



Integrating Wind Energy in the Australian National Electricity Market

PSERC Seminar 9 November 2004

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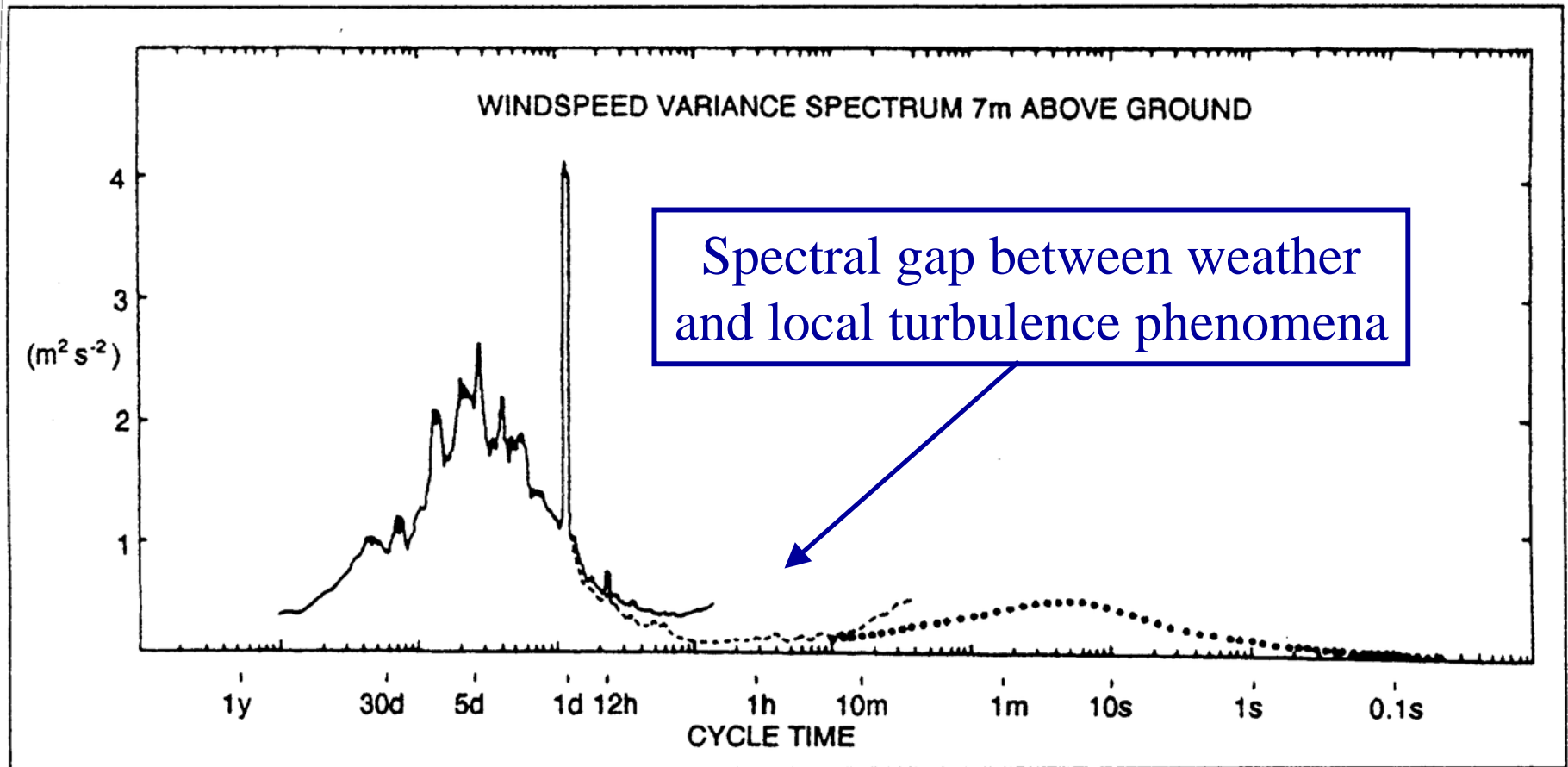
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Relevant characteristics of wind energy

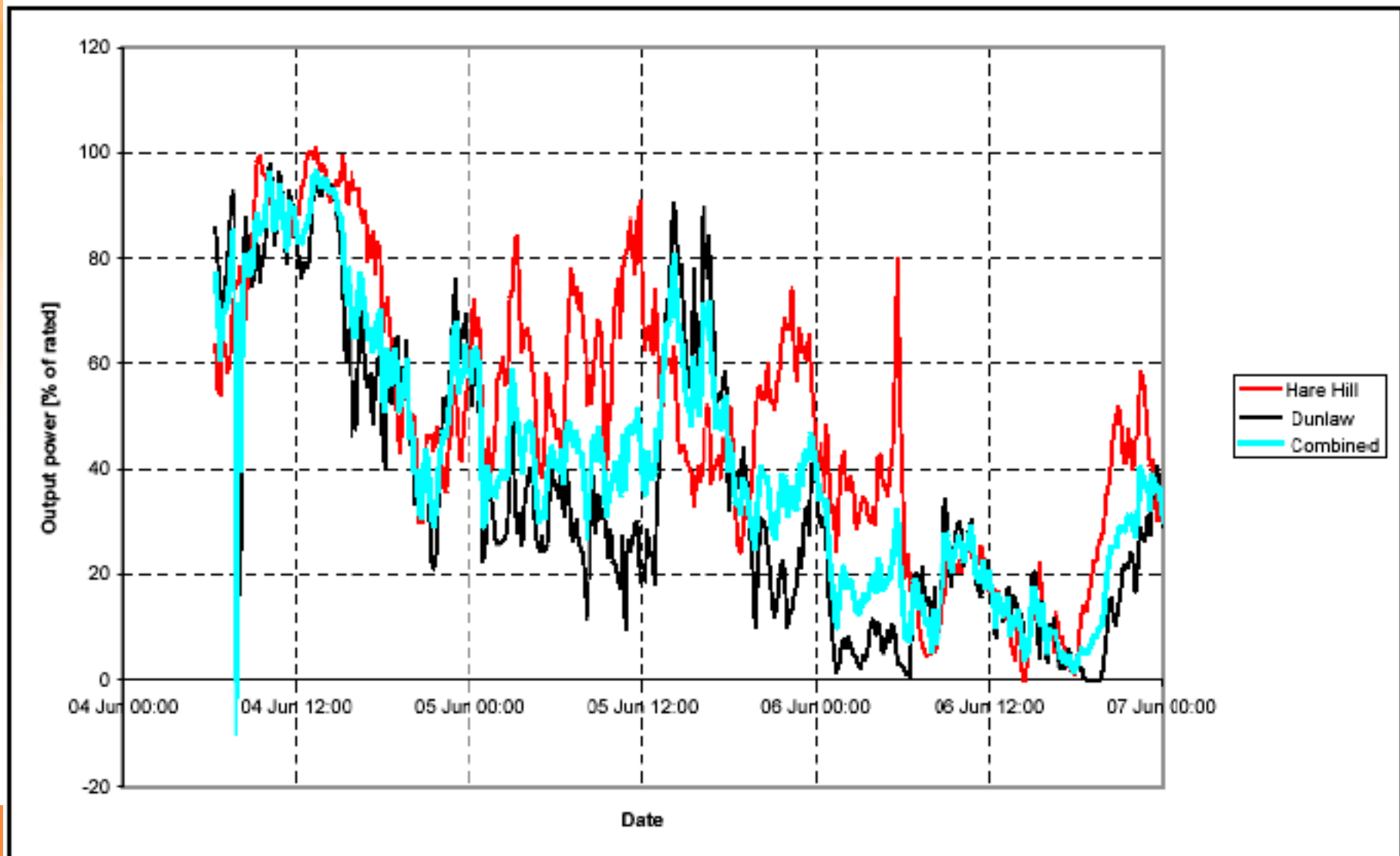
- Wind energy density:
 - A stochastic variable with properties that vary continuously in 3-dimensional space
 - Turbulence spectrum:
 - Maximum period ~30 minutes
 - Spatially correlated to a radius of ~20km
 - Weather spectrum (including diurnal behaviour):
 - Period range of ~30 minutes to ~ 1 week
 - Spatially correlated to a radius of 100's of km
 - Seasonal & climatic spectrum:
 - Longer term behaviour

