INTELLIGENT GRID RESEARCH CLUSTER

Executive Summary to the Final Reports

University of Technology, Sydney, University of Queensland, Curtin University,
Queensland University of Technology and University of South Australia

iGrid
intelligent grid
an Australian research collaboration

FIGURES

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1. INTELLIGENT GRID RESEARCH CLUSTER

In 2008, **the Intelligent Grid Research Cluster (iGrid**) was established**.** The iGrid Cluster is an Australian collaborative research venture between the five universities, supported by the CSIRO Energy Transformed Flagship. The purpose of the iGrid Research Cluster is to deliver a future vision for an electricity network in Australia. It provides a foundation for establishing an advanced electricity distribution network in Australia to meet the challenges of reducing carbon emissions and reining in the rising cost of power, while maintaining or improving reliability.

The iGrid Cluster has explored the economic, environmental and social impacts of the large-scale deployment of intelligent or smart grid (iGRID) technologies in Australian electricity networks. Decentralised energy (DE) resources, which bring increased energy efficiency, peak demand management and distributed generation, will play a critical part in such an energy system.

The Intelligent Grid Cluster project involved extensive engagement with industry and key energy stakeholders who helped to shape the research. The Cluster has modelled the market benefits of large-scale DE deployment in the National Electricity Market. It has identified the network benefits of large-scale DE deployment in Australian electricity networks and how DE can be deployed to alleviate network congestion and defer network investment. The intention is to fully and appropriately value the economic contribution of the intelligent grid and compare it to conventional energy technologies. The research identified the social issues around the uptake of DE. It explored the ways that people connect with and understand energy and how this might be influenced by intelligent grid technologies.

The electricity sector is Australia's largest source of greenhouse gas emissions, accounting for 36 percent of national emissions. For Australia to survive and prosper in a carbon-constrained future, it is imperative that the types of technologies adopted and the approaches employed to meet our energy needs shift dramatically. The generation of energy must become less carbon intensive and electricity must be produced and used more efficiently.

The Cluster will contribute to climate change response by reinforcing the credibility and legitimacy of an intelligent grid, by promoting decentralised energy as means to reduce greenhouse gas emissions, and by investigating ways to facilitate the uptake of these technologies. The Cluster contributes to the Energy Transformed Flagship's goals of halving greenhouse gas emissions and doubling the efficiency of the nation's new technologies for energy generation, energy supply and end uses.

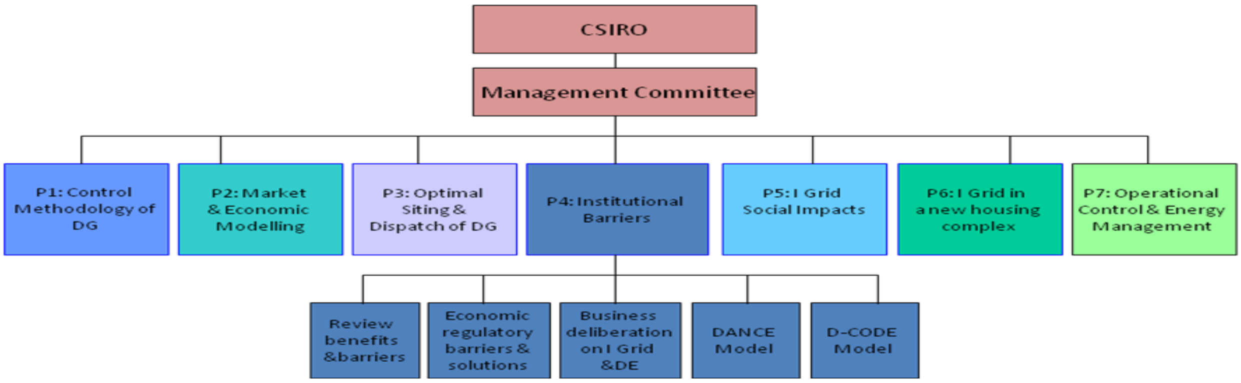
1.1 The iGrid Cluster structure

The Cluster is an interdisciplinary venture that brings together economists, engineers, social scientists, systems scientists and policy scientists to develop integrated insights that could not be achieved by working separately. The university partners include the University of Technology, Sydney, University of Queensland, Queensland University of Technology, Curtin University and the University of South Australia. This Cluster was led by the University of Technology, Sydney which coordinated the research outputs of the Cluster over the three-year period of its operation. This national research initiative is divided into seven different projects:

