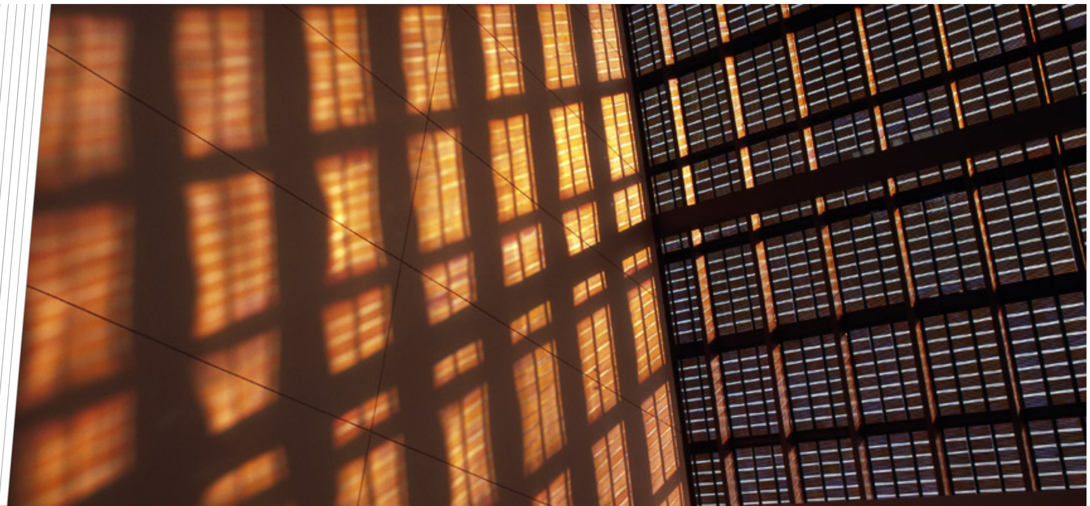

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Pathways to the Intelligent Grid

Energy Transformed Flagship

Geoff James, CSIRO ICT Centre
Presentation to UNSW CEEM
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Synopsis

- Intelligent Grid and Complexity
- Intelligent Grid Projects Worldwide
- Network Innovations and Dispersed Grids
- Distributed Generation and Demand Response

Intelligent Grid

- We are witnesses to a transformation of electricity industries worldwide driven by
  - Increasing demand and increasing peak demand
  - Diverse customer requirements for quality, reliability, security
  - Deregulated power grids and environmental market mechanisms
  - Technology giving investment choices for utilities & new entrants
  - Environmental pressures on new generation capacity
- New features are supplementing the 100-year paradigm of centralised supply, transmission, and distribution
  - Significant distributed generation (renewable & fuel-based)
  - Customer participation in demand-side management
  - Fine-grained data and cheap communications
  - Fine-grained control and embedded processing: Intelligent Grids

Implications

- Greater inter-regional connectivity and trade
  - Transmission utilities don't control what they carry
- More active elements in distribution networks
  - To manage bi-directional flows due to distributed generation
- More points at which decisions are made
  - Customers (or their devices) make active decisions based on real-time data about shedding, shifting, or generating
- Potential for more real-time data
  - Power-system components can make better-informed responses
- In a nutshell: increasing complexity
  - Challenging the ability of human operators and centralised control to manage the grid efficiently and reliably

Amin and Schewe, Scientific American, May 2007

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Complexity

- Intelligent grids can use self-organising principles to help manage complexity
  - Many interacting components acting on local information yet developing a coordinated system behaviour
- Self-organisation brings several attractive properties
  - Robustness in the face of perturbations from external factors
  - Adaptive reconfiguration with graceful degradation
  - Scalability to manage new components and connections
- The main challenge faced by designers of self-organising systems is how to achieve and control the desired dynamics
  - What are the rules?
  - There are quantitative methods to help choose the right balance between traditional design and self-organisation