Spectral analysis of Danish long-term wind data (17 years of data)

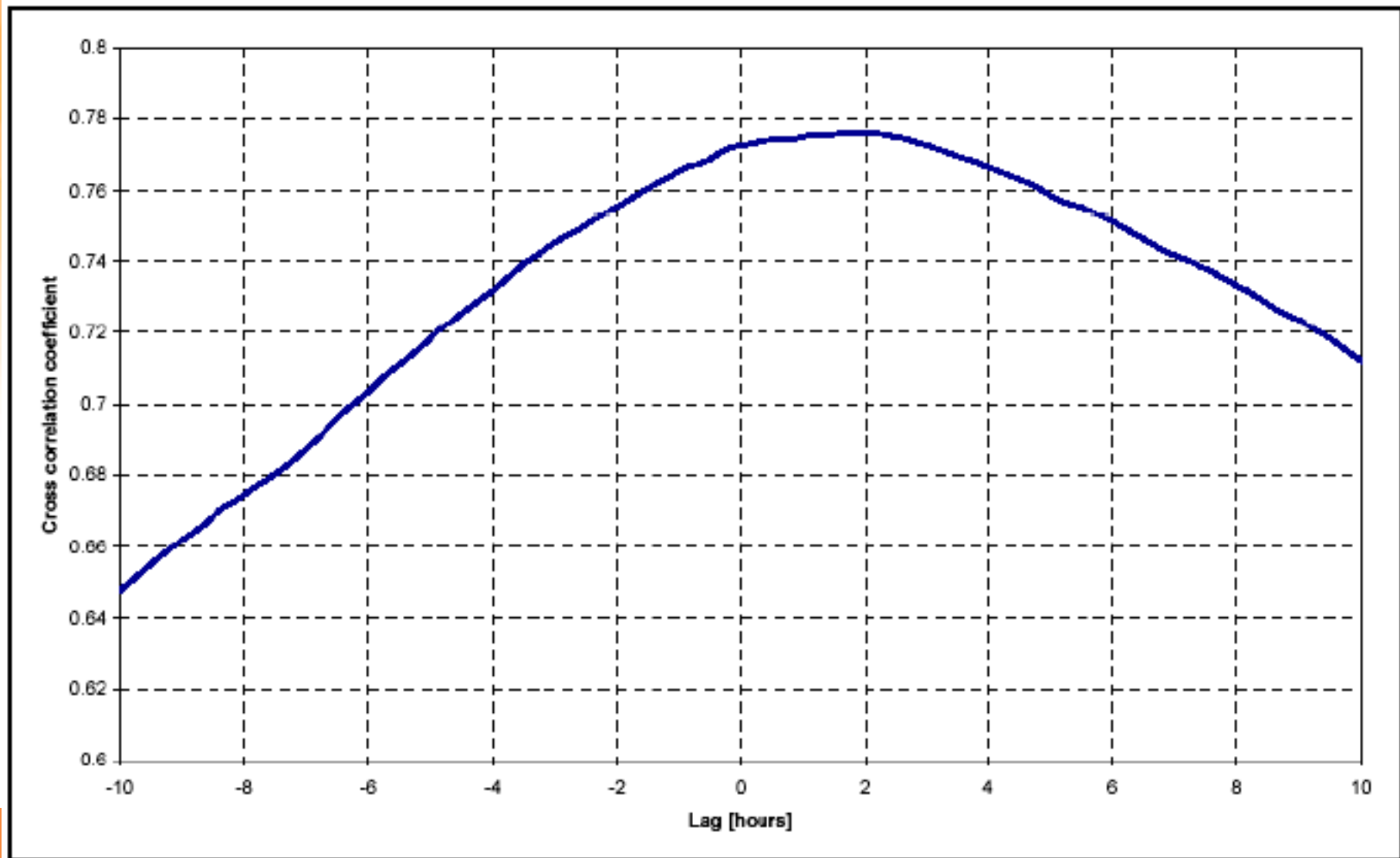


Combined output of 2 wind farms 80 km apart

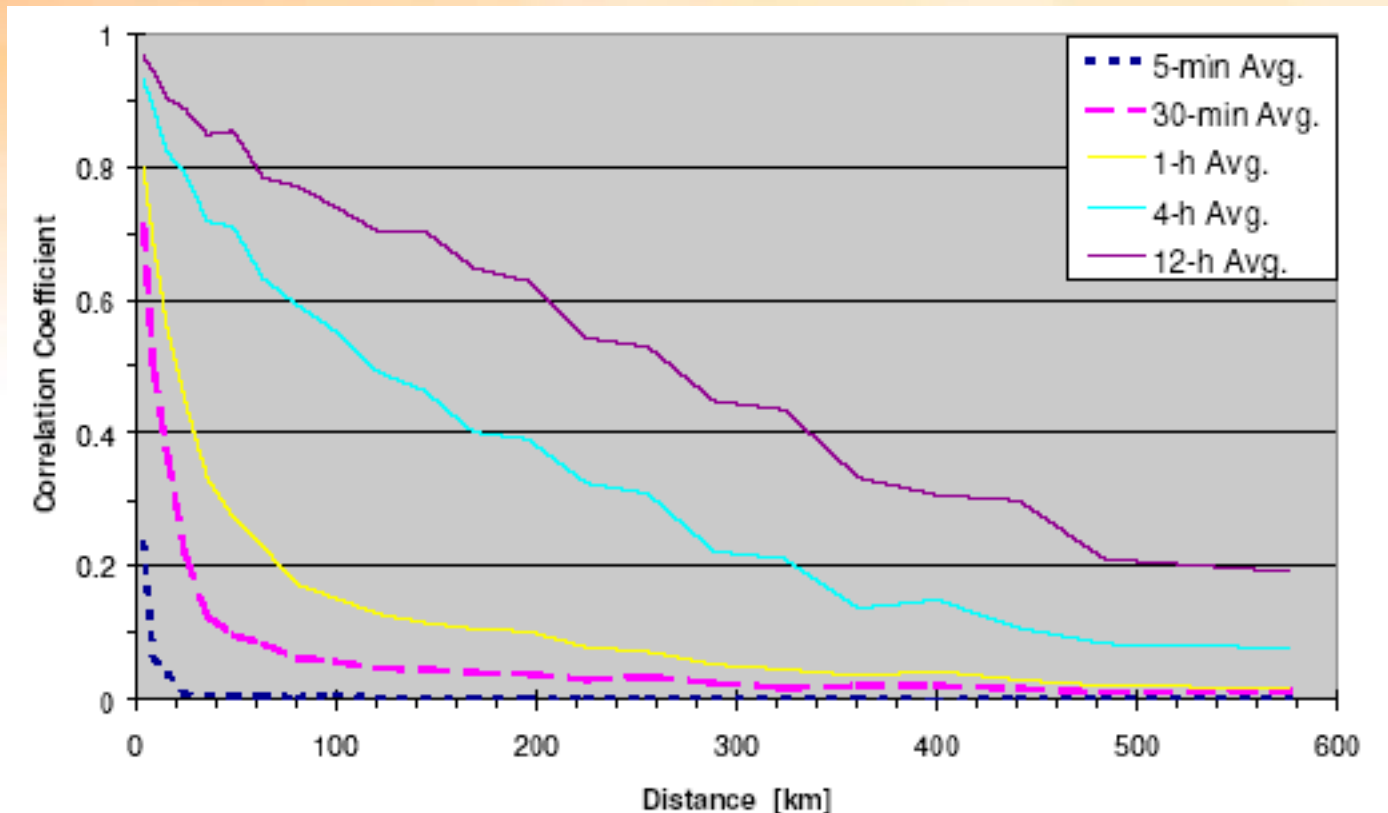
(Gardner et al, 2003)



