

Future Networks Research at the University of Sydney
6 Sep 2013

Future Power Grids¹

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School of Electrical
and Information
Engineering

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THE UNIVERSITY OF
SYDNEY

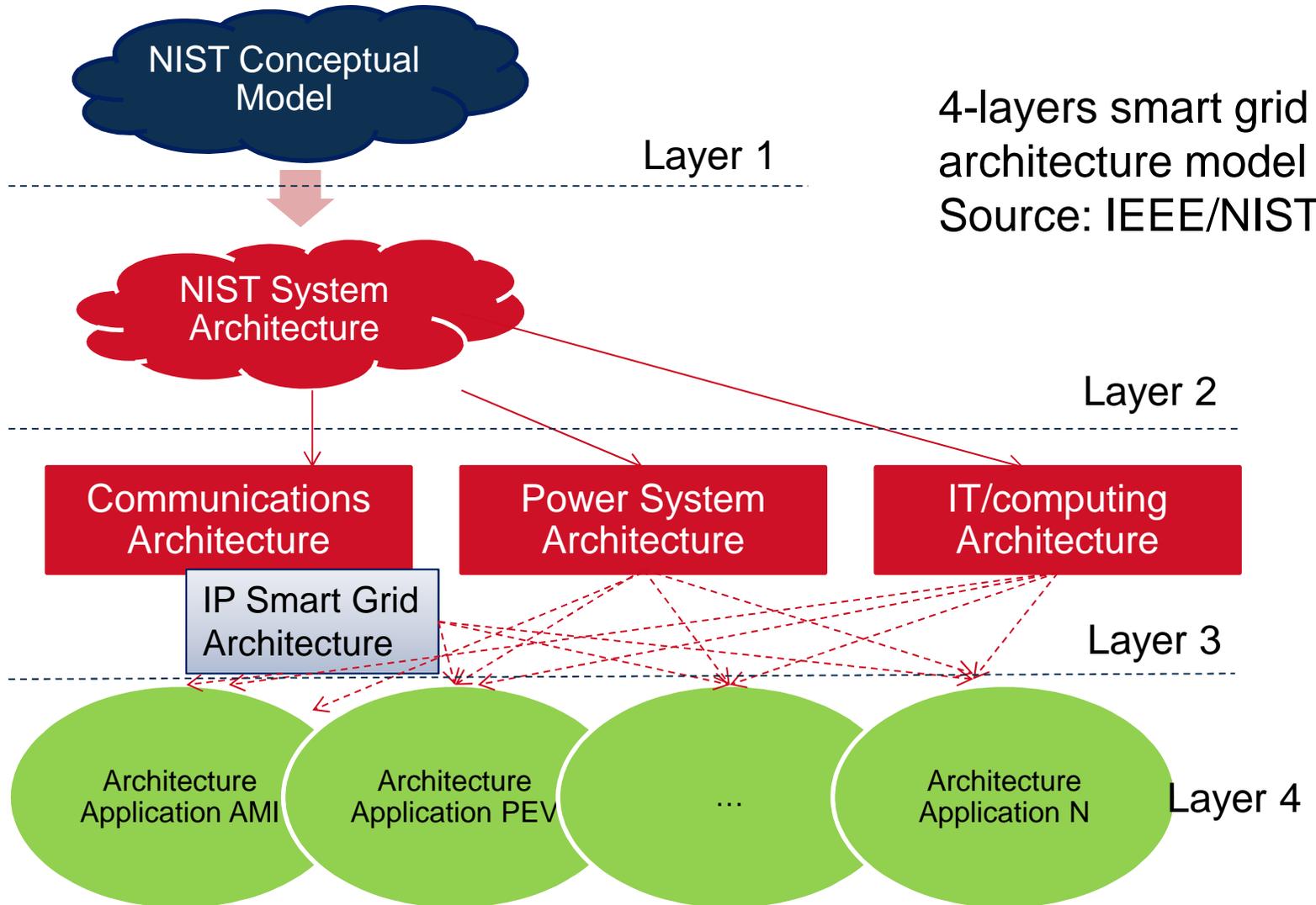
Current Research & Educational Capacity

- › EIE has been providing research and educational services in the following areas
- › Advanced sensor technology
- › Big data and computer networks
- › Defence technology
- › Fibre networks
- › Next generation telco technologies
- › Smart/future grid technologies
- › Renewable energy



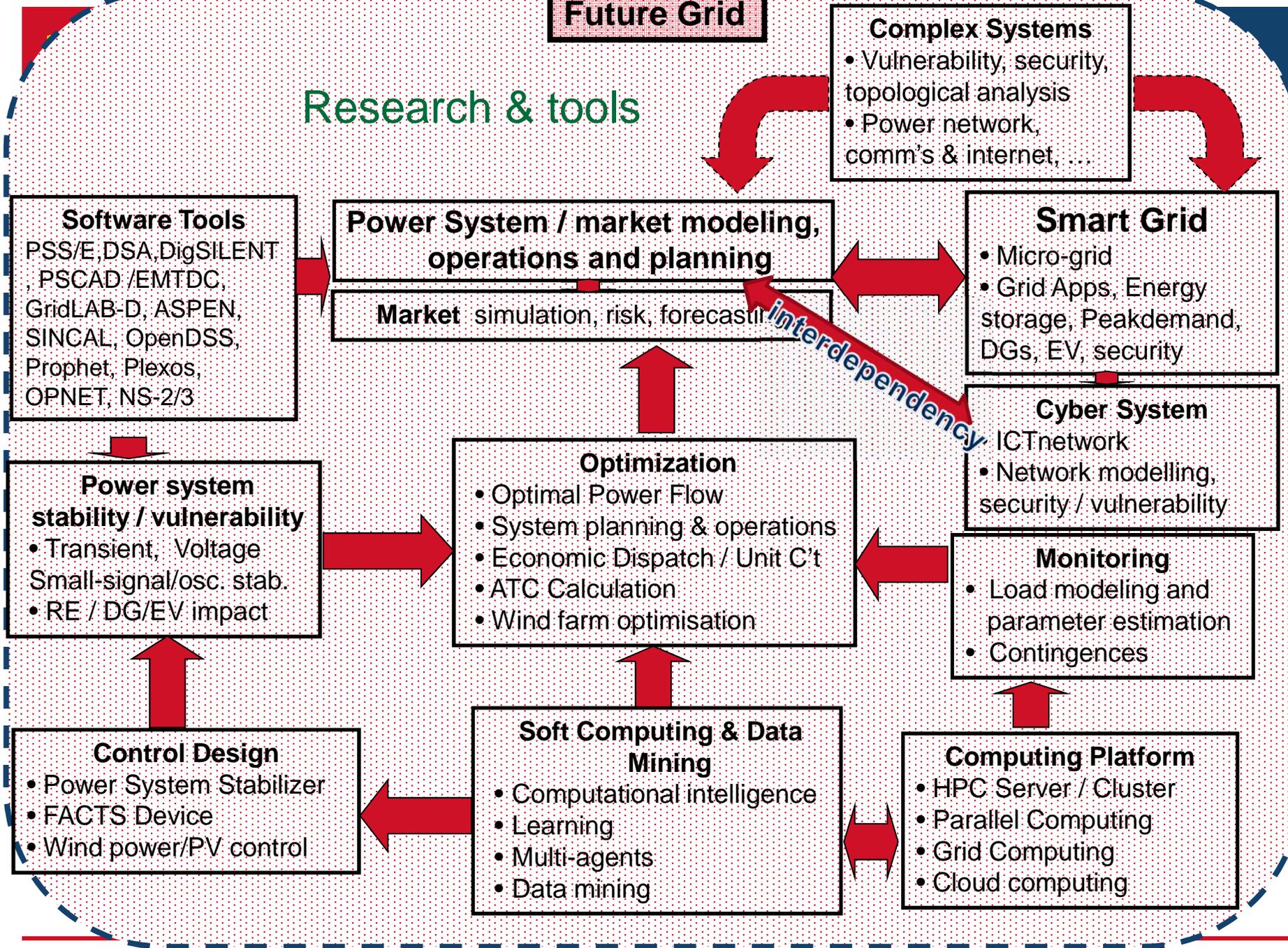
EIE Research Matching of the IEEE / NIST SG Layered Architecture

EIE has individual technologies & R&D capacity



Future Grid

Research & tools



Equipment

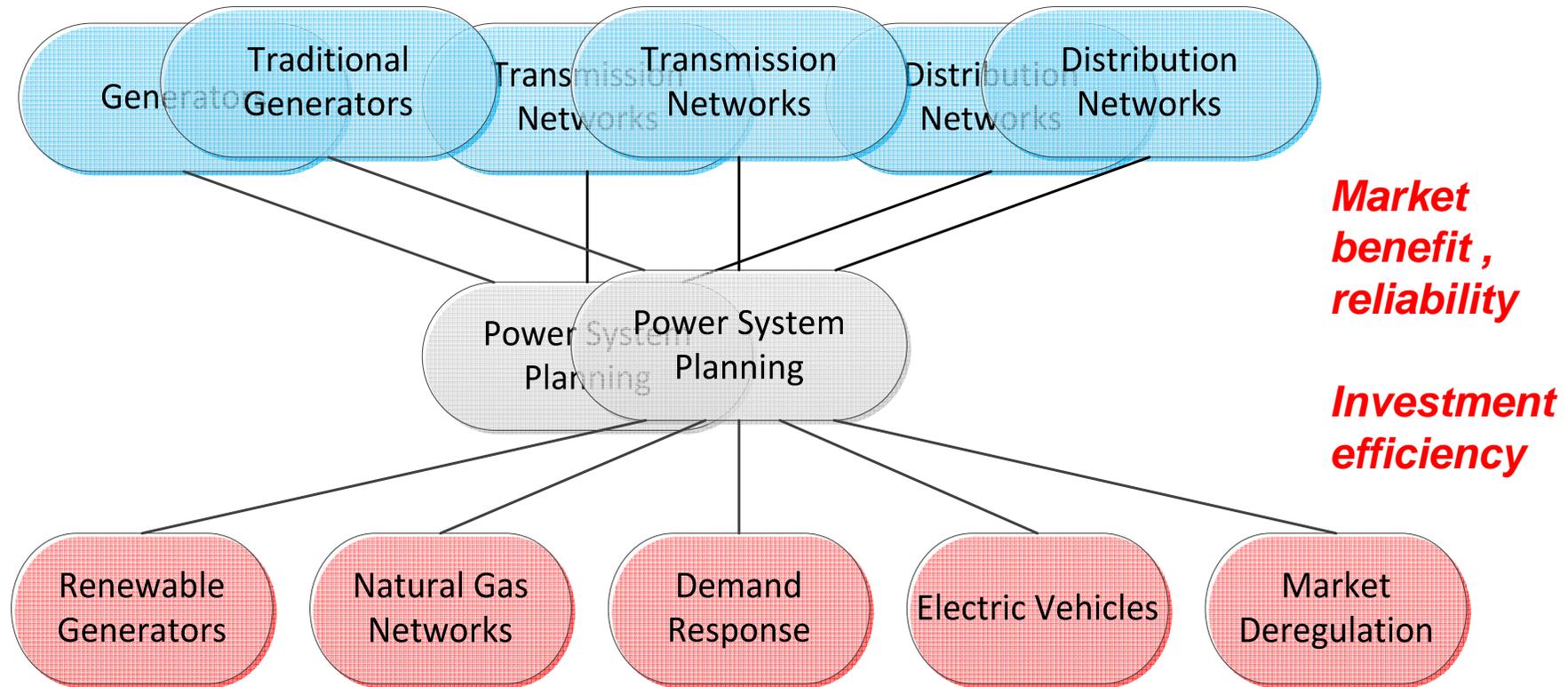
- › ABB power technologies equipment
- › Robotic arm
- › \$1m digital power system simulator

› Usage:

- Professional Training
- Teaching
- Research and
- Final year thesis project



New Challenges Faced by Power System Planning

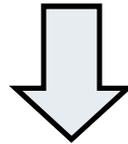


- Traditional power system planning only considers three main components.
- A number of new factors have to be taken into account in power system planning, which introduces significant challenges.