Prokopenko, Boschetti, Ryan, under review, 2007

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Intelligent Grid Projects

- CRISP
- EU-DEEP
- Modern Grid Initiative
- GridWise
- CSIRO ET Flagship

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CRISP

- European FP5 project (2003-2006) to investigate how modern ICT can improve the electricity grid
- Outputs
  - ICT is the key to designing and monitoring future smart networks with significant distributed and renewable resources
  - Innovative architecture: the grid comprises a hierarchy of cells managed by a Smart Grid Automation Device with fault detection, localisation, isolation, and reconfiguration by a Help Tool for Fault Diagnosis
  - Supply-demand matching: a service-oriented infrastructure using multi-agent systems and the PowerMatcher electronic market system (proven in field trials)
  - Voltage management: improved intelligence for automatic voltage regulation (commercialised with ABB)

EU-DEEP

- European FP6 project now underway (2005-2009) to assist the large-scale deployment of distributed energy resources (DERs)
- Foci
  - Markets: develop a European demand model covering at least eight countries and show how demand can be adapted to help DERs better fit market requirements
  - Technology: specify and foster development of key components and control approaches to allow the smooth integration of DERs
  - Implementation: dissemination to stakeholders and formation of a European Competence Group
- Expected output
  - Five fast-track options towards deployment of distributed energy resources matched with 5 coherent business models

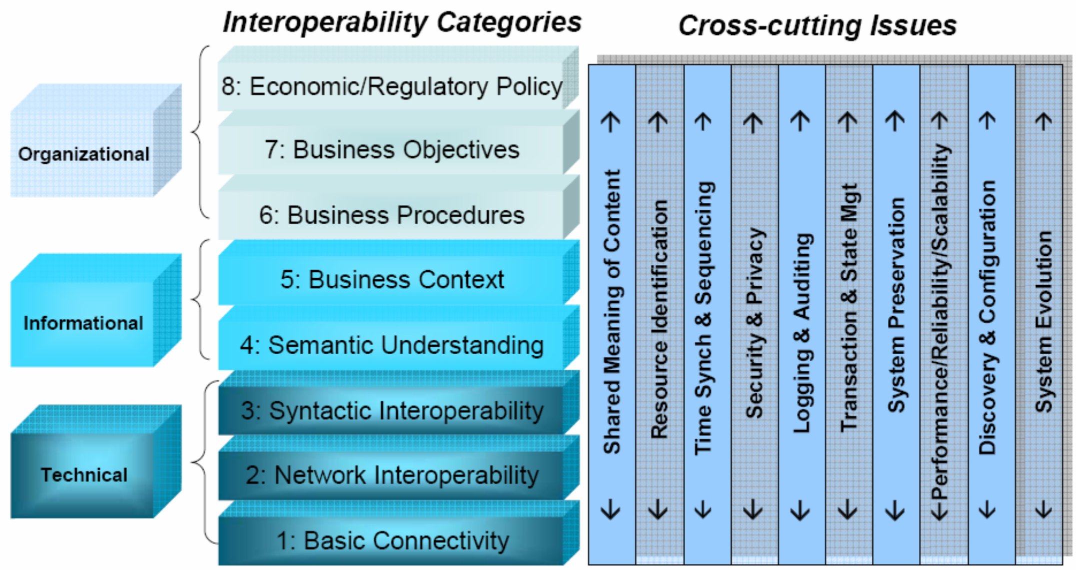
Modern Grid Initiative

- Sponsored by the US Department of Energy to create flagship partnerships and demonstration projects to accelerate the move to a modern electricity grid
  - Project plan 2005-2012 to completion of technology test program
  - Defined characteristics of modern grids
  - Identified necessary key technology areas
- The San Diego Smart Grid Study applied MGI concepts to a region and reported in October 2006
  - Excellent gap analysis in the key technology areas
  - Evaluation of costs and benefits leading to a recommended scenario with quick entry of sustained system and societal benefits and largest net present value
  - Two-phase plan of improvement initiatives

GridWise

- Imagine a time in the near future when homeowners can offer the management of their electricity demand to participate in a more efficient and environmentally friendly operation of the electric power grid
- Automation is growing across the electric system
- How can we facilitate this change and ensure reliability?
- The GridWise Architectural Council proposes a context-setting framework so that
  - Interoperability issues can be identified and debated
  - Improvements to address issues can be articulated
  - Actions can be prioritized and coordinated across the electric power community

Interoperability



GridWise Architectural Council, Interoperability Context-Setting Framework, Jan 2007