Cross-correlation function between the output powers of 2 wind farms 80 km apart (Gardner et al, 2003)



Cross-correlation functions between measured power outputs of German wind farms (Giebel, 2000)



Forecasting the output of wind farms

- 30 minute horizon (FCAS & spot market):
 - Turbulence spectrum - likely to be uncorrelated for turbines spaced > 20 km:
 - Then % power fluctuations $\sim N^{-0.5}$
 - eg for 100 identical wind farms spaced >20 km apart, %fluctuation in total power $\sim 0.1 \times$ %fluctuation for 1 farm
- 30 minutes to ~ 3 hours:
 - ARMA model best predictor of future output
- > 3 hours - NWP model best predictor:
- Key issue for power system & market operation:
 - Predicting large changes in the output of appropriately aggregated groups of wind farms

2-hour prediction for Lake Benton wind farm, USA

138 turbines, 103.5MW, hourly data (Hirst, 2001)

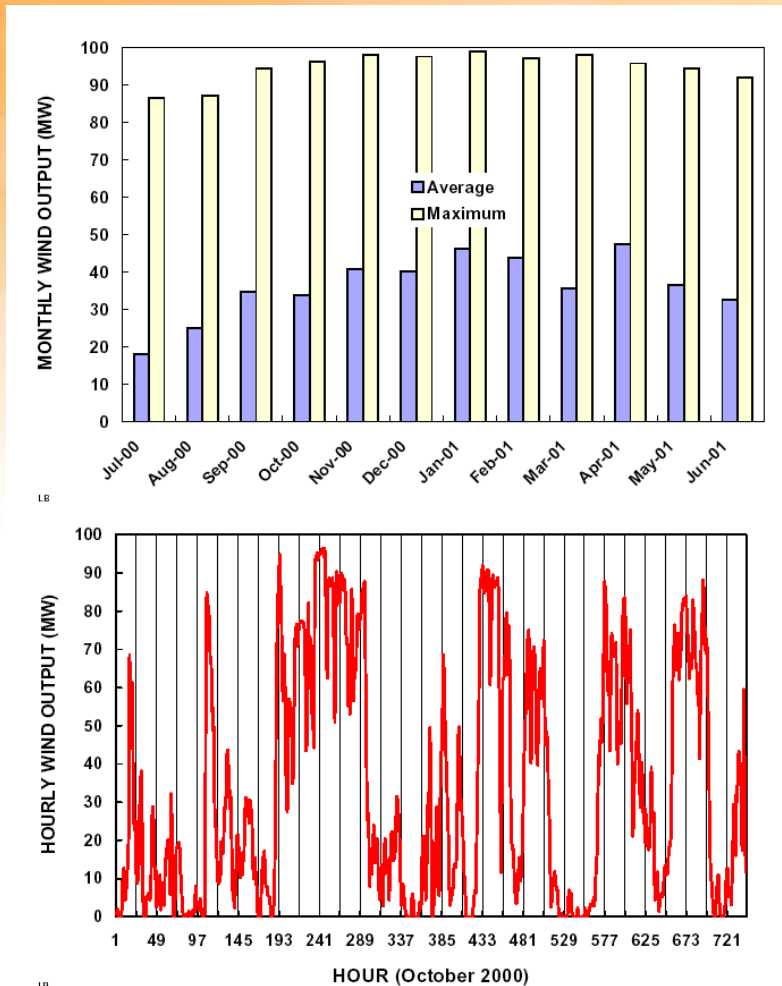


Fig. 3. Summary of hourly data on wind output (MW) by month (top) and hour-by-hour for October 2000 (bottom).

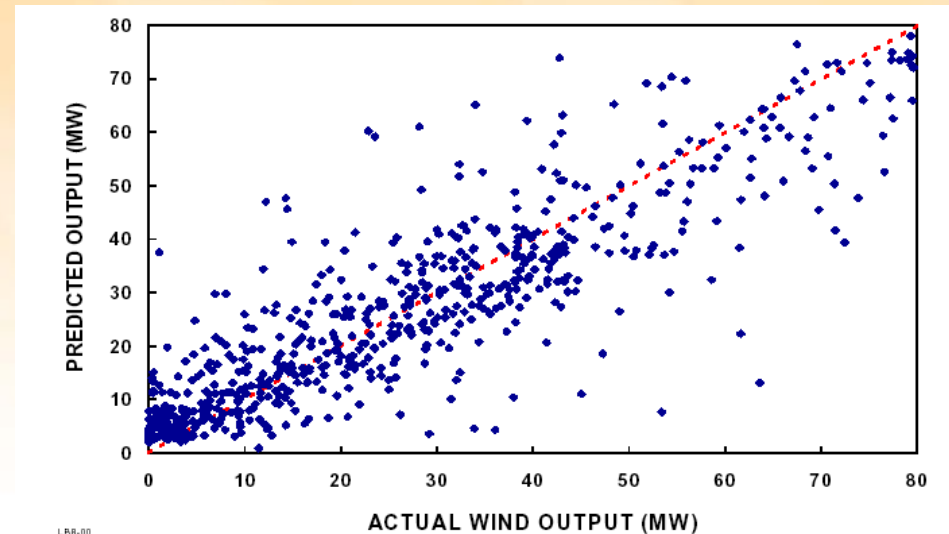


Fig. 7. Hourly predicted vs actual wind output for August 2000. The predicted and actual values are equal along the dotted line.