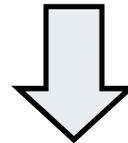


Problems in planning

1. The coordination of power system planning and natural gas network planning.



2. Flexible/stochastic/hybrid methods for handling the uncertainties in the planning process.



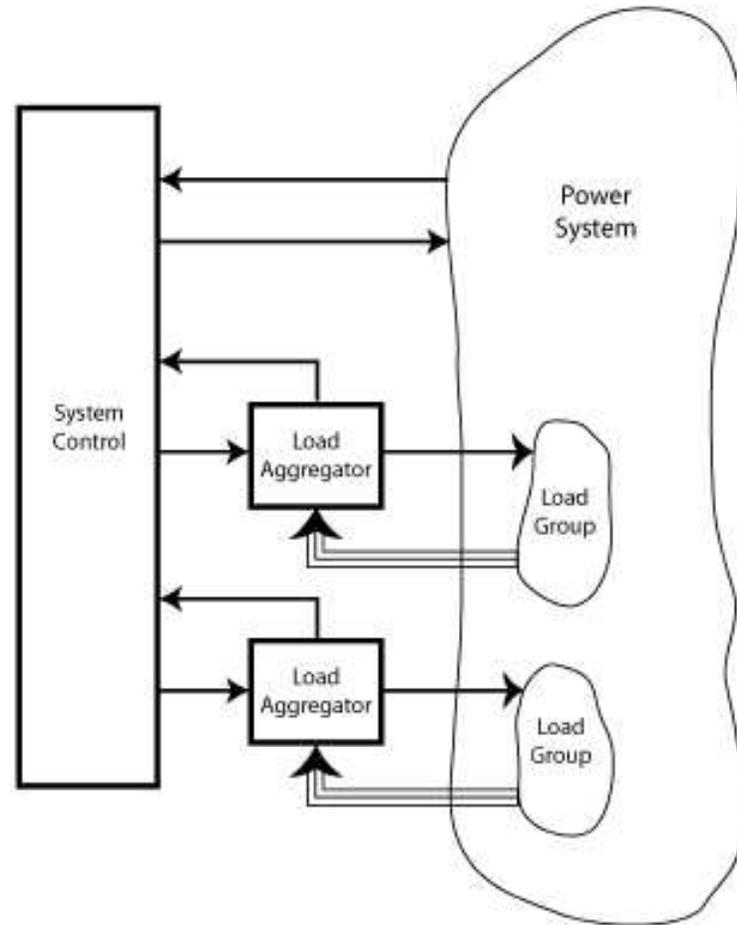
3. Analyze the impacts of increasing customer participation (e.g. demand response and PHEVs)

- › HOW to shape the whole grid so that:
 - It adapts to the energy mix trajectory over decades
 - with minimum cost
 - specified stability margins
 - limited carbon-emissions
 - limited reliability

- › We need to allow for controls used, including DM, reliability – or results too conservative

- › Excessive reliability costs too much – use probabilistic measures

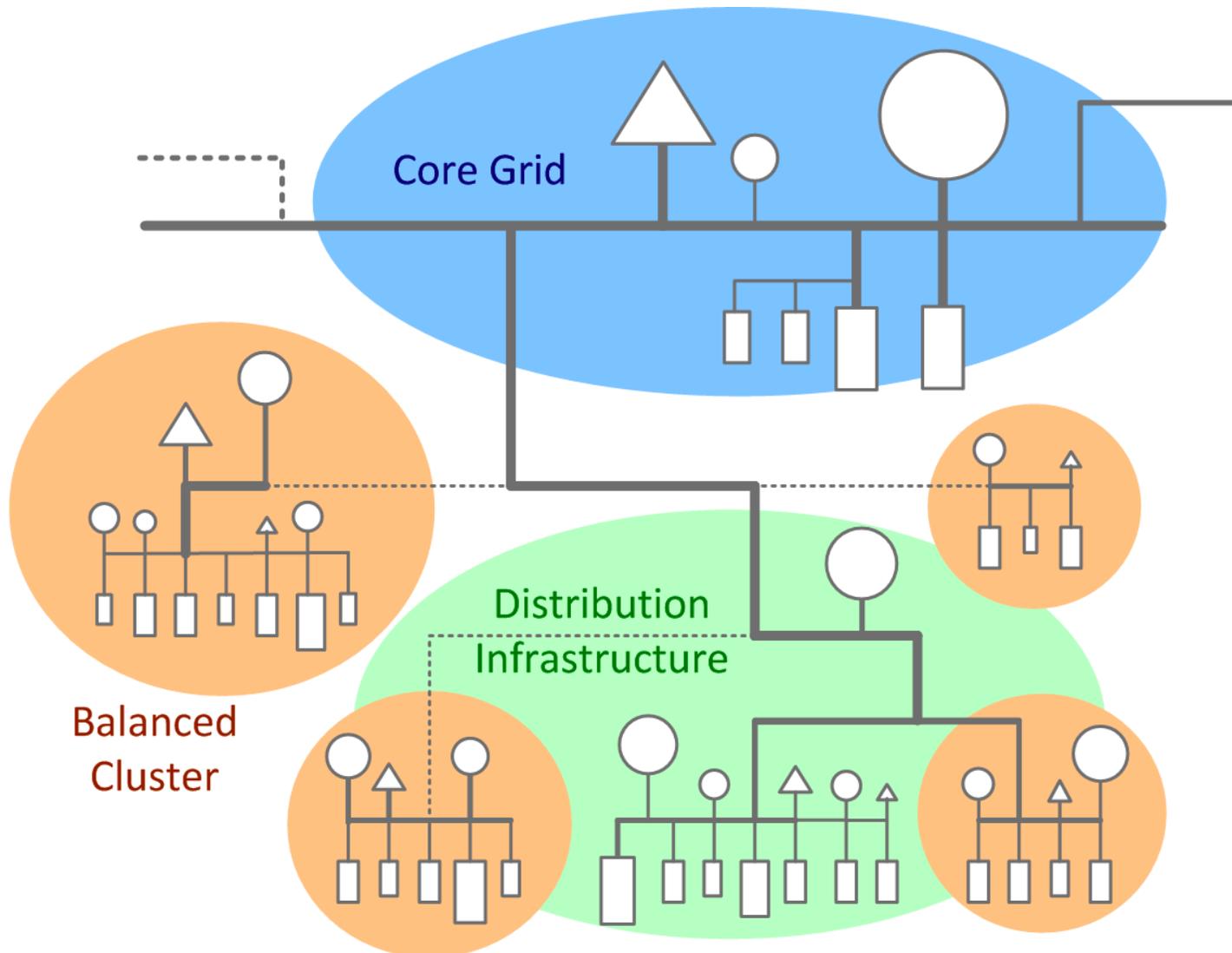
Distributed architectures for demand response



Ref: Calloway and Hiskens, Proc IEEE, 2011

Fig. 6. Schematic representation of a hierarchical load control strategy.

Grid2050 Architecture (Bakken et al.)



Bigger question - grid structure?

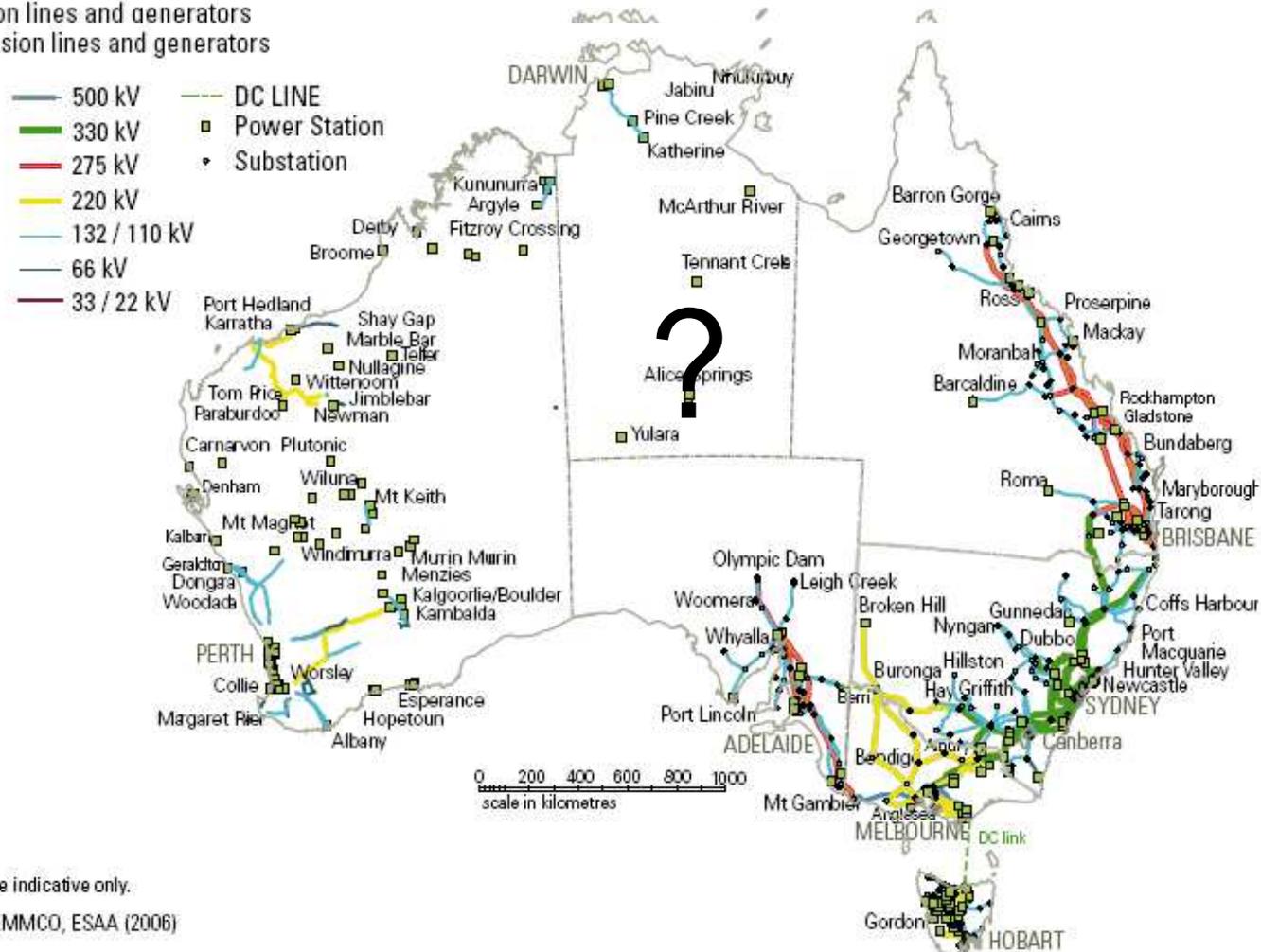
➤ There are already extreme scenarios

1. What if consumer prices go so high and local storage cost so low that most consumers can go off grid
2. Supergrids connecting continents to major sources of renewable power, e.g. Desertec

Studies of future grids have been too driven by possible ICT developments.