Project 1	Control methodologies of distributed generation	University of Queensland
Project 2	Market and economic modelling	University of Queensland
Project 3	Optimal siting and dispatch of distributed generators	Queensland University of Technology and Curtin University
Project 4	Institutional barriers, stakeholder engagement and economic modelling	University of Technology, Sydney
Project 5	Intelligent grid social impact	Curtin University
Project 6	The intelligent grid in a new housing complex	University of South Australia
Project 7	Operational control and energy management	Queensland University of Technology

The Figure 1 below shows the structure of the iGrid Research Cluster.

Figure 1: Intelligent Grid Research Program structure



1.2 Purpose and scope of the final report

This report provides an introduction and summary of the seven final project reports. This executive summary is divided into eight sections:

Section 1 provides an introduction to the iGrid research Cluster, its aims, the university partners and summarises the key research findings.

Section 2 outlines the research conducted in Project 4 – institutional barriers, stakeholder engagement and economic modelling.

Section 3 discusses the market and economic modelling of the Intelligent Grid – Project 2.

Section 4 looks at the social impact of the Intelligent Grid – Project 5.

Section 5 proposes appropriate control methodologies for distributed generation for enhanced network stability and control – Project 1.

Section 6 explores the optimal siting and dispatch of distributed generation – Project 3.

Section 7 looks at the operational control and energy management of distributed generation in a microgrid – Project 7.

Section 8 assesses the intelligent grid in a new housing development – Project 6.

1.3 What is an intelligent grid?

'Intelligent grid' refers to an electricity network that uses decentralised energy resources and advanced communication and control technologies to deliver electricity more cost-effectively, and with lower greenhouse intensity, than the current electricity supply mix, while being responsive to consumer needs. Decentralised energy (DE) refers to energy technologies and practices that optimise the use of local resources and reduce the need for large-scale energy supply infrastructure. The three elements of DE are: efficient use of energy; peak demand management and distributed generation. DE can supply energy for heating, cooling and powering a commercial building using a combination of solar panels, microturbines, fuel cells, energy efficiency and load control. These features facilitate the integration of electricity supply from more localised and distributed sources, improving the efficiency and security of the electricity network.

The intelligent grid of the future will involve not just smarter metering, control and communication but also smarter pricing, regulation and more informed decision-making. The intelligent grid provides a platform upon which to coordinate both the operation of, and decentralised investment in, decentralised energy resources . Significant input from diverse stakeholders will be required to ensure a smarter grid meets societal goals and delivers optimum societal, economic and environmental benefits.

Throughout the duration of the Cluster a number of research outputs were developed including research papers, journal papers, presentations, models and summary reports. These are available from the dedicated project website www.igrid.net.au.

The key conclusions of the Cluster research are:

- Decentralised energy has the potential to defer or reduce expenditure on transmission and distribution networks. Peak demand growth is one of the major drivers of network investment. Around one-third of the network investment projected to occur in Australia between 2010 and 2015, or $15 billion, is considered potentially avoidable if growth in demand is eliminated through a range of initiatives including principally decentralised energy measures (Section 2).
- Decentralised energy is a viable option for delivering significant cuts in carbon emissions and costs while securely and reliably meeting customer energy needs (Section 3).

- There is a high level of acceptance among energy (residential and commercial) consumers and the network of energy stakeholders that 'intelligent grid' solutions represent a genuine alternative to a centralised grid supply (Section 4)
- Distributed generation (DG) can provide benefits for both utilities and consumers. DG can reduce power loss, improve voltage profiles and reduce transmission and distribution costs if sited and sized appropriately (Sections 5, 6 and 7).
- The analysis of detailed monitoring of low emissions households demonstrates the effectiveness of household energy efficiency technologies such as insulation, solar hot water, solar PV systems. It shows how much energy and carbon emissions they save, as well as the payback period (Section 8).