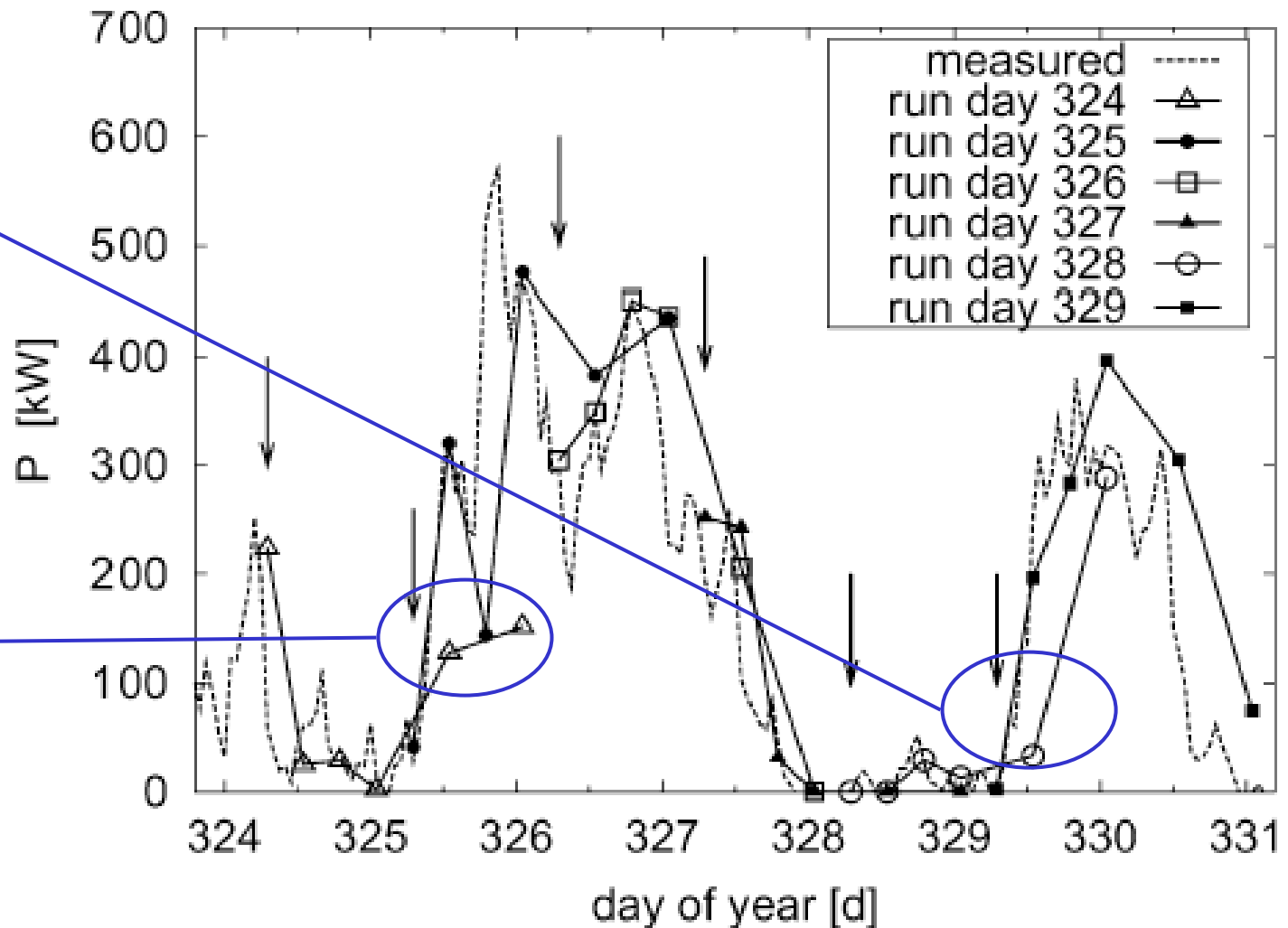
Two-hour ahead prediction of wind power:

$$MW_{Pred}(T+2) = 2.7 + 0.9 \times MW(T) + [MW(T) - MW(T-1)]$$

Predicting changes in output of a wind turbine 6, 12, 18, 24, 36 & 48 hours ahead (Focken et al, 2002)

48 & 36 hr
predictions:
Front timing
later than
actual

48 & 36 hr
predictions:
Front timing
ok but not
magnitude



Predicting wind farm behaviour using a numerical weather prediction model (single wind farm or groups of wind farms)

Global/Continental -scale data analysis



Regional-scale Model (TAPM)