Economics will decide, e.g. cost of storage vs grid costs!

Transmission lines and generators
Transmission lines and generators

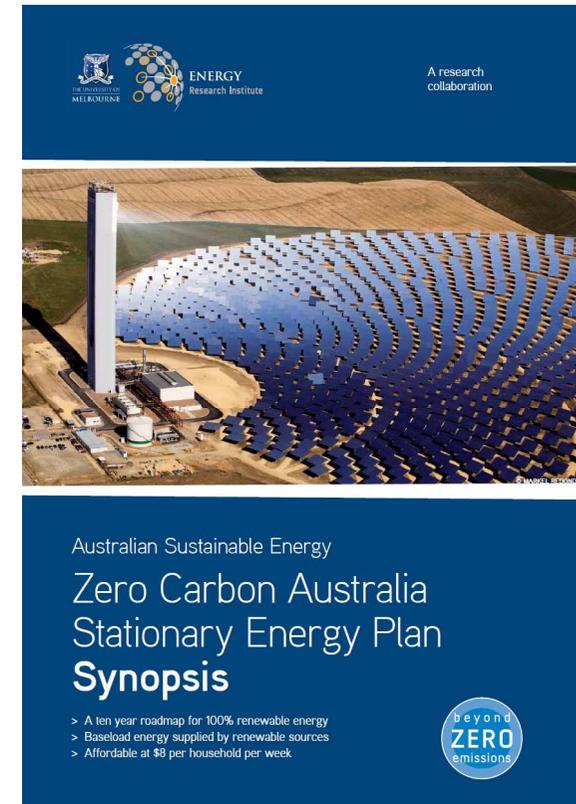


› Assume:

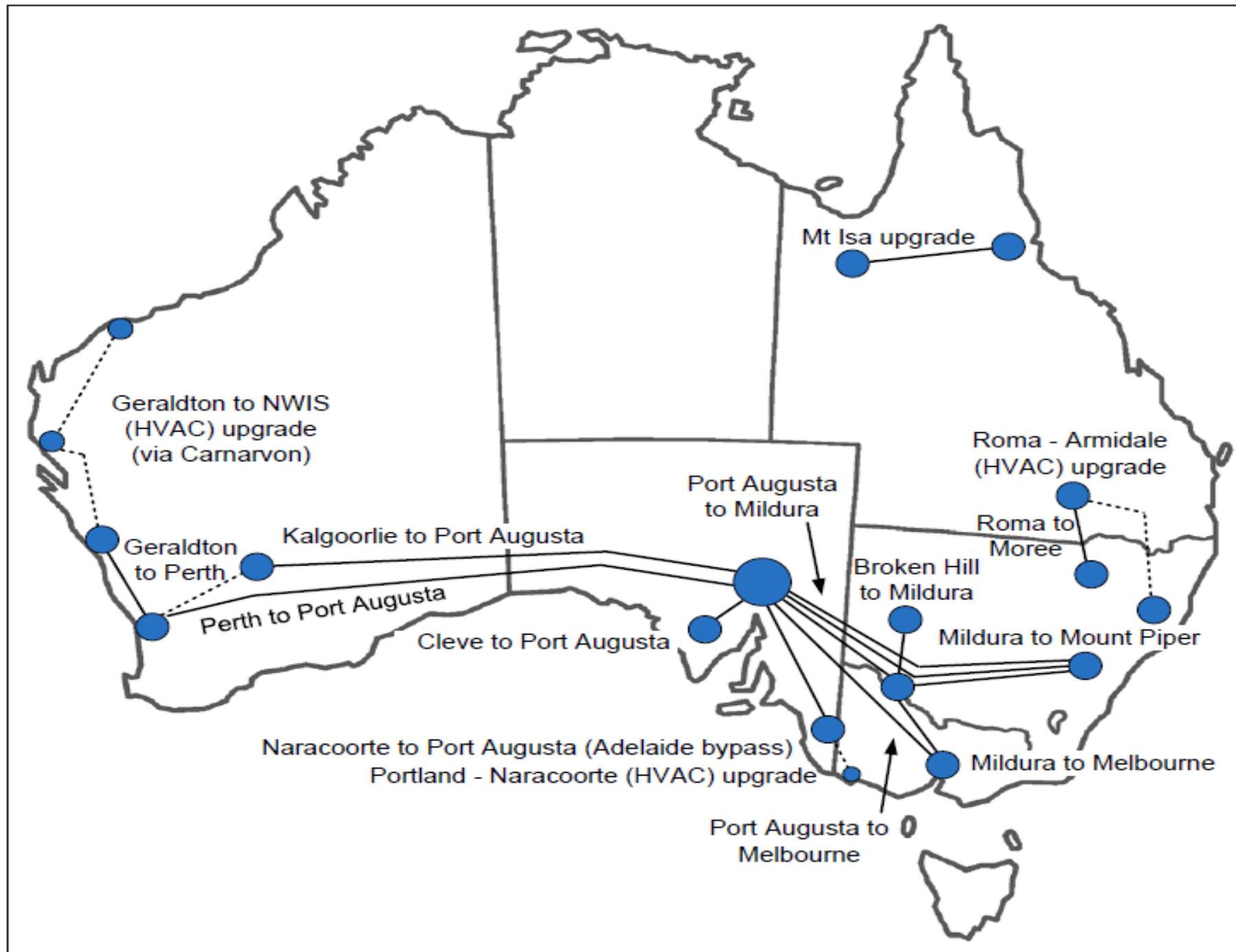
- generation is renewable (rooftop to farms)
- fixed distributed storage (batteries to pumped storage)
- mobile storage (EVs)

› Aim: Provide an effective and efficient grid

› Real example: Masdar City, Abu Dabhi



ZCA2020 proposed high voltage grid upgrades



- › Can we continue incrementally?
 - › Can we keep transmission following generation, i.e. create (government controlled) ‘electricity highways’ or ‘super grids’ and hubs based on solar, wind etc
 - › Need expanded computer analysis to solve ‘network of network’ problems, e.g. how electricity and gas systems interact, and water, transport
 - › Must always model stability and capability to control
-

- › Robustness to all the uncertainty (Hiskens)

- › Dependence on structure
 - Find the vulnerable points for collapse
 - Study motifs for the new situations (project in Aus)
 - Bigger questions: Backbone networks vs weakly connected clusters for diverse generation

- › For theorists: How to guarantee stability from local checks
 - certificates (with some exchange)
 - can these be granulated?

- › At this point just have a lot of observations
- › All stability types affected by new dynamics, but it is hard to make many general statements
- › Locations and generation types important, loads as before
- › Structure of network important

Need more fundamental studies that can be applied generically

- Mechanism models, cf. as for voltage stability
- Control responses

- › Numerous scenarios (millions)

- › How to scale up solutions to such large systems and all scenarios – ideas from optimization and learning theory

- › How to find the weak spots
 - Transient instability
 - Oscillations
 - Vulnerable points for collapse

Future Grid Cluster

- The proposed cluster, consisting of four of Australia's leading universities, will assist CSIRO (and Australia) in delivering the first analytical framework of its kind to systematically investigate the most economically efficient energy network (electricity and natural gas) configurations for Australia.
- With this framework, to identify the lowest cost pathway to integrate significant amounts of large and small scale renewables into our grid with existing technologies while maintaining operational stability.
- To pave the way for significant emissions reductions in Australia's most carbon intensive economic sector.

Funded by CSIRO, led by The University of Sydney - also a FG Forum for utilities on a shorter time-scale

- › Population 35million
 - › Large nuclear, geothermal and gas units with characteristics similar to present large units
 - › Thousands of small renewable generators assembled (virtual generators) at 25kv to 330kv
 - › Our special 'stringy' grid will be less so, but how?
 - › Still 'no infinite bus'? cf. Denmark
 - › Major changes to loads: AI plants gone, new desalination plants, demand management, EVs
-