2. INSTITUTIONAL BARRIERS, STAKEHOLDER ENGAGEMENT AND ECONOMIC MODELLING – PROJECT 4

This section provides a summary of the research of Project 4: Institutional Barriers, Stakeholder Engagement and Economic Modelling. Project 4 was conducted by the team at the Institute for Sustainable Futures based at the University of Technology, Sydney. There were five main areas of investigation in this project:

- assessing the benefits of decentralised energy
- a systematic identification of the institutional barriers that inhibit a wider-scale deployment of DE, and the provision of solutions to overcome those barriers
- quantification of the value of DE to networks – the Dynamic Avoidable Network Cost Evaluation, or DANCE model
- the Description and Costs of Decentralised Energy – the D-CODE model
- stakeholder engagement – the research was informed by a series of consultations with stakeholders from the energy sector in Australia that took place between December 2008 and August 2010. The consultation and engagement of stakeholders was a key element of the development of the report 'Think Small: The Australian Decentralised Energy Roadmap'. More details of this project can be found in the Project 4 final report.

2.1 The status of decentralised energy in Australia

Distributed generation is growing rapidly internationally, but Australia is lagging behind the world average. DG accounts for 5.4 percent of Australia's total electricity generation, which is about half of the global average of 11 percent. Australia is also lagging behind other developed economies in its performance on energy efficiency. Australia's economy is more energy intense than those of most other developed countries. Significant barriers remain to the uptake of decentralised energy initiatives generally. Many of them stem from the physical, commercial and regulatory structures associated with the current Australian electricity system. Not enough is information known about the current size of the Australian DE sector. Filling this gap is important for the long-term development of a sustainable energy sector. For a more comprehensive analysis of the status of DE in Australia refer to Section 3 of the Roadmap.

2.2 Decentralised Energy in an Intelligent Grid

Australian consumers are facing a period of steeply rising energy bills, driven to a large extent by capital expenditure on network infrastructure. There are three primary drivers for this capital expenditure: replacement of ageing infrastructure; increased reliability standards imposed by governments on electricity utilities; and growth in peak electricity demand. This amounts to over $45 billion of planned electricity network infrastructure in the period 2010 to 2015. This investment is driving substantial increases in electricity prices around Australia, with five-year nominal price increases as high as 83 percent in the case of Sydney metropolitan area customers. Peak demand growth is one of the three major drivers of this investment, and is projected to continue to outstrip growth in energy consumption over the next 10 years, placing pressure on electricity prices.

The introduction of decentralised energy can *defer* or *avoid* the building of new infrastructure and provides an attractive alternative approach to addressing peak load growth. The problem of peak load growth can be solved by installing DG within the electricity network, by adaptive load management during critical peak periods and by the implementation of energy efficiency measures. Around one-third of the projected network investment between 2010 and 2015, or $15 billion, is considered potentially avoidable if demand growth is eliminated through measures such as decentralised energy. This is supported by research from iGrid Project 2: Market and economic modeling of the impacts of Distributed Generation. The research conducted in Project 2 is outlined in Section 3 of the Executive Summary.

2.3 Benefits of Decentralised Energy

DE has the potential to offer major cost savings and carbon emission reductions while securely and reliably meeting customer energy needs. The major benefits are affordability, sustainability, security and reliability, which accrue to key stakeholders in different ways.

Sustainable development is achieved as a result of the ability of DE to reduce greenhouse gas emissions from electricity services. This is due to:

- an overall increase in fuel efficiency
- exploitation of cheap fuel options
- the potential for higher penetration of low carbon renewable energy sources
- the potential for integration of electric vehicles which can feed power back into the grid.