CSIRO ET Flagship

- The CSIRO Energy Transformed Flagship includes two projects aimed at facilitating large-scale DE uptake
- Intelligent Energy – developing and deploying intelligent agents to manage customer loads and generators
  - Algorithms for aggregating DE for market dispatch and other applications
  - Simulations of large-scale DE
  - Hardware demonstration at the Newcastle Energy Centre
- Intelligent Grid – forming a quantitative value proposition for distributed energy in Australia
  - Social, economic, environmental, and simulation research based on several near-term high-impact scenarios
  - Working closely with a stakeholder Advisory Group (government, retail, network, market, customers, environment, regulatory)

Hardware Demonstration

Minigrid

Microturbine

Solar PV

Wind turbine

Cool rooms

Refrigerators

HVAC

Software platform

Grid connection

Data feeds

Network Innovations

- Enhanced SCADA
- Intelligent Transformers
- Agents in IEDs
- Intelligent Cables
- Dispersed Grids

Enhanced SCADA

- Expand the scope and decrease the cost of supervisory control and data acquisition (SCADA)
- Integrated communications
  - Backhaul: Internet2, Ethernet over fibre
  - Mid-haul: Broadband over Powerline (BPL), 4th Generation (4G) WiMAX
  - Last mile: 3rd Generation (3G) Wireless Voice and Data, Zigbee / WiMedia / WiFi, Wireless Sensor Networks
- Introduce advanced control methods
  - Agent and Multi-Agent Systems
  - Substation Automation
  - Distribution (Feeder) Automation
  - Web Services and Grid Computing

San Diego Smart Grid Study, Final Report, Oct 2006

Intelligent Transformers

- Advanced on-load tap-changer (OLTC) technology
  - Keeps the voltage on the LV side of a power transformer within a preset deadband
  - Doesn’t accelerate power system voltage collapse by reacting to abnormal voltage variations on the HV side
  - Offers good automatic voltage regulation (AVR) during large voltage variations on the transformer HV side
- Can also be used to improve time coordination of OLTCs connected in series
  - Impose a temporary block on downstream AVR while upstream AVR reacts to correct the intermediate voltage
  - Minimises the number of OLTC operations in the power system
  - (To a complex systems engineer these are agent rules governing an emergent behaviour!)

Gajić, Karlsson, Kockott, ABB Power Technologies, 2006 (supported by CRISP)

Agents in IEDs

- Intelligent agents can be loaded into intelligent electronic devices (IEDs) controlling protection systems
  - Interface to existing power system components
  - Use off-the-shelf communication technology
  - (Standardisation efforts such as the Utility Communications Architecture and IEC 61850 hint at this approach)
- Agent-based systems rely on communication networks to add functionality beyond what can be achieved by traditional methods
  - Decision making is made based on knowledge received from other agents as well as on local measurements
- Simulations of some protection scenarios are already available
  - Agents could greatly increase system protection performance by exchanging basic information within their local zones through network communication

Thorp, Wang, Hopkinson, Coury, Giovanini, Securing Critical Infrastructures, Oct 2004

Intelligent Cables

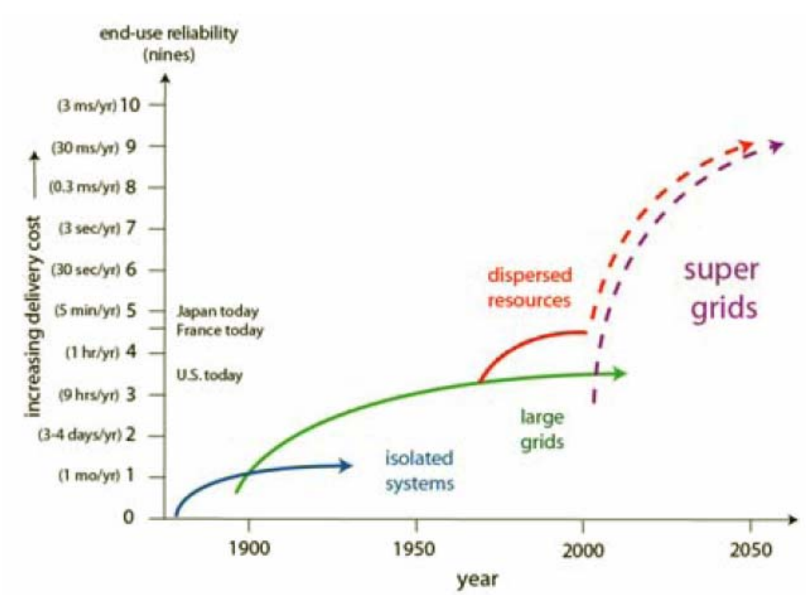
- Network safety margins are presently calculated based on long-term power ratings
  - 30-min safe rating is significantly higher
  - 5-min safe rating is higher again
  - Provided power returns to safe long-term level after this period
- The dispatch engine can use this additional short-term capacity to carry peak load
  - Perhaps an extra 50% capacity for minimal investment
- Sensing of local wind and temperature conditions for each stretch of line informs accurate rating calculations
  - Rich exchange of data and real-time computation – another intelligent grid application