Four Projects

P1 - Power and Energy Systems Modelling and Security

P2 - Grid Planning and Co-optimisation

P3 - Economic and Investment Models

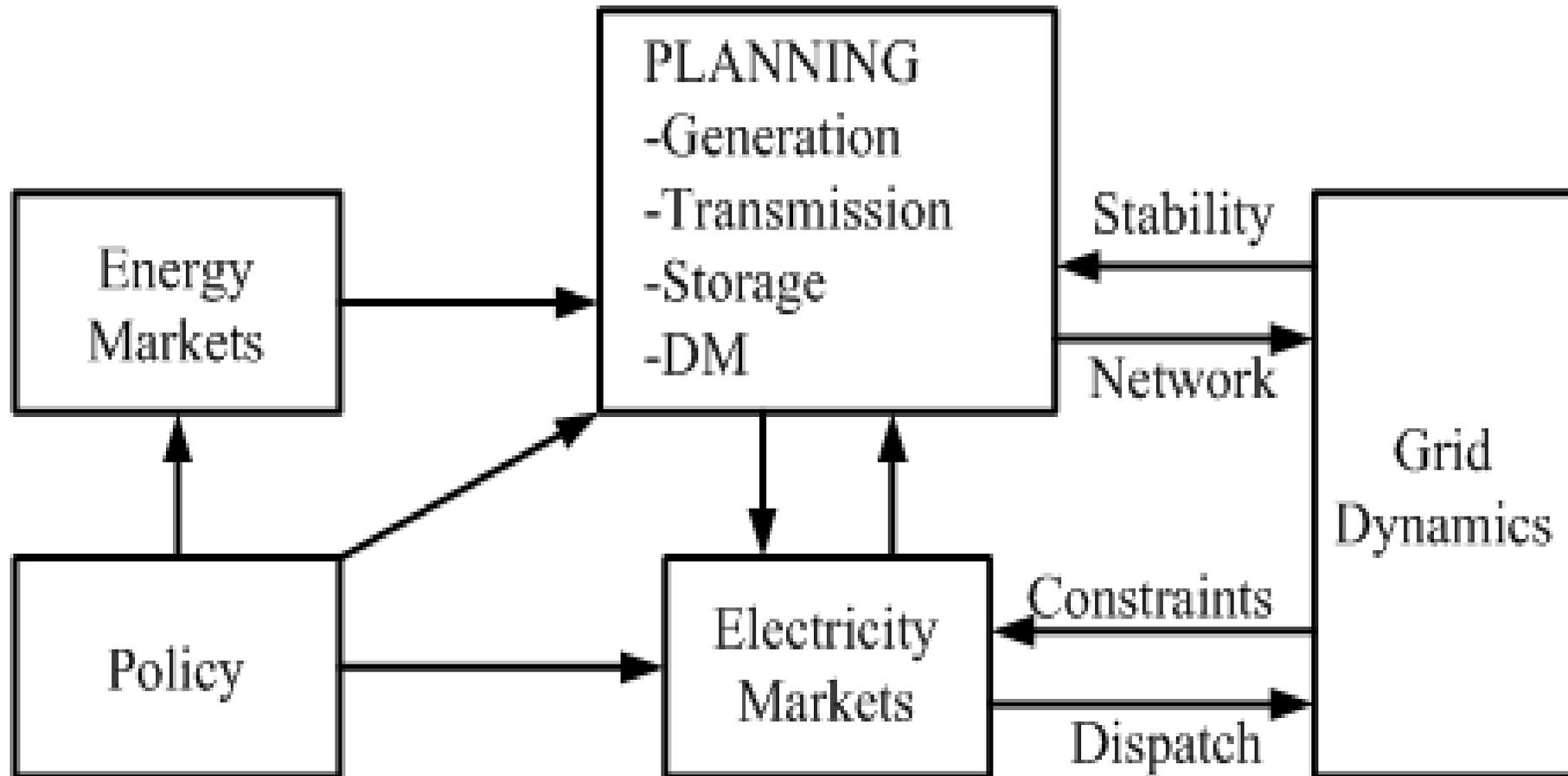
P4 - Robust Energy Policy Frameworks for Investment in the Future Grid

P1 – Power and Energy Systems Modelling and Security - University of Sydney lead

- To provide a modelling framework for the future Australian electricity grid out to 2050.
- To analyse beyond energy balancing to include grid power flows, stability implications, security and resilience to changing technologies.
- Diverse scenarios for levels and placement of renewable generation, different transmission and topologies, differing load management and storage technologies will be considered.
- Balancing power, stability and vulnerability to collapse. Impacts of technology and policy change will also be assessed.

P2 - Grid Planning and Co-optimisation - University of Newcastle lead

- Investigate the mechanisms of natural gas and electricity grid planning and the co-optimisation problem;
 - To solve the multi-stage, multi-objective planning problem to find optimal planning options considering the natural gas and electricity grids simultaneously.
- Develop a co-optimisation framework to ensure that the electricity and natural gas networks are co-optimised for prescribed scenarios consistent with long-term planning approaches and short-term operational requirements.
- The objective is to maximise overall social benefit subject to constraints associated with the natural gas and electricity grid networks.



- › USA DOE Future Grid university cluster

- <http://www.pserc.wisc.edu/research/FutureGrid.aspx>

- › Fraunhofer Institut

- <http://www.iwes.fraunhofer.de/en.html>

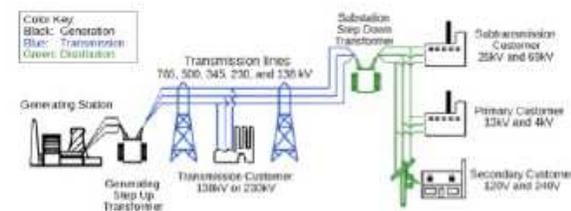
- › UK Grand Challenges

The Future Grid to Enable Sustainable Energy Systems

A Department of Energy-Supported Initiative
of the Power Systems Engineering Research Center

What will the future grid look like?

A systematic transformation of today's electric grid is underway to enable high penetrations of sustainable energy systems. The grid is evolving from a network architecture with relatively few large, hierarchically-connected, tightly synchronized energy resources supplying large, medium, and very many small passive consumers. It is evolving toward a network driven by many distributed and concentrated, highly variable energy resources mixed with large central generation sources, energy storage and responsive users. The effective transformation of the grid requires decisions based on identification and solution of major operating, planning, workforce, economic and public policy challenges.



Traditional Grid Model (Click image to enlarge)



Wind Energy & Energy System Technology

Fraunhofer Institute for Wind Energy and Energy System Technology



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- Universities
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Motivation

Future grids

Stability, control, planning

Research questions

Projects

- Modelling with DM
- Stability with renewables
- Networked RE farm control
- Probabilistic margins
- Stochastic TNEP
- Generic market constraints with RE
- Co-optimisation across GenTrans
- Network vulnerability

Conclusions

- › Identify the granulated graphs
- › Taxonomies of buses, lines, ‘motifs’
- › Taxonomies of dynamics
- › Aggregation up the levels

Lots of work here before we can begin analysis!

› Zero Carbon Australia proposal for HV grid upgrade

FIGURE 5.3
ZCA2020 proposed high voltage grid upgrades

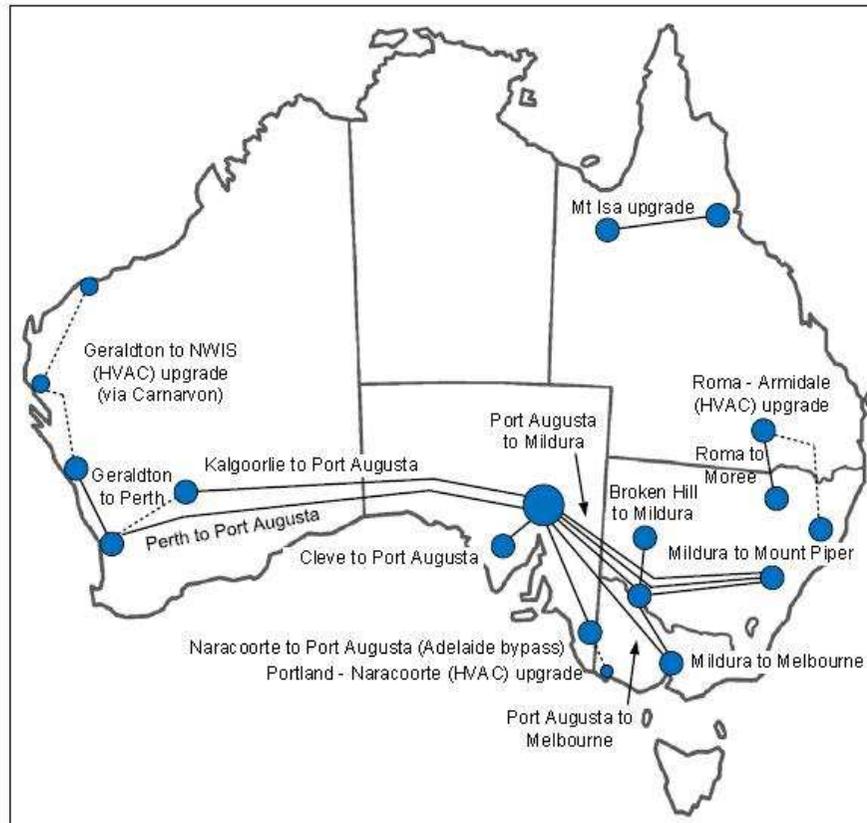
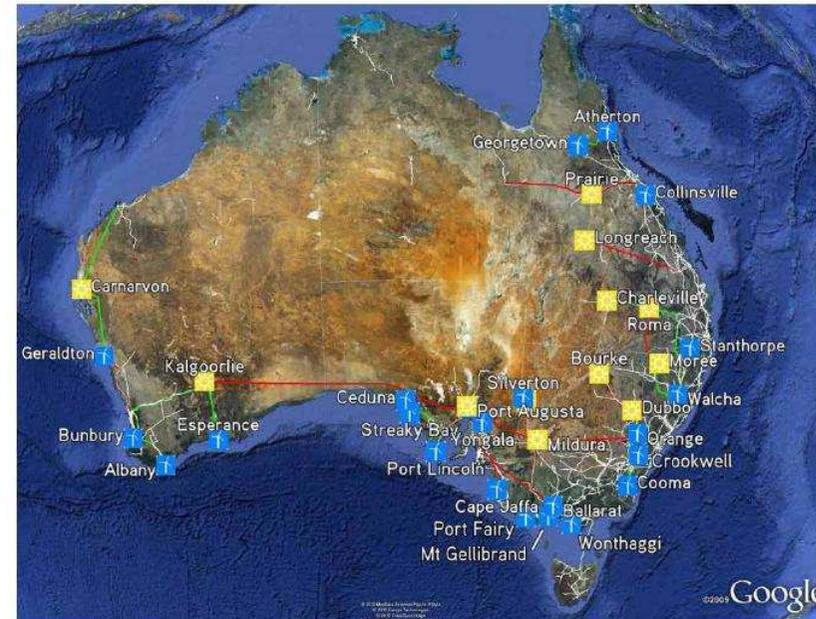


FIGURE 5.2
Proposed ZCA2020 National Grid
Solar sites are shown as yellow icons. Wind sites are shown as blue icons.
HVAC links are shown as green lines. HVDC links are shown as red lines



Source: Australian Sustainable Energy Zero Carbon Australia Stationary Energy Plan 2010

- › Scanning tool – fast simulation
- › Revive direct methods, but load models no longer work
- › Maybe EEAC type
- › Most likely new algorithmic approaches
- › Find weak points
- › Network science ideas on vulnerability

- › ‘Future grids’ a different and bigger question to ‘smart grids’ – long-term planning vs just better control
- › Should we plan or grow the network incrementally – different scenarios
- › Coordinated planning and control for high RE needs development
- › Algorithms for planning (and control) – computational challenges
- › Networks science ideas look promising BUT only after redone on useful models