Improved reliability of electricity supply, with improved energy security, can be achieved through:

- a more diversified supply base
- dynamic demand-side participation and peak load management
- self-healing grids via improved monitoring and communications, and automation of fault detection resulting in faster restoration of power after outages
- network benefits such as voltage support and reduced reactive power losses
- improved system ancillary services, such as black start capability and spinning reserves.

Improving affordability through costs to consumers which are lower than those of traditional centralised supply result in better economic efficiency, due to:

- the potential to unlock alternatives which are more cost-effective than business-as-usual modes of energy service delivery
- reduced peak load and reduced peak load growth resulting in reduced and optimised network investment
- two-way communication with customers enabling cost-sensitive pricing and active energy management, including remote switching of customer loads to manage peak demands.

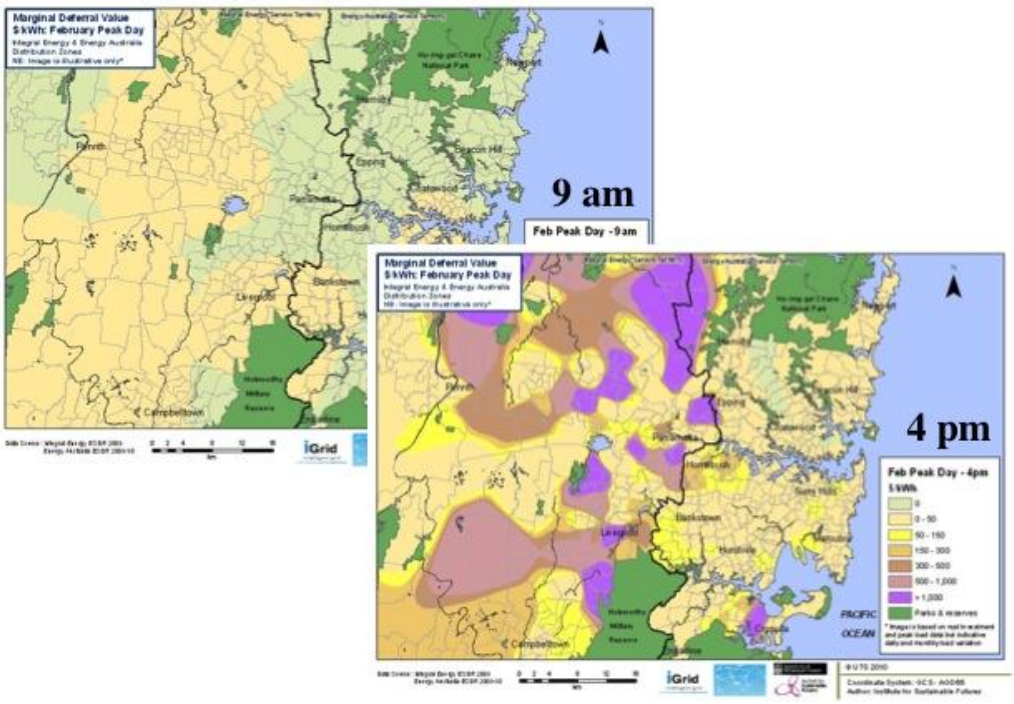
Decentralised energy in a smarter grid provides a number of benefits for utilities, energy retailers and transmission and distribution companies. These benefits are explained in detail in Section 5 of the Decentralised Energy Roadmap for Australia.

2.4 The Dynamic Avoidable Network Cost Evaluation (DANCE) model

The DANCE model was developed to help overcome the lack of accessible information on the timing and location of electricity network constraints and can be used as a communication tool to identify opportunities in space and time to alleviate network constraints using DE. Recently, Sustainability Victoria has used the model to identify opportunities for DE in the Victorian electricity network.

Through powerful interactive visual outputs, DANCE aims to make this information accessible to policy makers needing to understand the dynamics of how DM can contribute to beneficial economic and environmental outcomes, and to DE service providers who need to know in advance the geographical areas in which they should be looking to develop project in order to achieve the greatest benefit from their products.