~ 20km resolution



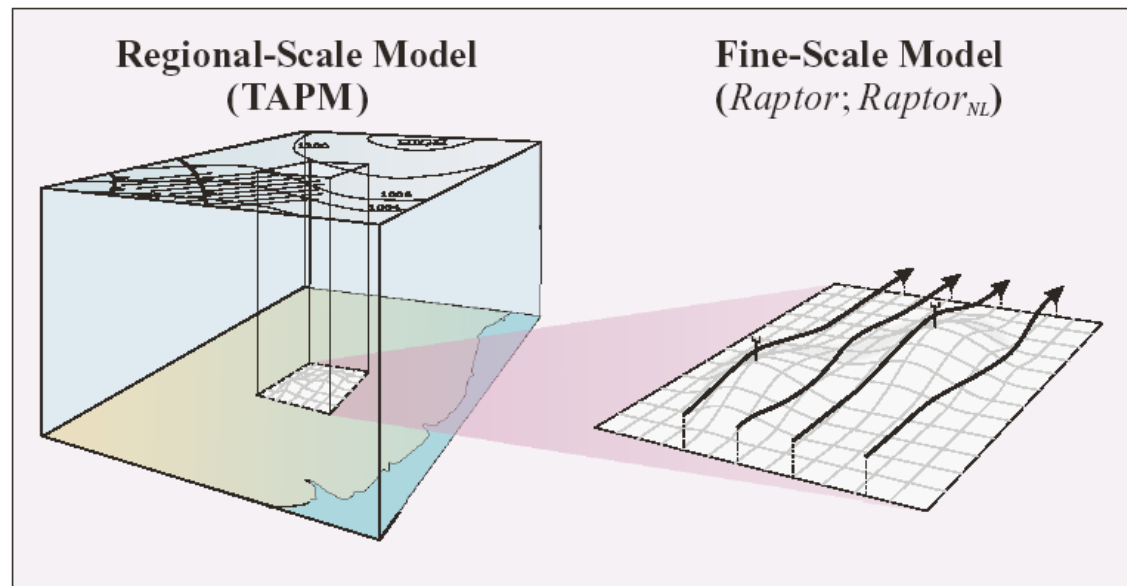
~ 8km resolution



~ 3km resolution

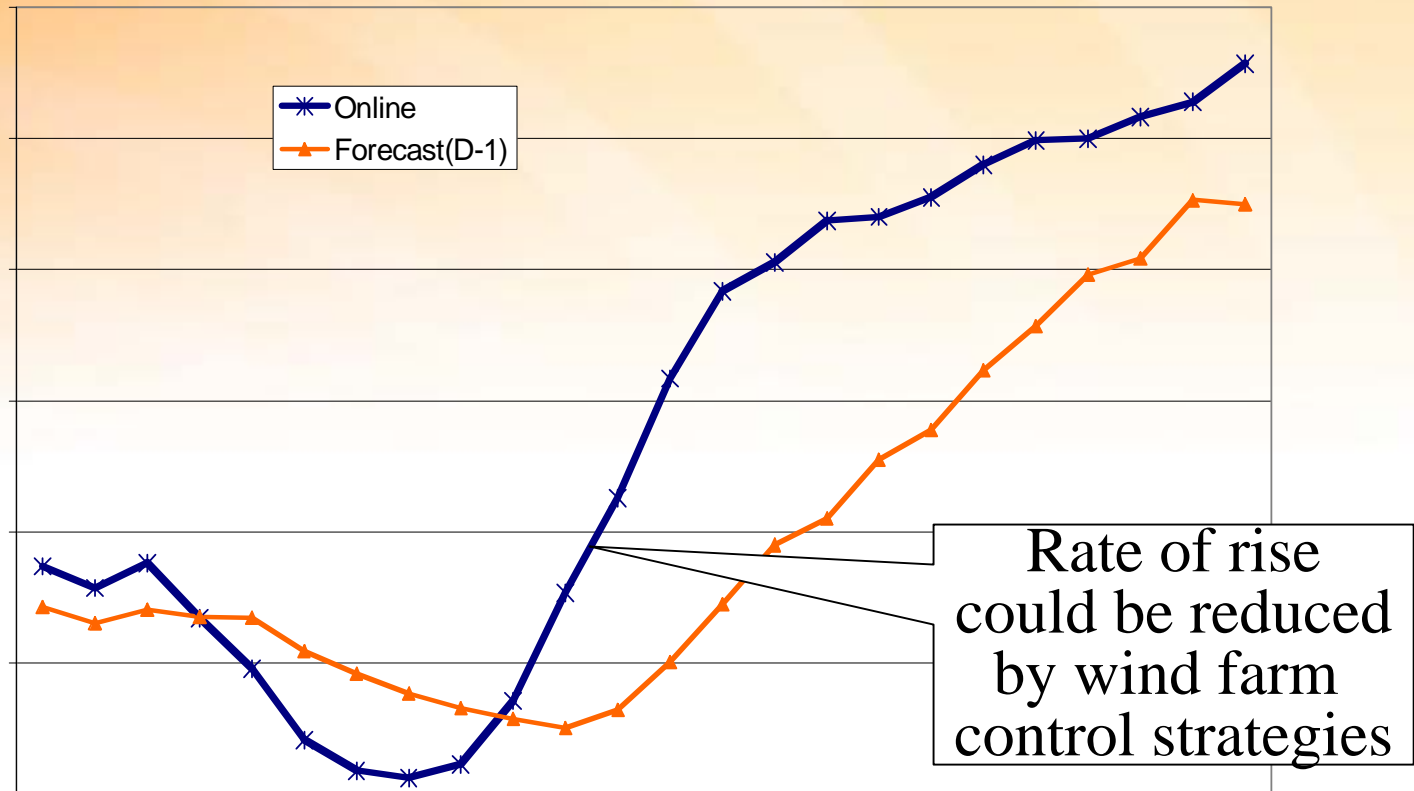


Fine-scale model
Raptor or *Raptor_{NL}*
~ 100m resolution



(Steggle et al, CSIRO, March 2002)

Predicting changes in aggregated wind farm power output (CSIRO, 2004)



Wind - power system integration issues

- Continuous voltage & frequency control:
 - Unlikely to be a problem with modern wind turbines
- Contingencies & power system security:
 - Wind farm starting & stopping transients, including high-speed shut-down
 - Wind farm fault ride-through (modern turbines better)
 - Large changes in aggregated wind farm output
- Long-term generation & network planning:
 - Wind resource may be best where network is weak
 - Long-term wind energy resource behaviour is uncertain

Wind - electricity market issues

- Aggregated wind farm behaviour more predictable than individual wind farms:
 - Difficult to represent in bilateral contracts
 - Difficulty increases with wind farm penetration
- Location (network) values also challenging:
 - Wind farms may be located in weak parts of network
 - Network services essential to capturing wind farm aggregation benefits
- Security & ancillary service costs difficult to quantify & assign



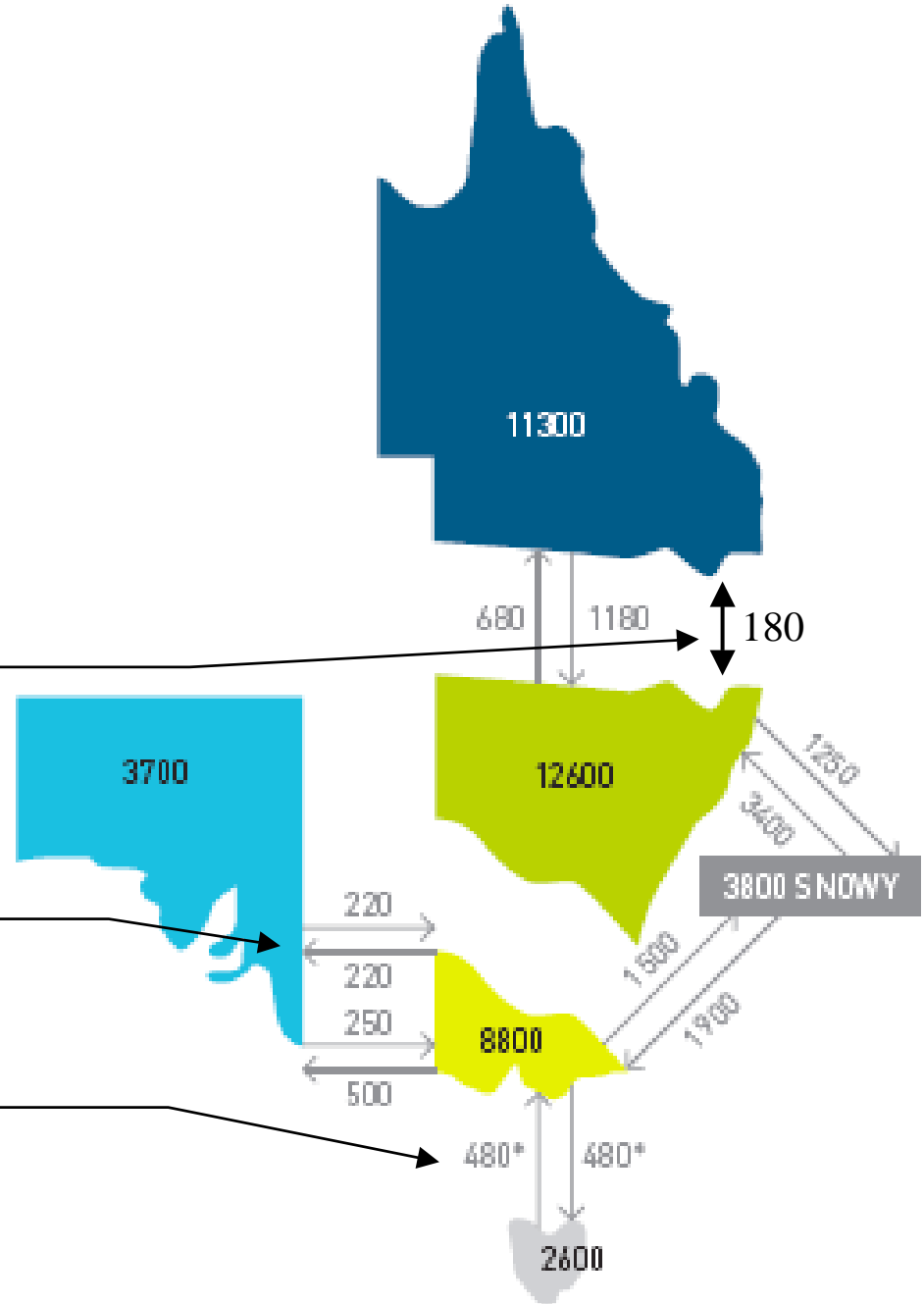
Australian National Electricity Market Scope

(Securing Australia's Energy Future, 2004)

Directlink DC link, currently MNSP

Murraylink DC link, now regulated, formerly MNSP

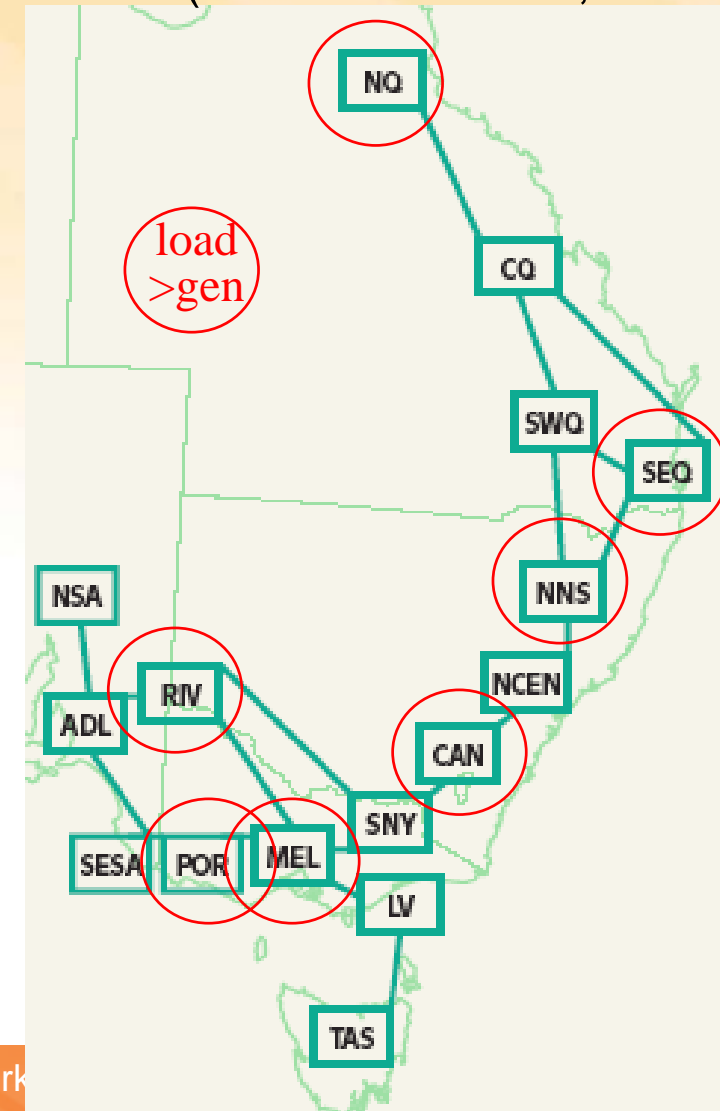
Basslink DC link MNSP (2005?)
600MW short term rating (north)