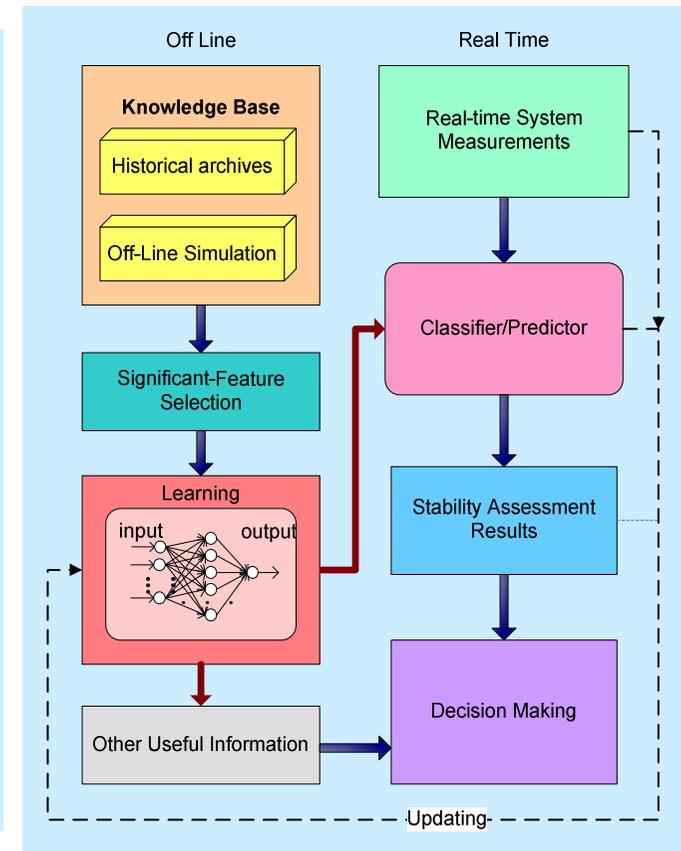
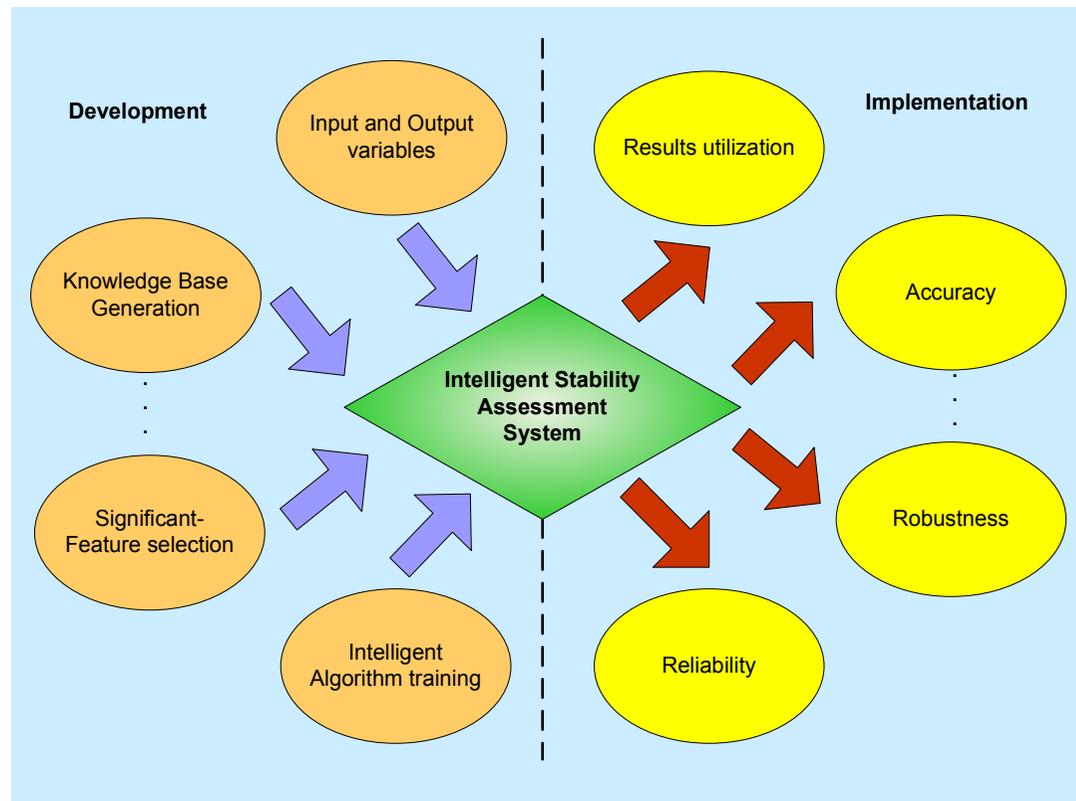
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System security and vulnerability assessment

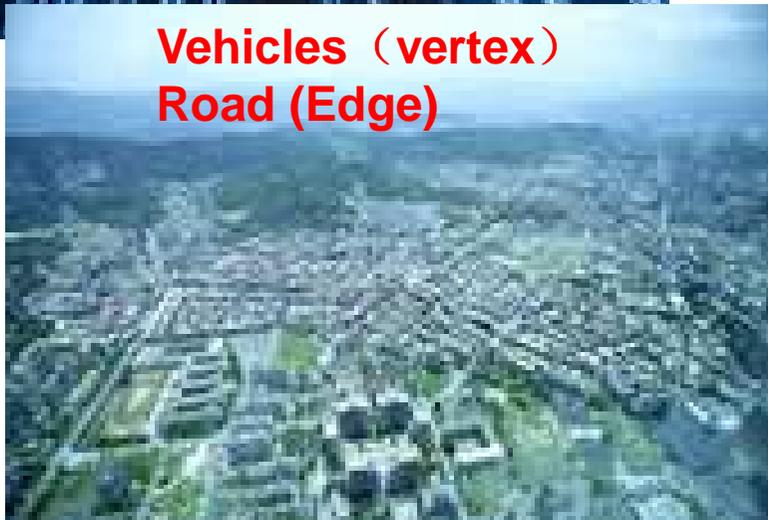
- › System security assessment to avoid cascading failure requires high computational efficiency
 - Deterministic vs probabilistic stability assessment
 - Grid computing
 - Load modelling & its impact
- › In addition to conventional time domain methods and energy based methods, new methods have been proposed
 - Data mining & intelligent system & WAMS based approach
 - Complex system based approach
 - Sensitivity based approach

EPRI funds, IEEE Taskforce member on cascading failure, State Grid funds, PM&C funds

Intelligent system based security assessment

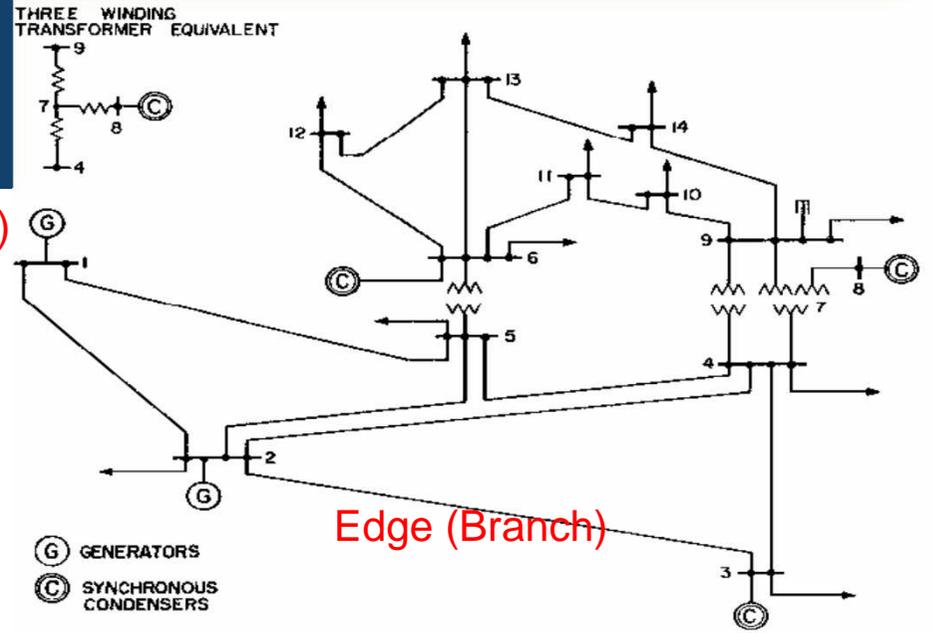


Complex Systems approach

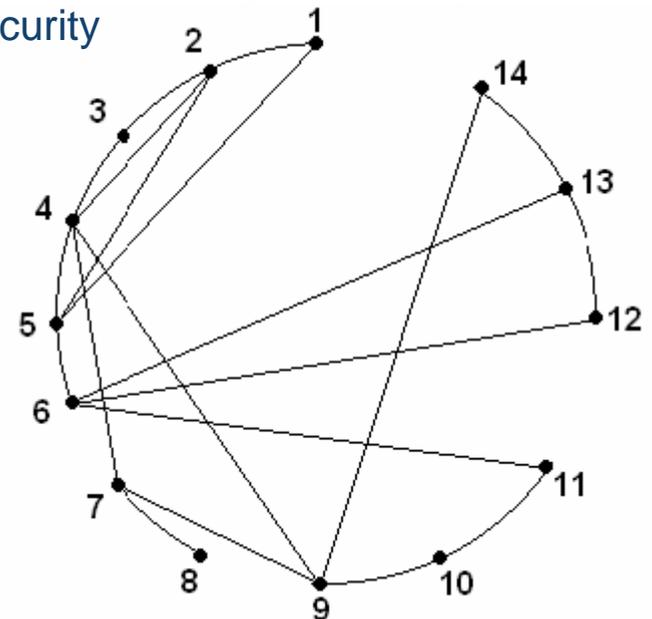


Vehicles (vertex)
Road (Edge)

Vertex (Bus)



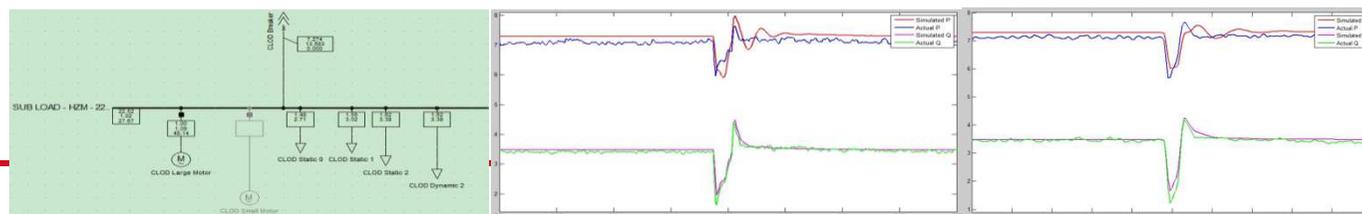
The information exchange efficiency measures the network security