Figure 2: Marginal deferral value at specific times on the February peak day

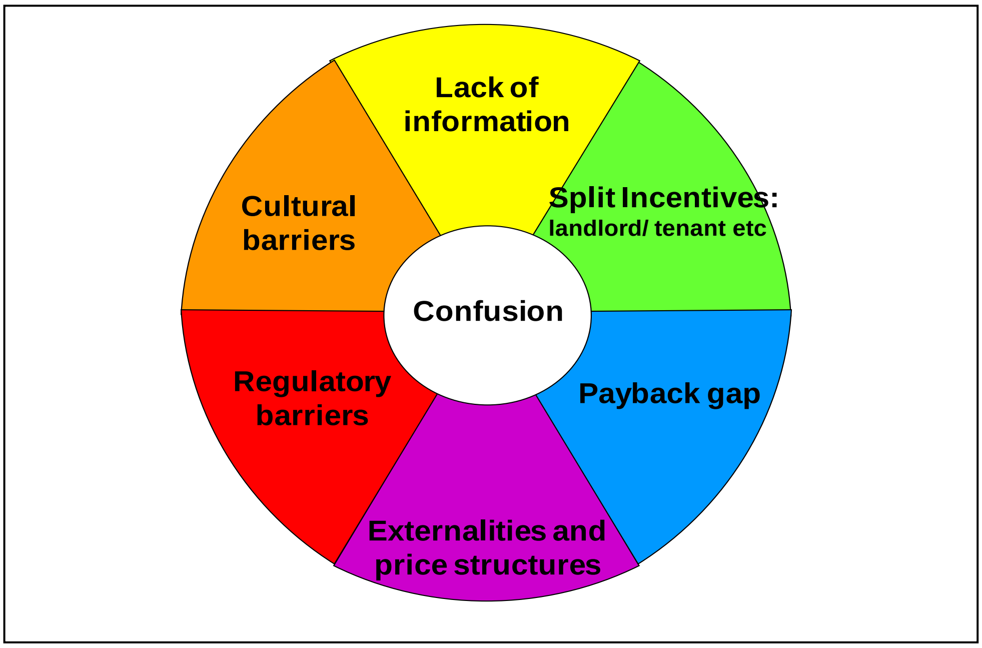


The primary geographical information system (GIS) mapping outputs from DANCE include images showing the location and magnitude of network capacity constraints figure 2 and the marginal value that this could represent for decentralised energy across a given year, month or hour of the peak day (Figure 2). Areas in Figure 2 with neutral colours are those with limited to no deferral value, while marginal deferral value increases strongly towards the brown and purple categories. It demonstrates even in constrained zones with lower deferral value, we are seeing figures of $300 per kWh: 1500 times the $0.20/kWh value that a typical residential customer on a flat tariff is actually paying for power at that time. This demonstrates the inability of even current time of use tariffs (at $0.40) to pass on an adequate pricing signal to consumers to steeply reduce demand. As politically it is impossible for truly cost reflective pricing at the values shown in Figure 2, it is important that if efficient DM options are to be realised, non-network solutions that reduce peak be recompensed up to the extent that tariffs are not cost-reflective. This is the key to value of the DANCE model to efficient network planning and to the DE industry. See Working Paper 4.4 for more information.

2.5 Institutional barriers to Decentralised Energy

Although the potential benefits of DE are great, tapping these benefits will require extensive changes in many areas of our energy policy, culture and institutions. Cost effective DE options are being stymied by a host of institutional barriers. These barriers can be classified into six broad areas, as shown in Figure 3. Categorising barriers establishes a logical structure to assist in considering the causal factors underlying institutional impediments to DE. However, the barriers do not always clearly fall into a single category and may have roots in more than one category or be strongly linked to other barriers. Each of the categories is explained In Section 7 of the DE Roadmap and also in Working Paper 4-1: Institutional Barriers to Intelligent Grid.

