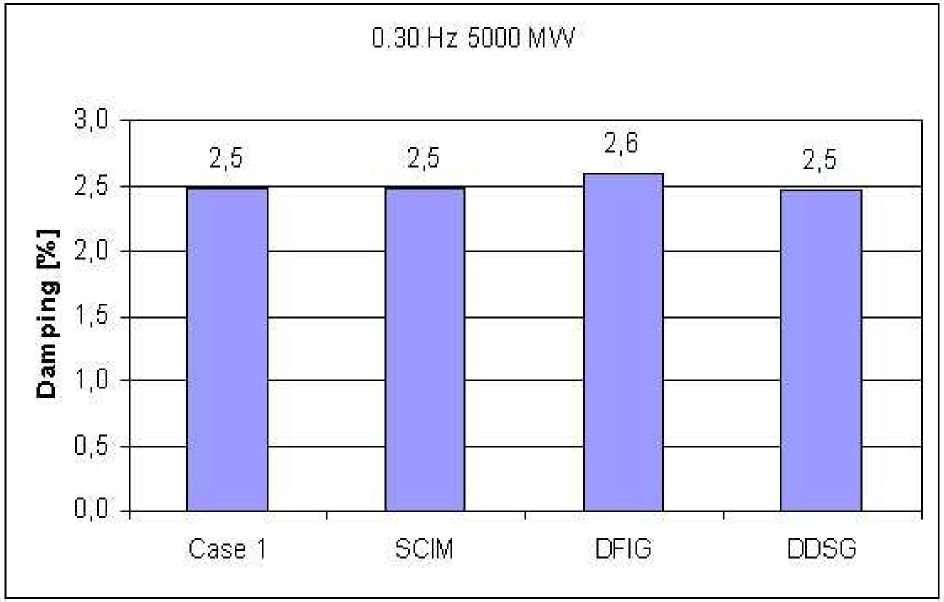
- Total amount of balancing power activated: 1038.1 MW
- No frequency problems
- With more than 1600 MW wind power production in Mid-Norway there is a severe overload between Mid-Norway and North-Sweden (More than 100 %).
- Overload can be decreased by not activating BP in Mid Norway (instead activate more expensive BP somewhere else), but only to around 50 %
- The impedances causes power to flow from North-Norway to Mid-Norway and this way worsening the overload on the transmission Mid-Norway – North-Sweden. This problem would not be revealed by the planning tool
- A new line between Mid-Norway and North-Sweden is planned in 2008/2009. The simulation indicates that this is relevant.
- The overload of the line between North-Sweden and Finland in the 23 generator model is mainly because the transmission capacity from Norway to Finland has been neglected compared to the JMM model, and because of a high impedance in the modelled line from North-Sweden to Finland.

Small signal stability

- How does large integration of wind power in Norway influence the dominant inter-area oscillations in the Nordel system ?
- Studies performed in PSS/E with the 23 generator model (Studies done independent of WP6 simulation)
- Two dominant inter-area modes in the Nordel system are the 0.3 Hz mode and the 0.58 Hz mode
- The 0.3 Hz mode is mainly generators in Finland oscillating against generators in South-Sweden
- The 0.58 Hz mode is mainly generators in South-Norway oscillating against generators in South-Sweden

Small signal stability





Case 1, no wind power integrated. In the other cases 5000 MW of the specified technology is integrated in Norway.

For the 0.58 Hz mode it is improved damping with Sqirrel Cage Induction Machine, and less damping with DFIG and DDSG.

The 0.3 Hz mode is not influenced significantly with large scale integration of wind power in Norway, as this mode is oscillations between Sweden and Finland.

Transient stability

- The 23 generator model was converted from PSS/E to Power Factory from DigSilent
- An extension of the model was done for East-Denmark to study :
  - How short-circuit faults impact on the wind turbines
  - How the response of the wind turbines (to short-circuit faults) influence the post fault behaviour of the Nordic power system

- The land based wind turbines distributed on the islands south in East-Denmark are modeled as one wind turbine
- The turbines in the existing Nysted offshore windfarm is modeled as one wind turbine
- A future offshore windfarm at Nysted is also modeled as one wind turbine

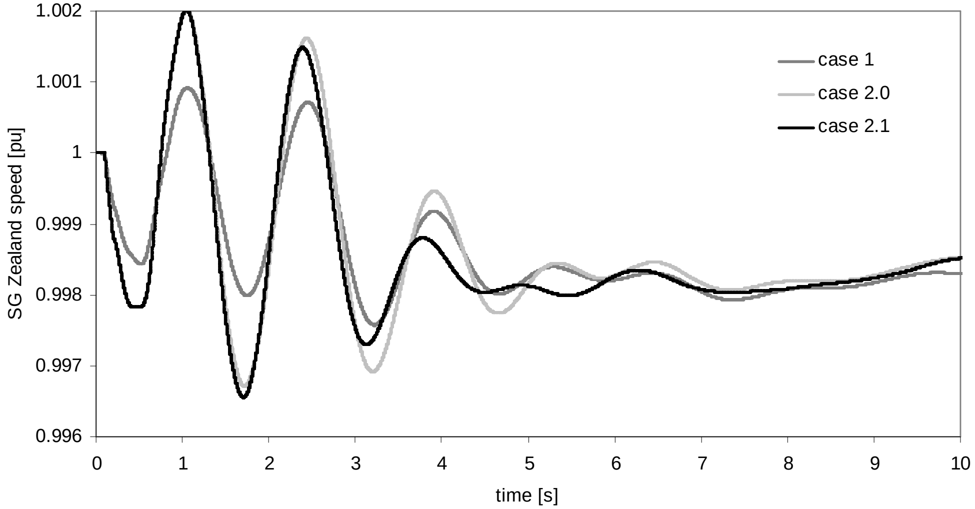
Transient stability

- Three cases were simulated:
  - Case 1: The present day situation (land based + existing Nysted)
  - Case 2.0: The future situation (future Nysted added to Case 1)
  - Case 2.1: Future situation including grid frequency stabiliser in the control system of the future Nysted wind farm
- In all cases a 100 ms 3-phase symmetrical fault causing a near 0.8 pu voltage drop at Nysted (and 0.1-0.15 pu voltage drop at the synchronous generator representing conventional production in East-Denmark) was used to trigger the transient response