undirected weighted graph

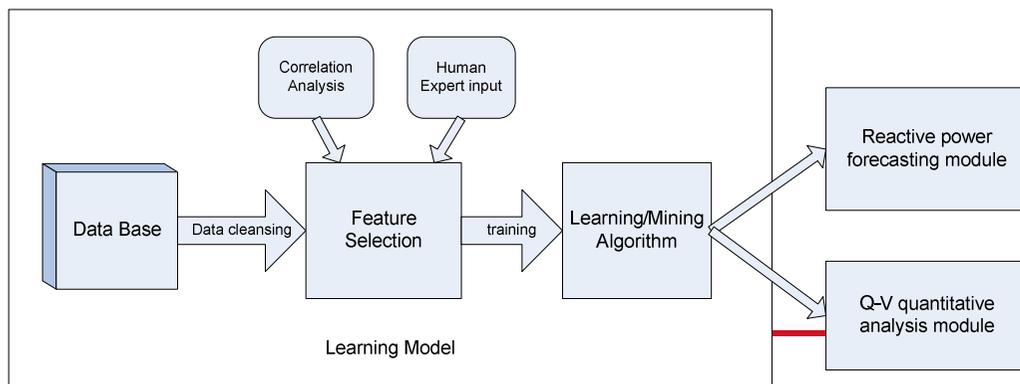
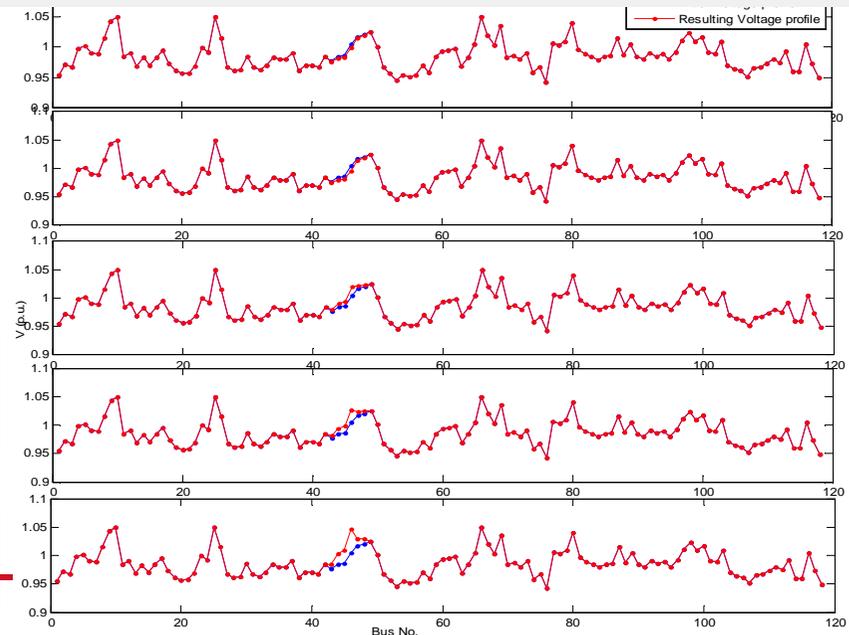
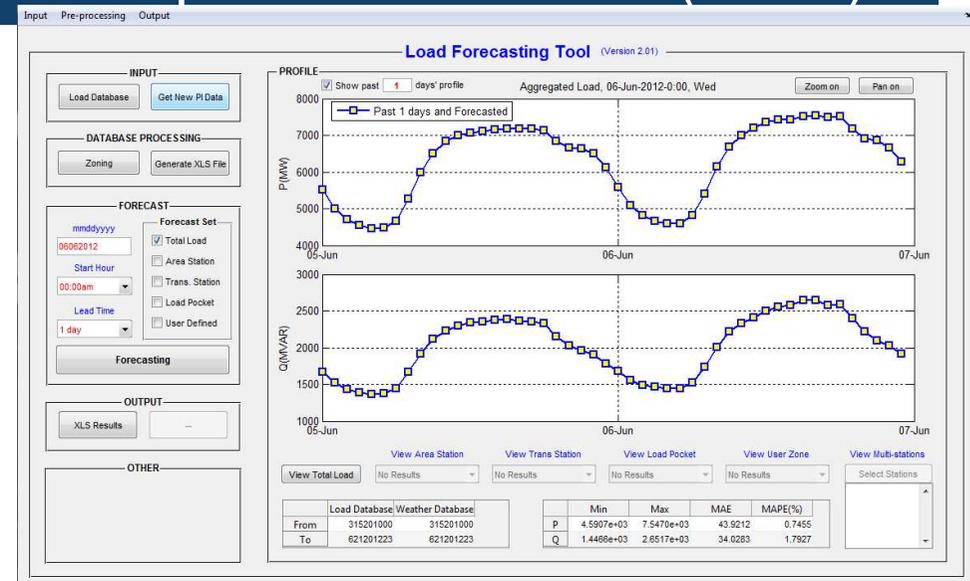
Load Modelling (load model parameter identification & generalisation)

- › Research Problems:
 - Different values of parameters describe different dynamic properties of load model.
 - using different dynamic response data in the task of parameter identification will obtain different parameter values.
 - how the real dynamic properties of load model can be reflected by the appropriate selection of load model parameters.
 - Specific measurement based load modelling, PSS_E, DigSILENT
- › Support: EPRI, ARC, HKPU, SG/EPRI, Western Power Corp, AEMO
- › CIGRE C4.605: Modelling and Aggregation of Loads in Flexible Power Networks



On-line automatic var predictive control (EPRI)

- › Operational data (CIM format)
- › Predict system Var & recommend reactive power switching to maintain overall grid voltage stability

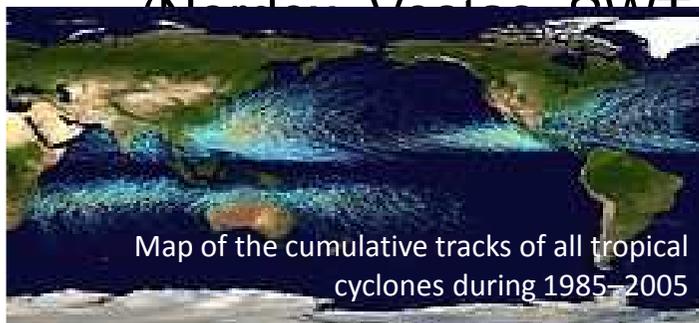
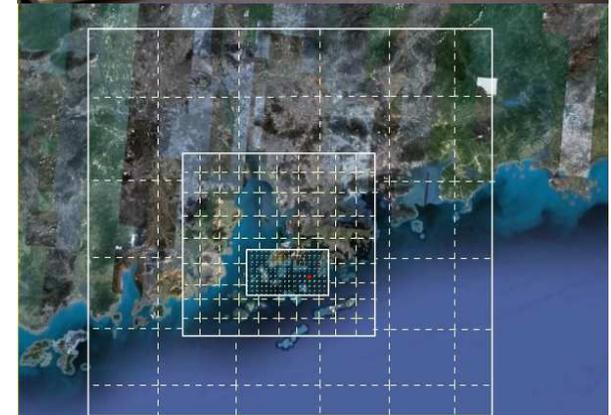




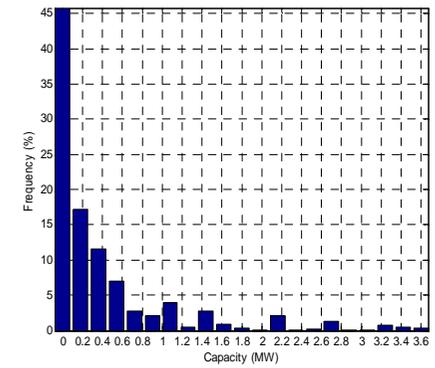
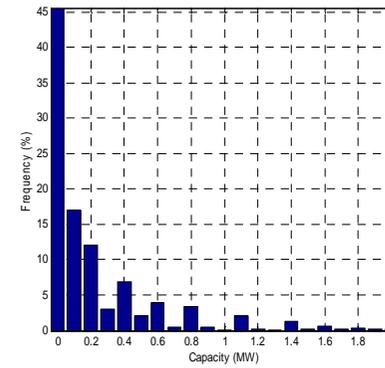
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Wind Resource Analysis and Prediction Package – OptiWIND©

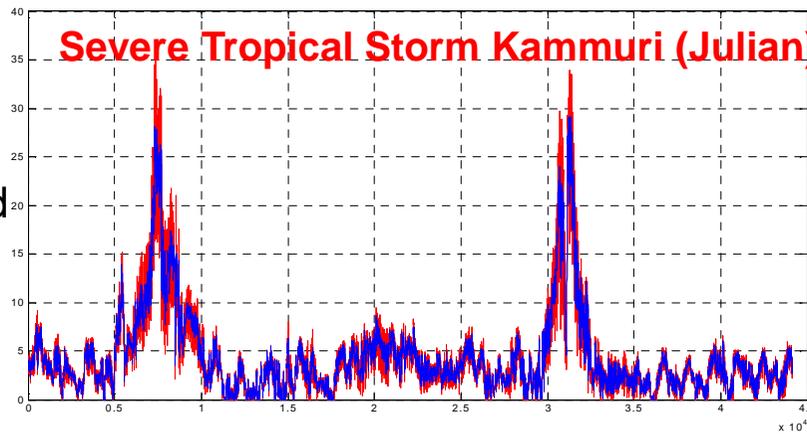
- › Short term wind forecast (min, hours, days)
 - For operations
- › Long term wind resource analysis (n x years)
 - For wind farm planning, and wind Atlas
- › Stand alone at client PC
- › Server based
- › Interactive graphic user interface
- › Most commonly used wind turbines (Nacelle, Mast, OWT, CF)



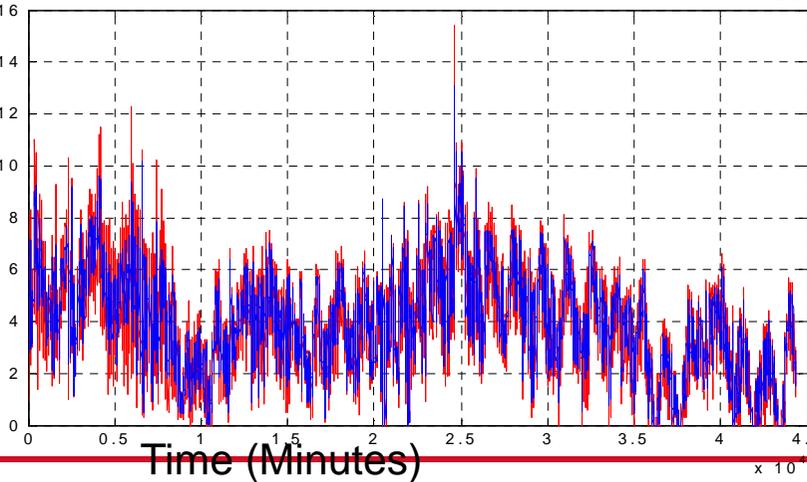
Wind Power Output: Vestas V80 vs Siemens SWT-3.6