Figure 3: Institutional barriers to decentralised energy



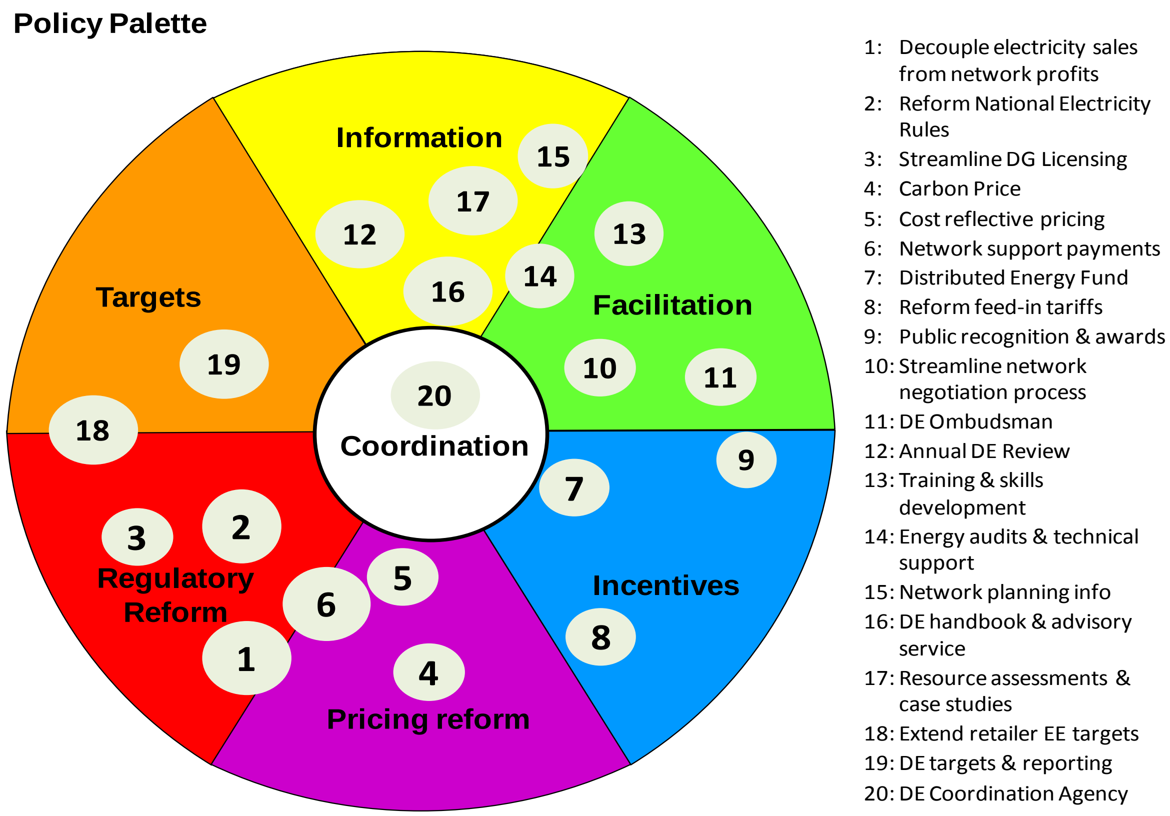
In order to assess which of the above barriers pose the most significant obstacles to the intelligent grid and to the broader uptake of DE, a survey of 200 key industry figures was conducted. These stakeholders represented electricity end users, regulators, electricity supply utilities, DE providers and environmental and other advocacy groups. The survey asked respondents to rate their level of agreement or disagreement with the rankings of 25 barriers to the uptake of DE. The 25 barriers were categorised according to the seven categories outlined above. The top three barriers to DE as rated by energy industry stakeholders are:

- **Confusion** resulting from a lack of coordination and leadership on DE development
- The lack of an environmental objective in the National Electricity Market (**cultural barrier**)
- A lack of **cost-reflective pricing.**

2.6 Policy tools to develop decentralised energy

The full potential of DE is not being realised due to a range of institutional barriers that must be overcome in order to deliver low-cost, low-emission energy services in Australia. Policies need to be coordinated to ensure that funding is used to abate carbon in the most effective manner at the least cost. Section 8 of the DE Roadmap discusses a suite of policy measures that could be enacted over the next 5–10 years to provide strategic and targeted growth in the DE sector. Figure 4 below provides a summary of proposed policy measures.