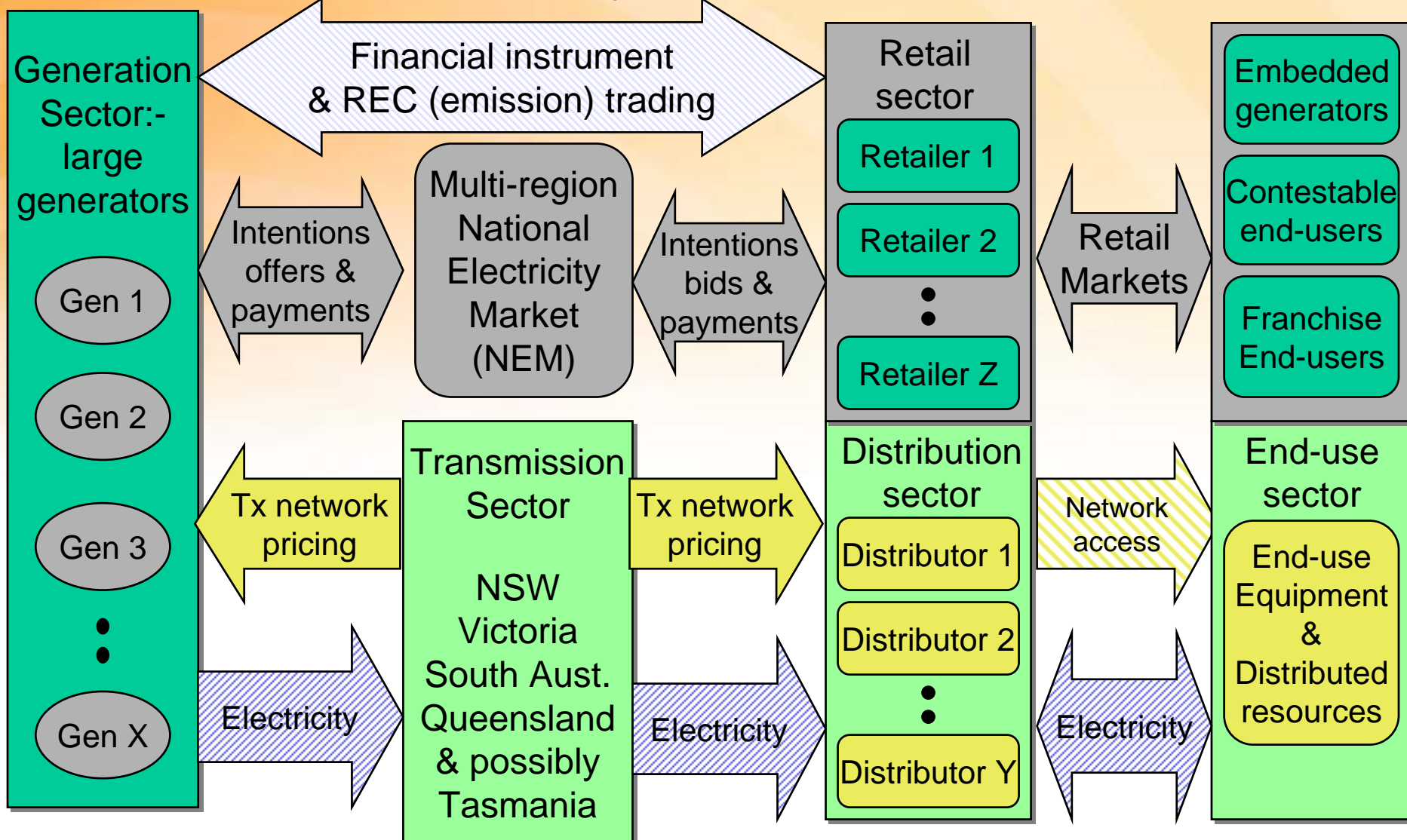


16 region NEM model (NEMMCO SOO, 2004)

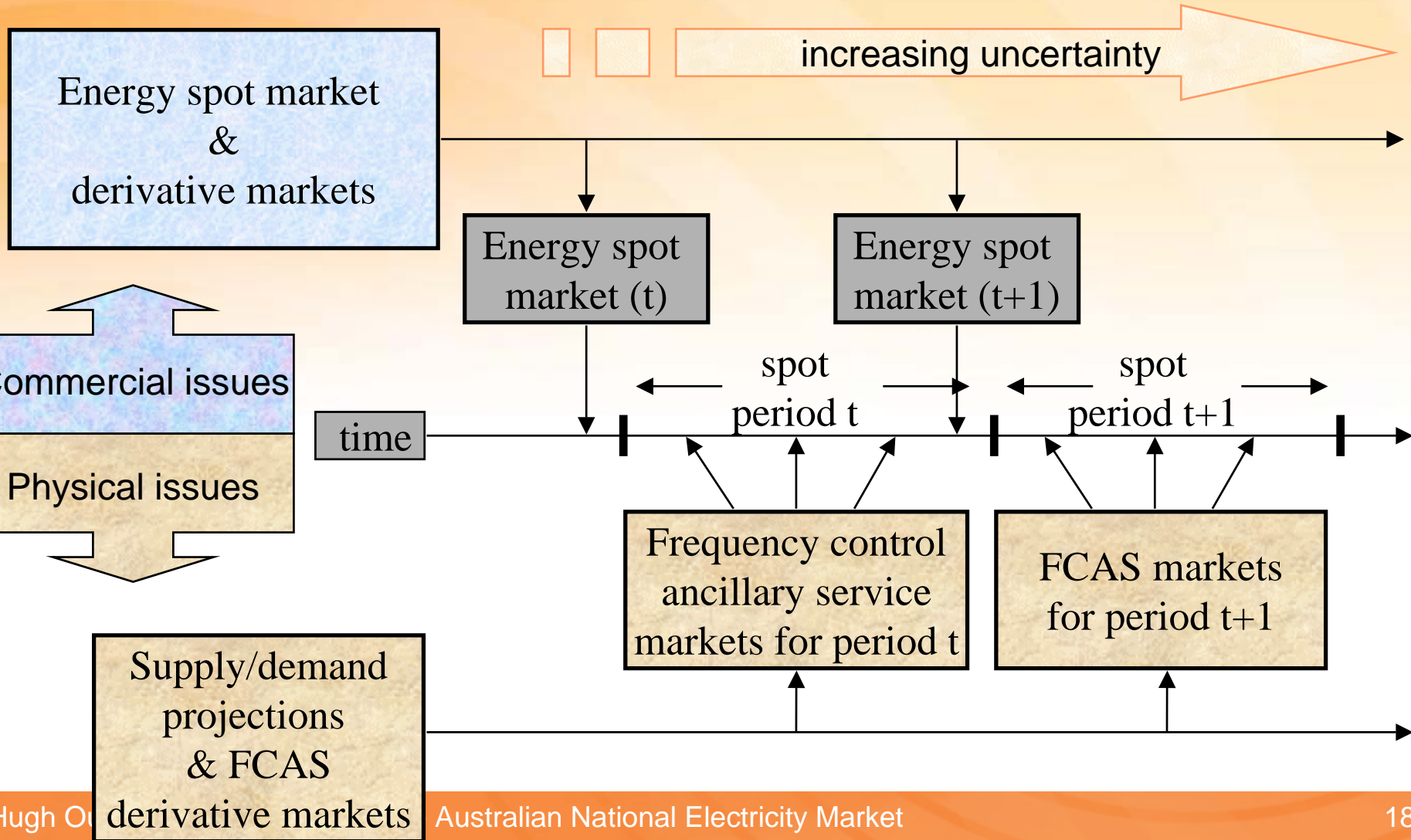
Node	Pk Ld (MW)	Gen Cap (MW)	Net Gen (MW)
NQ	1250	800	- 450
CQ	1900	4150	2250
SWQ	200	2150	1950
SEQ	4350	1450	- 2900
NNS	800	150	- 650
NCEN	10000	11650	1650
CAN	800	300	- 500
SNY	800	3900	3100
MEL	5750	800	- 4950
LV	900	7000	6100
POR	650	0	- 650
SESA	100	150	50
RIV	500	50	- 450
ADE	2100	2250	150
NSA	200	1100	900
TAS	1500	2500	1000