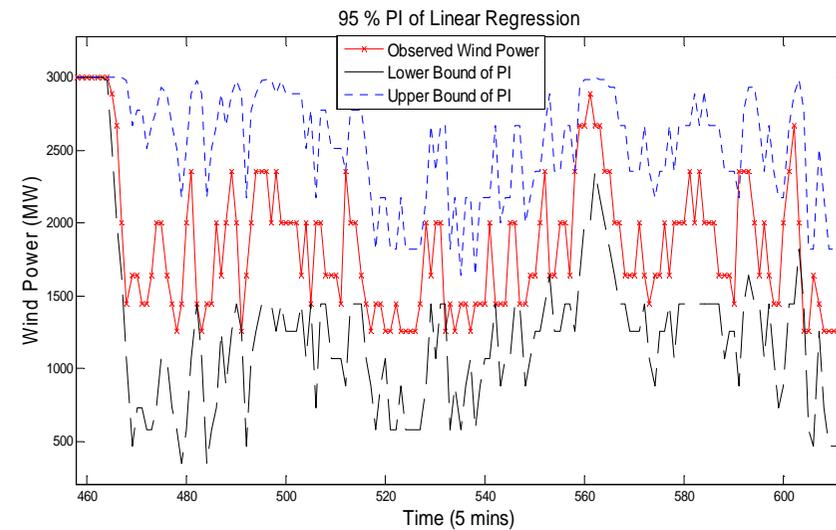
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- Predict
- Actual



➤ Short-term wind power interval forecasting (TAS wind)



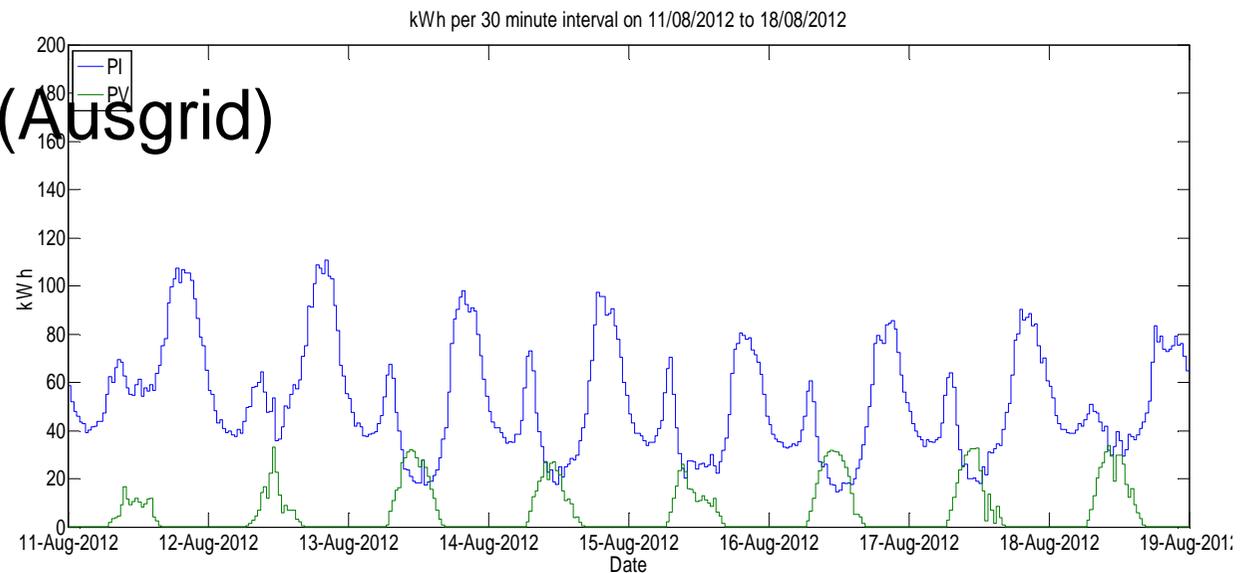
› PV panel coating technology:

- Improve efficiency upto 20%
- Absorbs light from all angles
- Self-cleaning, scratch resistant
- Low maintenance costs

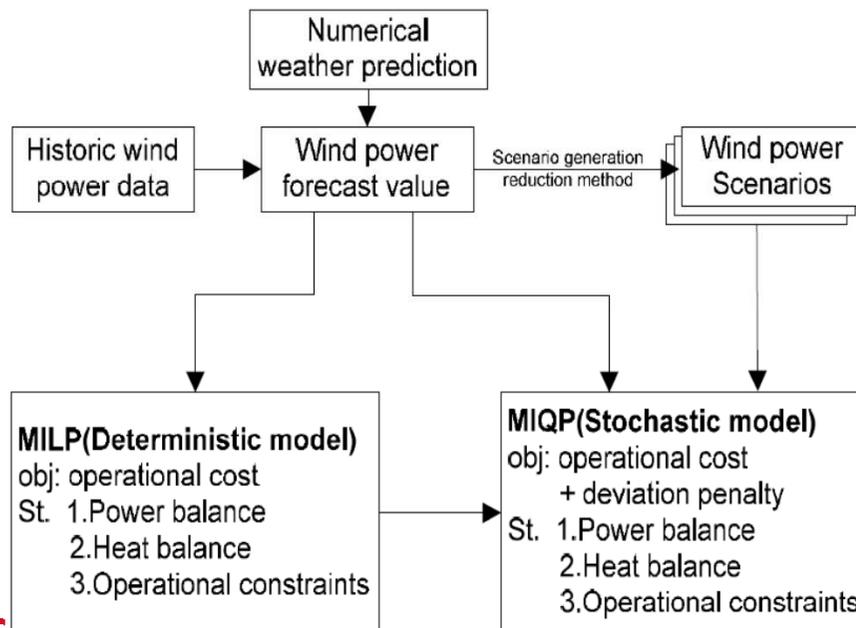


› PV impact studies (Ausgrid)

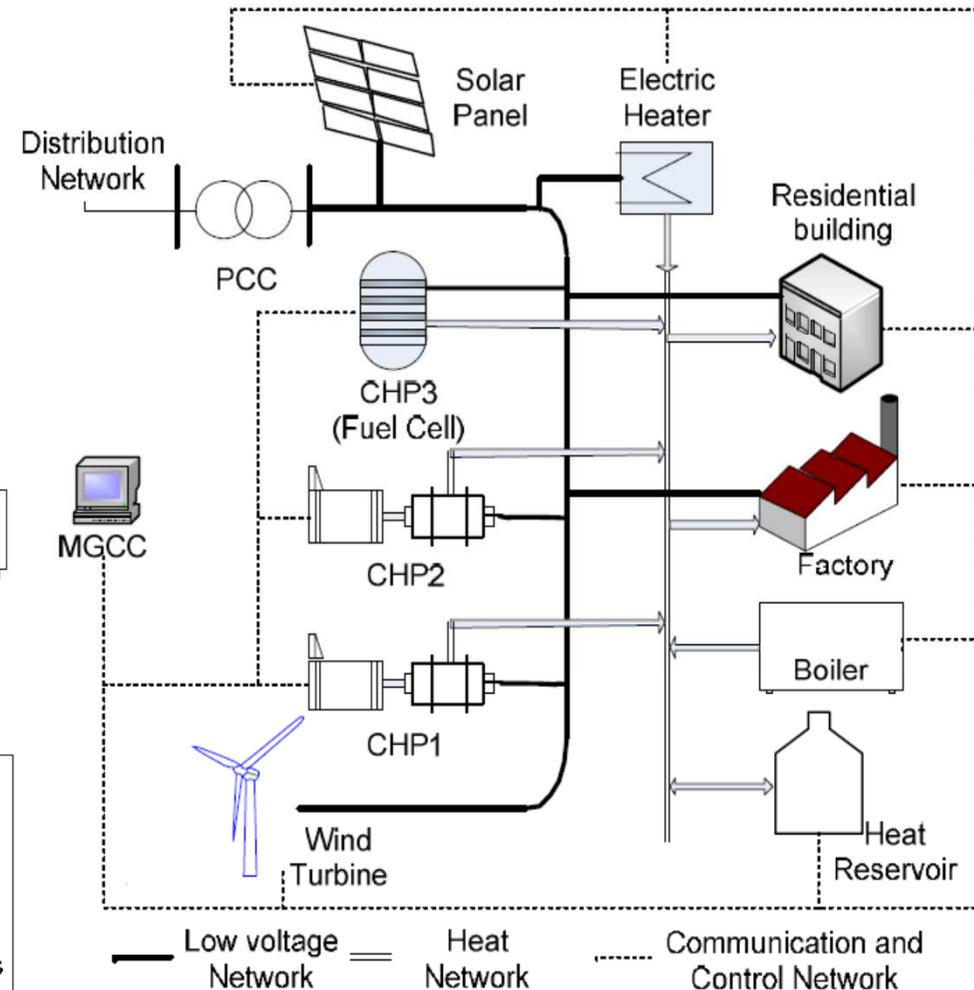
- Peak demand
- Protection
- Energy storage



- › How to schedule a microgrid to maximise the utilisation of RE while maintaining reliability
- › point of common coupling (PCC) power, electric heater and boiler to accommodate the fluctuation of wind power