Figure 4: Policy Palette with 20 policy options mapped (Working Paper 4-2)



2.7 Costs and potential of Decentralised Energy

The research of Project 4 aimed to highlight the huge untapped potential of decentralised energy in Australia by developing a comprehensive framework for recognising and incorporating the full benefits and costs of DE options. In order to quantify the costs and technology options the Description and Costs of DE (D-CODE) model was developed in-house. Results from the model show that DE could generate:

- 22,608 MW of peak capacity (> 50 percent of total peak demand) and
- 86 GWh per annum energy generation capacity (40 percent of energy demand).

Many of these DE options are cheaper than traditional centralised energy supply when network costs are taken into consideration. With full deployment of DE, electricity sector emissions could be reduced by up to 73Mt per annum (a 35 percent reduction on 2009 levels). The lowest cost deployment of DE could unlock $3 billion of savings per year for electricity consumers by 2020.

The D-CODE model is an electricity cost comparison and electricity system planning model developed by the Institute for Sustainable Futures, publicly available at no charge. D-CODE aims to both stimulate discussion on the costing of energy services, and to assist governments, utilities and other interested stakeholder groups to make informed energy planning decisions. It helps to determine the most cost-effective options to meet our future electricity needs, using supply technologies and demand management programs available today. D-CODE breaks new ground by incorporating network costs into the investment equation, thereby removing the inherent bias against DE options that ignores the *delivered* cost of electricity. See Section 5 of the DE Roadmap for a further explanation of the model and the assumptions.

3. MARKET AND ECONOMIC MODELLING OF THE INTELLIGENT GRID – PROJECT 2

The overall goal of Project 2 – Market and Economic Modelling of the Impacts of Distributed Generation has been to provide a comprehensive understanding of the impacts of distributed generation (DG) on the Australian electricity system. The research team at the University of Queensland (UQ) Energy Economics and Management Group (EEMG) developed a variety of sophisticated models to analyse the various impacts of significant increases in DG. These models stress that the spatial configuration of the grid is very important, however this has tended to be neglected in economic discussions of the costs of DG relative to conventional, centralised power generation. The modelling shows that efficient storage systems will often be critical in solving transient stability problems on the grid as we move toward greater penetration of renewable DG. The research shows that DG can help to defer transmission investments in certain conditions. The existing grid structure was constructed at a time when priorities were different and its replacement can come at a prohibitive cost unless the capability of the local grid to accommodate DG is assessed very carefully.

The final report – Market and Economic Modelling of the Impacts of Distributed Generation is divided into five sections:

1) Economic viability of distributed generation versus centralised supply
2) Assessing the impact of DG deployment
3) Assessing the economic impact of DG
4) Development of a commercial scale experimental PV array: the case of the University of Queensland
5) Investigating the impact of distributed generation on transmission network investment deferral.

3.1 The economic viability of DG versus centralised supply

This section assesses the true costs of different generating technologies by incorporating all future costs, revenue streams and their associated net present values. When making decisions about investing in different forms of power generation, comparisons have to be made of the whole costs and anticipated revenue streams from point of purchase to retiring the technology. The conventional way to do this is to calculate net present values and undertake Levelised Cost of Energy (LCOE) analysis.

What has been lacking, however, is the integration of distribution use of service (DUOS) and transmission use of service (TUOS) charges. This research compares different types of DG to a range of centralised power generation options using the best information currently available when explicitly integrating the DUOS and TUOS charges. This can greatly affect the final cost of electricity to retail customers. This section also considers different carbon abatement scenarios. It compares the emissions from eight different scenarios.

With the inclusion of all the externalities considered in the Australian Energy Market Operator, National Transmission Network Development Plan and DUOS/TUOS in the LCOE, it is clear that DG can compete without a DUOS discount against centralised generation. The PLEXOS modelling simulations suggest that DG is a viable option to deliver significant cuts in emissions and reductions in expenditure on the transmission network.