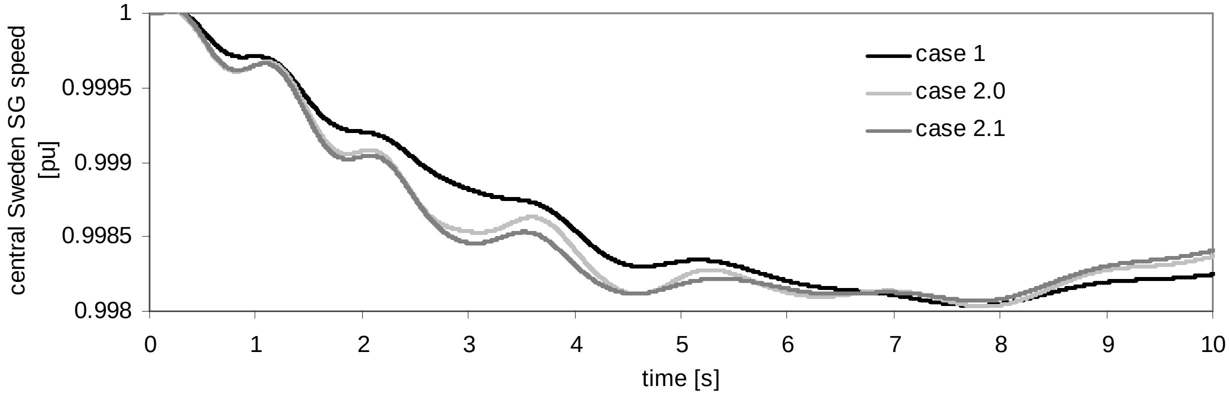
Transient stability

- The simulations shows that the future offshore wind farm at Nysted will cause increased stress on the voltage locally in South-East Denmark
- It will also upset the grid frequency, as it causes strong rotor speed oscillations in the synchronous generator modelling East-Denmark (these oscillations are observed throughout the Nordel system)
- The grid frequency controller in the new wind farm at Nysted will give positive damping of these oscillation, and improve the voltage response at Nysted after the fault has been disconnected

Transient stability



Examples on how the grid frequency controller damp the rotor speed oscillations in synchronous generators in East-Denmark and Central-Sweden



Conclusions

- Stability analysis connected to large-scale integration of wind power in the Northern-European system have been performed
- Different tools and methods have been performed for the Frequency Stability analysis. There is a good agreement between the results obtained by the different models
- With the Frequency Stability analysis, different potential problems have been identified:
  - Location of balancing power
  - Overloads
- No major problems related to frequency control and balancing power have been identified.

Conclusions cont.

- The Small Signal Stability analysis indicate how different wind power technologies influence on damping of inter-area oscillation modes.
  - Squirrel cage induction generator increase the damping
  - DFIG, and DDSG decrease the damping
- Solutions to increase the damping in the power system are well known and not necessarily costly. However, such solutions have not been tested in WP5
- The Transient Stability analysis shows how one may use the control system of wind farms to damp system oscillations and improve voltage control in the local area and in the wind farm

Conclusions cont.

- The specific objectives of WP5 has been to
  - Identify and quantify specific potential stability problems in particular related to large-scale integration of intermittent renewable energy generation into the power system
  - Identify and evaluate various solutions to eliminate / reduce problems
- The first objective above has been fully performed
- The second objective has been fully performed for the Transient Stability analysis, and good solutions also already exists for Small Signal Stability (even not implemented here)
- On frequency control, solutions are identified but only to a limited degree evaluated and analysed.

Main conclusions

- Different types of stability problems are expected:

- Voltage stability:
  - Mainly a local / regional problem due to limited network capacity
- Transient stability:
  - Local (wind farm related) problem with possible system wide impacts (may impact on operational transmission limits)
- Power oscillation damping:
  - Local and system wide problem (system dependent)
- Frequency stability (balancing control):
  - System problem (but also local impacts)

Evaluation of possible solutions

- Voltage stability:
  - Related to limited local network capacity
  - Technical solutions readily available
    - Control of reactive power
    - Network reinforcements
  - Wind farms must be able to perform Automatic Voltage Control
- Transient stability:
  - Wind farm control problem (Various solutions are being devolped)
- Power oscillation damping:
  - Potentially increasing problem with variable speed technology (power electronics interface)
  - Technical solutions exist (power system stabilisers)
- Frequency stability (balancing control):
  - System problem (but also local impacts)
  - Presently a manageable problem
  - Increasing towards 2010
  - Most important challenge with very large scale integration
  - Solutions:
    - Increase on-line reserves and frequency bias (expensive solution)
    - Stimulate Active Demand participation in balancing control and reserve markets
    - Implement Market based AGC solutions to obtain faster response in the balancing control