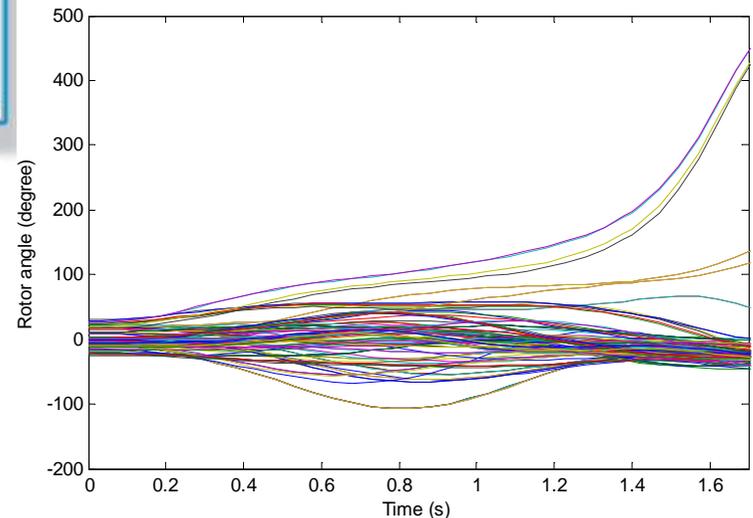
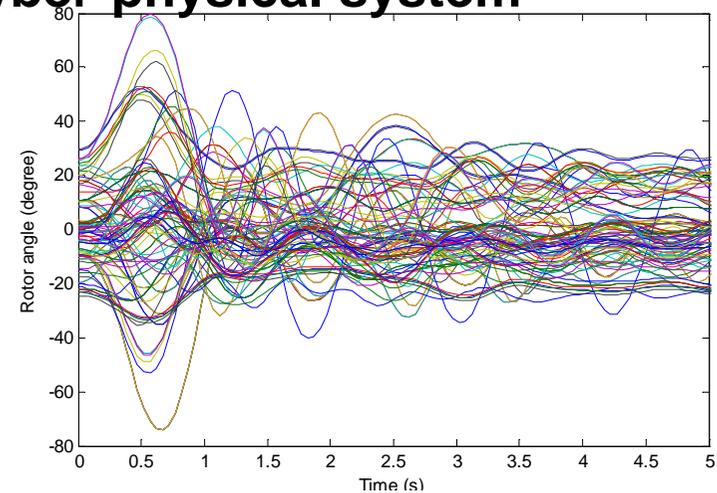
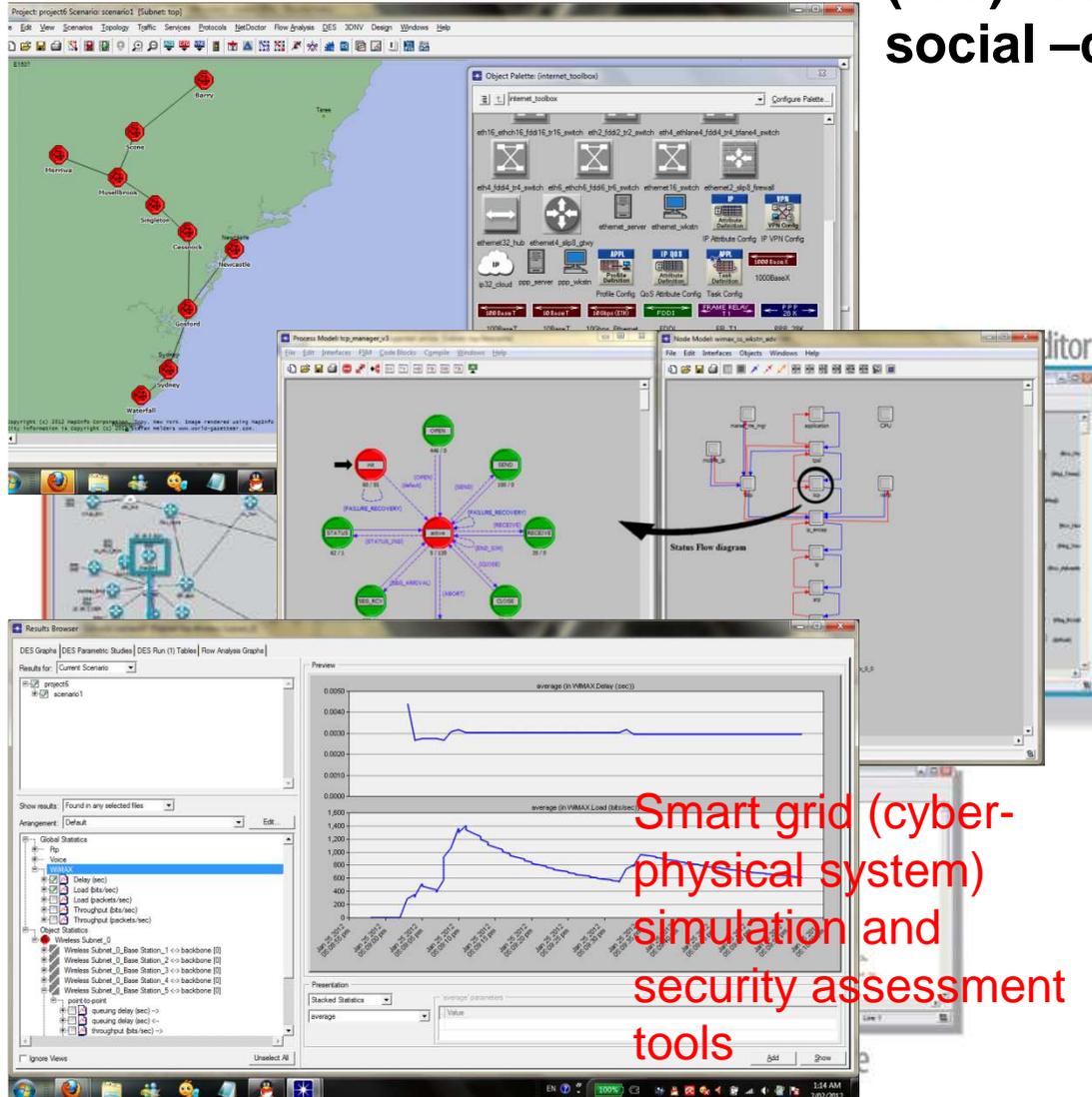


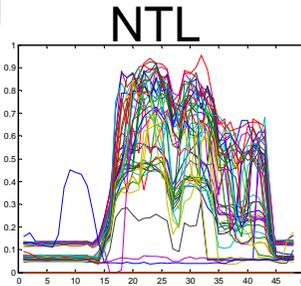
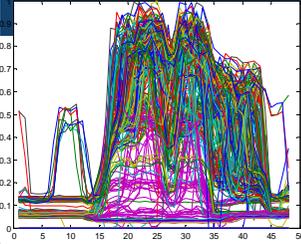
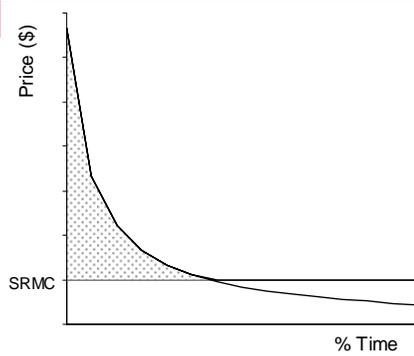
(in collaboration with Denmark)



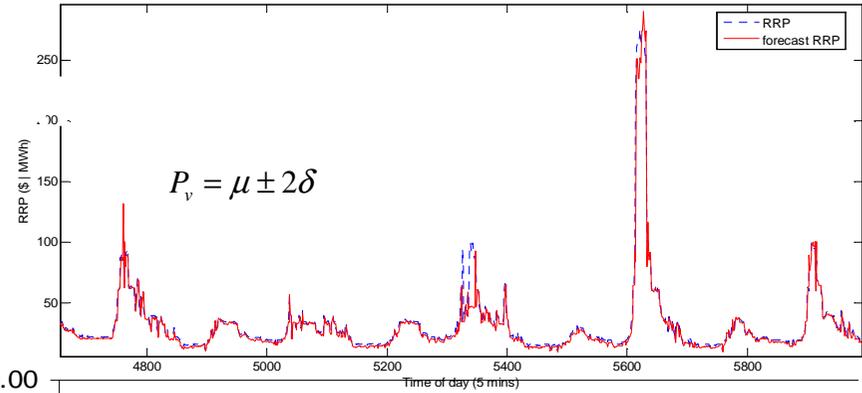
Future smart grid: a social-cyber-physical system

Physical (power system) → Cyber (ICT) and physical system → social – cyber-physical system



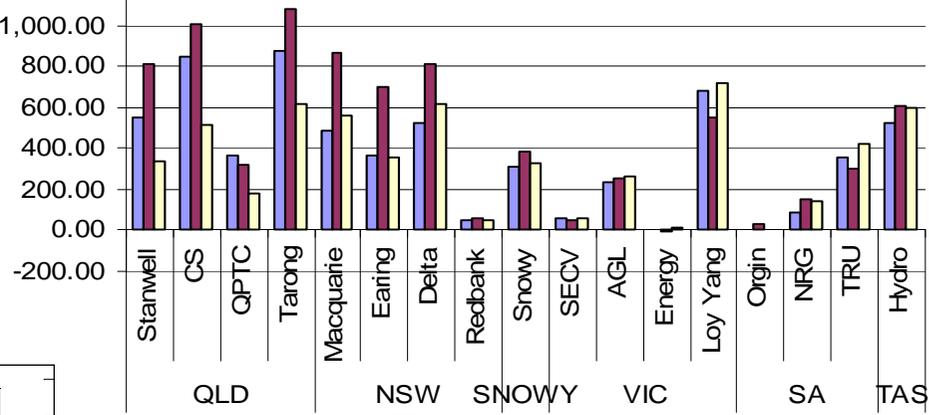


Price Duration Curve Displaying Premium Calculation

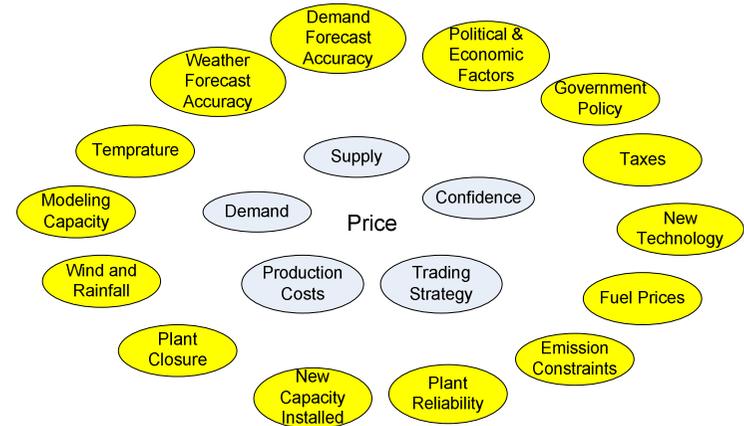
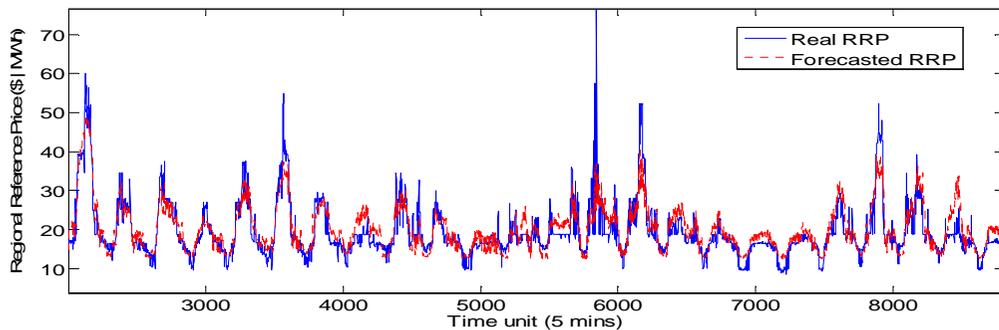
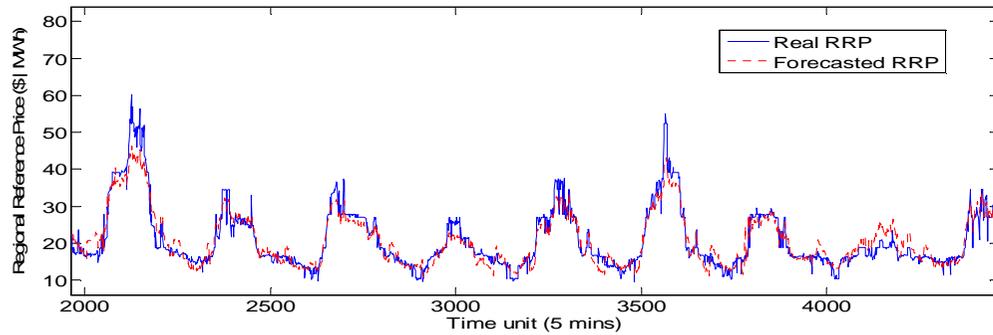


1,200.00

\$Million



Free permit ETS purchase Non-ETS





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Future grid: National vs international? Transmission vs distribution? Energy, water, gas, telco, traffic, service, social, cash flow?

Thank you

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