NEM industry & market structure



Managing supply-demand balance in the NEM



Dispatch, Pre-dispatch, PASA, SOO & ANTS

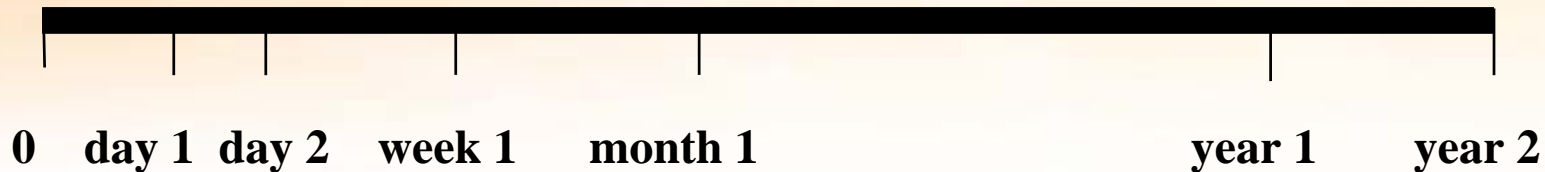
(source: NEMMCO)

SOO & ANTS (10 yr)

Medium Term PASA (2 yr, daily peak)

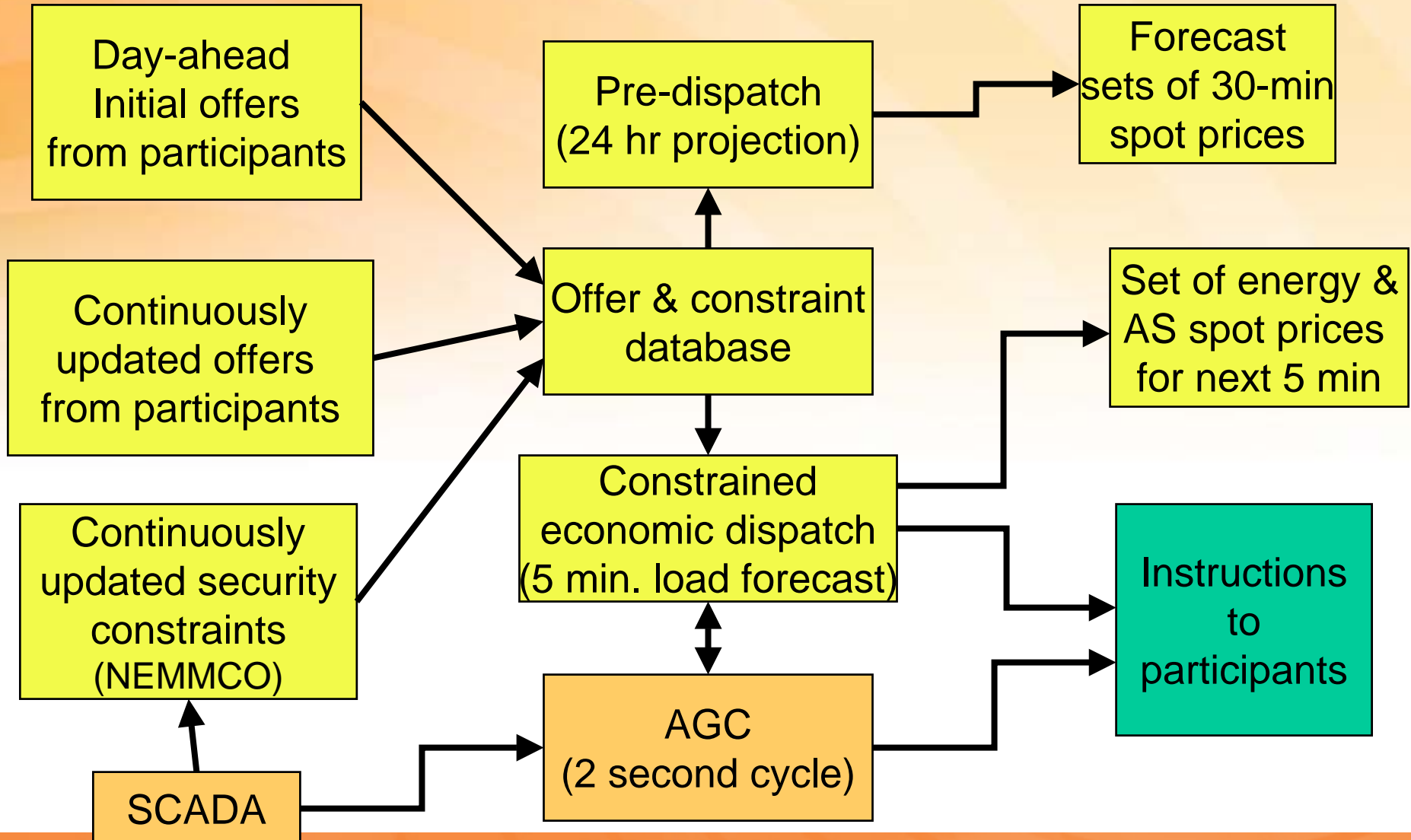
Short Term PASA (7 days, 30 min res, 2hr update)

Pre-dispatch, re-bid & final dispatch (5-min spot prices & projections)



- ST & MT Projected Assessment of System Adequacy support reserve assessment & participant operating decisions. ST PASA projects region demand & reserve for 7 days @ 30 min resolution, updated every 2 hours. MT PASA projects region daily peak demand & reserve for 2 yrs, updated weekly.
- Statement of Opportunities (SOO) & Annual National Transmission Statement (ANTS) are intended to inform generation, demand & network investment decisions (10 year horizon, issued annually)