NEMMCO, private communication, Aug 2007

Dispersed Grids

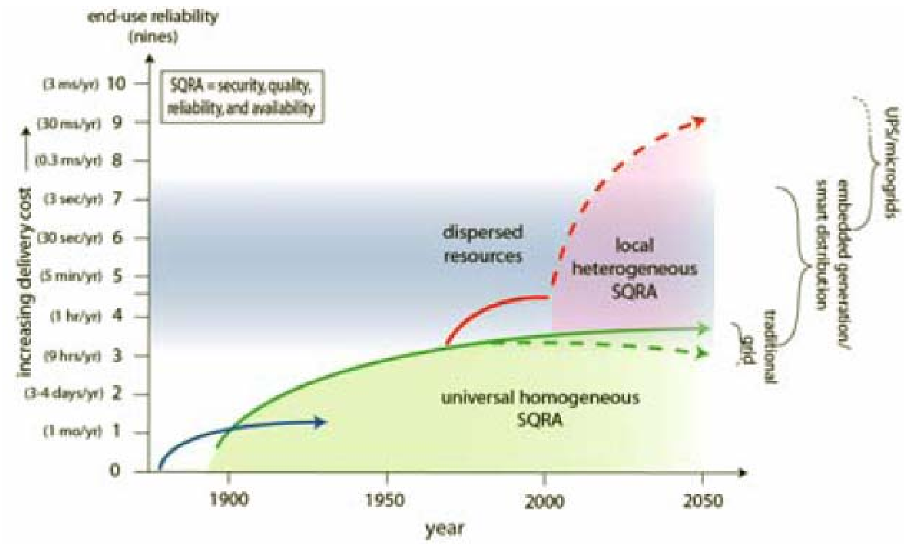
- Existing grids were built on a presumption of universal power quality and reliability to all customers
- But enhancing grids to provide universal service at the level of sensitive loads ("supergrids") is wasteful
  - And requires significant technological advances
- Points to moderate grid enhancement plus widespread use of distributed generation and other local resources
  - Does not depend on significant technical breakthroughs
  - Does not need investment far upstream from the growing energy use and sensitive loads
- If requirements of sensitive loads are met downstream, the required upstream performance of the centralised grid might even be lower than it is today

Super Grids??



Incremental role for dispersed resources

Dispersed Grids



Fundamental role for dispersed resources

Marnay, Power Conversion Conference, Apr 2007

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DG and DR

- Distributed Generation
- Demand Response

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Distributed Generation

- DG is defined as close to the load and less than 30 MW
  - Too small for market dispatch
  - Connection to the grid presently handled on a one-off basis
  - Only reciprocating engines (frequently used as back-up generators and for network reinforcement) are presently cost-competitive in Australia
  - Rising energy prices and carbon taxation will improve the proposition for gas engines and turbines and renewables
- DG has many advantages
  - Can be aggregated (there have been trials in Australia)
  - Can be very efficient through combined-heat-and-power systems
  - Reduces transmission losses through proximity to load centres
  - Defers capital investment in networks by peak shaving
  - Improved emissions profiles

DG Proposition

- The value proposition for DG is complex
  - Emission studies and whole-of-life environmental impacts compared to centralised generation
  - Analysis of business cases considering contribution to network deferral and reduction of exposure to wholesale price peaks
  - Analysis of customer attitudes and the regulatory environment
  - Simulation of realistic scenarios and what if’s