NEM Pre-dispatch, dispatch & AGC

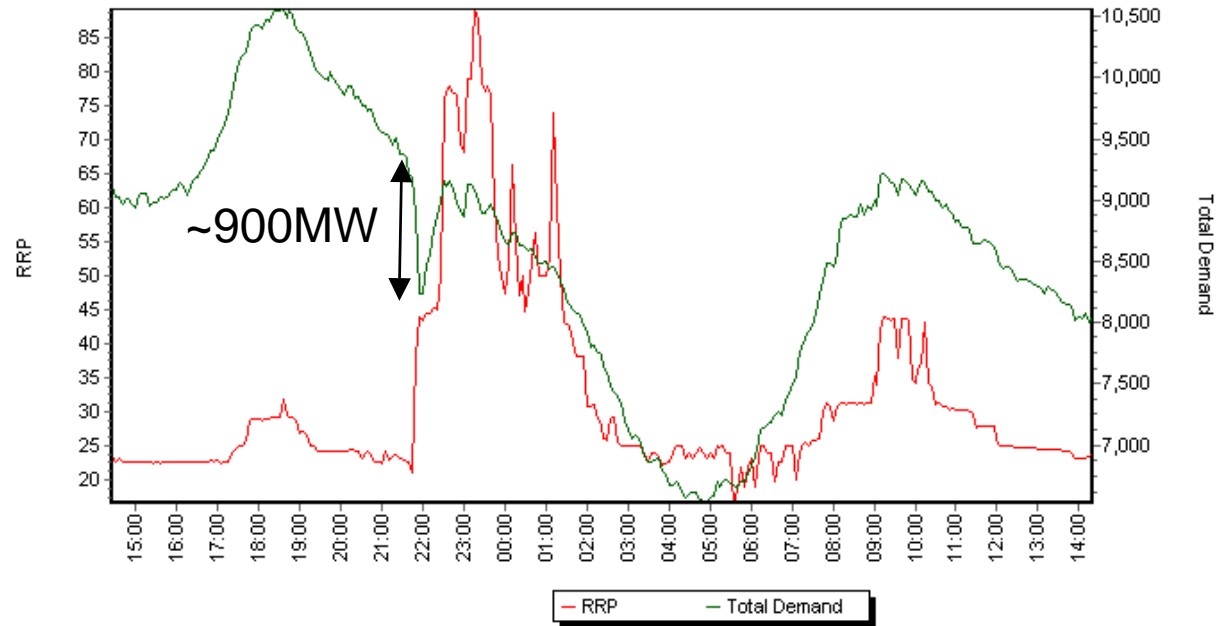




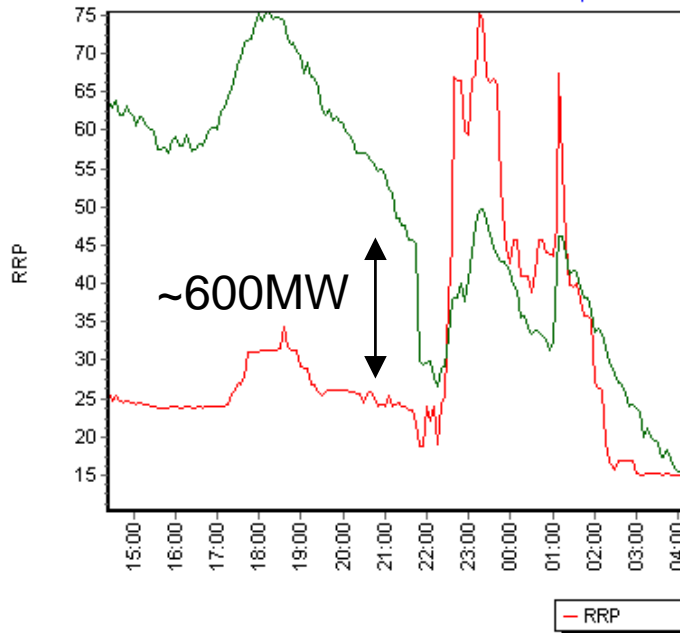
NEM is robust

3100 MW generation trip on 13 August 2004
Frequency fell to 48.9Hz,
~2100 MW load drop in NSW, Qld, Vic & SA
(www.nemmco.com.au)

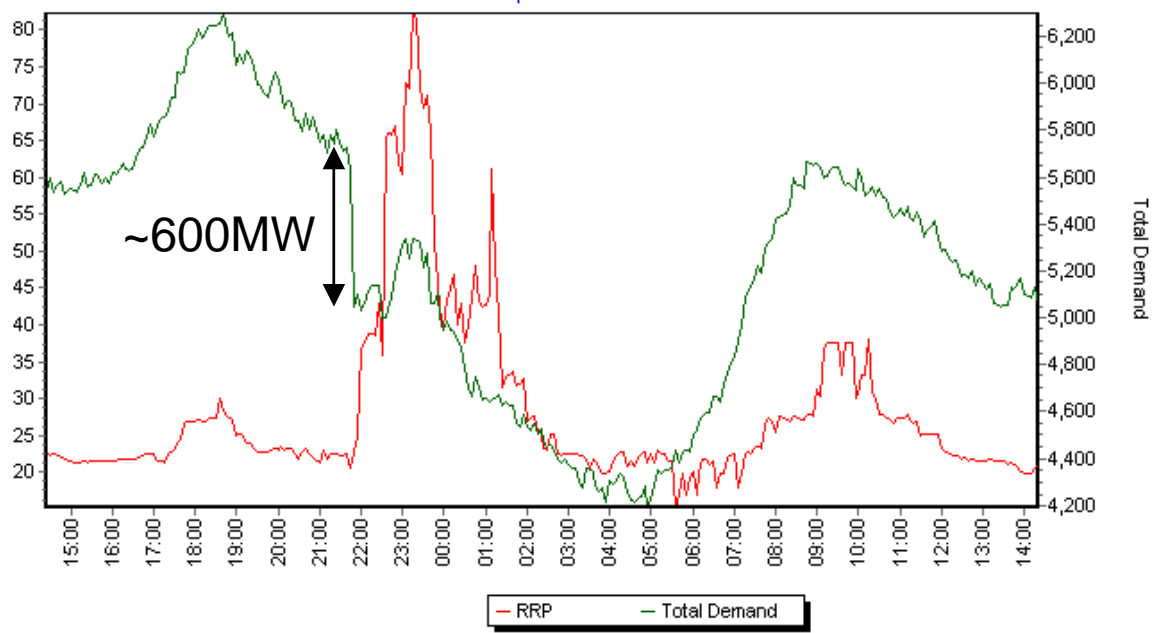
NSW1 5 minute Demand and Price for period 13/08/2004 00:00 to 14/08/2004 14:20



VIC1 5 minute Demand and Price for period 13/08/2004 00:00 to 14/08/2004 14:20



QLD1 5 minute Demand and Price for period 13/08/2004 00:00 to 14/08/2004 14:20



Wind integration issues for NEM

- Power system operation & security assessment:
 - Appropriately aggregated wind farm behaviour:
 - Typical chronological data sets for Monte Carlo studies
 - Probability distributions for convolution-based assessments
 - 5-minute to 10-year timeframe
- Ancillary services & energy - spot & derivative markets:
 - Appropriately aggregated wind farm behaviour:
 - 5-minute forecast for spot price calculation (ANN?)
 - 24-hour chronological projection with error band for pre-dispatch
 - Probability distributions of volume & price for derivative markets
- Network investment:
 - Location-based forecasts of wind development
 - Clarification of financing obligations

Conclusions

- Wind energy is a complex, stochastic resource:
 - Tests the robustness of electricity industry restructuring:
 - Management of power system security (information, aggregation)
 - Effectiveness of market design, including aggregation issues
 - Network investment protocols, including aggregation issues
 - Integration & consistency of overall approach
- Australian NEM is reasonably prepared:
 - Single, accountable (spot) market & system operator
 - Coherent, integrated security & market design
- More work needed:
 - Aggregated derivative markets; network investment



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