DG Simulation

- Quantitative results for large uptake require simulation
  - Characterise the behaviour of each DG technology
  - Formulate optimisation and dispatch mechanisms suitable for SME-level and household-level deployments
  - Simulate large-scale deployments using these technologies and mechanisms
  - Extract measures to characterise the aggregated effect of groups of DG resources
  - Provide as input to network simulation tools to determine the magnitude of reverse flows and other network consequences
  - Provide as input to market simulation tools to estimate the effect of aggregated DG on dispatch computation and wholesale price

Demand Response

- Demand response is a matter of course for large industrial and commercial customers
  - Australia already has one aggregator of smaller customers
  - These are firm demand response programs including direct load control, emergency programs, and interruptible or curtailable rates
- Domestic customers, who create the problematic peak demand, are presently addressed by price-based demand response programs (under trial in Australia)
  - Based on voluntary response to dynamic price signals
  - Generally not regarded as firm by utilities: in the US they are often seen as improving overall efficiency rather than providing a a specific DR resource
  - Some domestic customers submit to direct load control

Hopper, Goldman, Bharvirkar, Engel, The Electricity Journal, Jun 2007

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DR Firmness

- Demand response programs achieve significant environmental benefits
  - Typically 4% energy savings for price-based programs and 11% energy savings for firm programs with customer feedback
- Intelligent grids can find a middle road
  - Measure comfort/service-related data to allow tailored responses for individual customers
  - Improve the customer proposition with a local interface that accepts preferences
  - Improve firmness by coordinating over a region that includes a diversity of customer preferences

Nemtzow, Delurey, King, Public Utilities Fortnightly, Mar 2007

DR Simulation

- As for DG quantitative performance for large-scale DR in an intelligent grid can be estimated by simulation
  - Accounting for both technical and customer considerations
- Use a scientific demand management methodology
  - Define the demand management programs under consideration
  - Gather data on the anticipated customer base for each program
  - Develop a simulation model of the programs
  - Calibrate and validate against existing programs and trials
  - Run simulation at full scale and extract firmness measures
  - Perform a sensitivity analysis to determine the main sources of uncertainty

Conclusions

- Increasing complexity suggests new solutions to manage modern intelligent grids
- Various trials and research programs worldwide show the way ahead
- Dispersed intelligent grids have high penetration of distributed generation and demand response
  - Together these can be used to create self-managing mini-grids
- Simulation can quantify expected performance and impact on markets and networks
- Information & Communications Technology provides the crucial underpinning platform for all visions of future intelligent grids

CSIRO's plans

- Virtual power stations
- Simulation tools
- Domestic load control
- Minigrids = DG + DR
- Comparing aggregation methods
- Active distribution networks
- Influencing key stakeholders
- International partnerships

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Student opportunities

- Flagship PhD top-up scholarships (closing 31st Oct)
  - See http://recruitment.csiro.au (search under Flagship Programs)
  - Details and projects at http://www.csiro.au/org/psq5.html
  - Intelligent agents for active distribution networks with significant embedded generation
  - Matching supply and demand in self-managing mini-grids for urban and remote communities
  - Quantifying the impacts of renewable energy storage on transmission grids and energy markets
- Final-year project opportunities (by arrangement)
  - Happy to consider collaborative projects in relevant areas
  - Talk to your supervisor and me if you're interested

Possible PhD topic

- Intelligent Agents for Active Distribution Networks with Significant Embedded Generation
  - Electricity distribution networks are increasingly supported by local generators to help meet growing demand and to provide a low-emissions alternative to centralised generation and transmission.
  - In addition, intelligent customer loads and network control equipment capable of local sensing and response are populating networks that traditionally have been passive at the voltage levels at which most customers are connected.
  - Network data, market information, signals from utilities, and other data are available to assist local decision making, yet conflicting responses from multiple devices, at multiple time scales, may hinder the effective balancing of supply and demand.
  - Regarding such active distribution networks as distributed multi-agent systems, this project will survey existing control methods and develop multi-agent algorithms and handover techniques aimed at well-regulated operation with significant, highly variable embedded generation.
- Many variations possible on this theme!

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