PLEXOS is a commercially available optimisation theory-based electricity market simulation platform. PLEXOS has been used extensively by Australian market participants to provide forecasts of NEM variables to guide their generation strategies. It is also used by publicly listed Australian generators to provide detailed market performance analysis for their annual audit reporting requirements. For further details of the capabilities of PLEXOS see section 3 of the final report.

3.2 Assessing the impact of DG deployment

PLEXOS modelling was applied extensively to assess the impact of significant deployments of DG on wholesale electricity prices, emissions and investment in network and centralised generation assets. Five policy scenarios were simulated to provide a snap shot of estimated future effects of the deployment of DG across the National Electricity Market (NEM). These scenarios varied in terms of energy demand, fuel costs, carbon prices and the scale and scope of installed technology types. The development of an analytical framework that can model the NEM and capture price variations associated with the rollout of DG energy can provide significant support to decision makers seeking emissions reduction via both technological improvements and alternative investment prioritisation.

The roll out of DG will have a significant impact on the average price of energy throughout the NEM. DG can improve the likelihood that there will be a reduction of electricity prices and emissions over the longer term. An additional benefit is the reduced volatility of observed prices on the wholesale market. Lower volatility of spot price behaviour also provides significant benefits from a risk management perspective and reduces the cost of serving the retail consumer base.

3.3 Assessing the economic impact of DG

In Section 4 of the Final Report of Project 2, the objective is to model the economic consequences of large –scale investment in DE in conjunction with carbon pricing. The methods used include a load shaving profile using the Australian National Electricity Market (ANEM) model. The focus of the research was the load shaving capability at daily peaks using PV as an example. Load shaving at peaks can both reduce carbon emissions and delay transmission and distribution network investments.

We found clear evidence that a demand side policy, promoting the take-up of solar PV, particularly when combined with a carbon price signal, would have significant benefits. These findings strongly support the installation of significant commercial PV (that is, PV capacity installed on the roofs of commercial premises), in addition to residential-based PV. However, in order to realise the benefits of peak load shaving there need to be more incentives available for commercial installations. The load shaving from DG through, for example, PV or smart metering, has the potential to defer transmission investments that are largely driven by peak demand in the middle of the day, or early afternoon.

3.4 Development of a commercial scale experimental PV array

Section 5 discusses the development of a commercial-sized PV array that was installed at the University of Queensland (UQ) St Lucia Campus. The array will produce approximately 6 percent of the St Lucia Campus peak demand and will be fed directly into the internal grid. Economic evaluations have provided valuable insights concerning the viability of commercial PV at different kinds of sites. There is an ability to scale up our findings in relation to the UQ PV array into a full simulation of the impacts of large-scale investments in commercial PV on the NEM. We shall also be able to measure the costs incurred in dealing with voltage instability, either through line and substation upgrades or through the use of battery technologies.

To date, very few studies have assessed the impact of DG sources such as wind and solar PV, on transmission investments. The project modelled the decision about whether to install the UQ PV array as a cost minimisation problem subject to system reliability and alternating current (AC) power flow constraints and system security constraints. The simulation results indicate that, although DG generally can defer transmission investments, it is inappropriate to offer a general conclusion about the strength of this effect. In practice, the locations of DG units, the network topology, and the original power flow patterns all have significant impacts on DG’s investment deferral effect. It is important to carefully consider these technical constraints when evaluating the actual benefits of DG in the context of transmission network investments. For more detailed information refer to Section 5 of the report – Market and Economic Modelling of the Impacts of Distributed Generation. Similar findings are outlined in the final report for Project 1– Control Methodologies of Distributed Generation for Enhanced Network Stability and Control (UQ).

3.5 Investigating the impact of DG on the transmission network investment

Geographical considerations and the impact on transmission costs have tended to be neglected in discussions of the costs of DG relative to conventional, centralised power generation. An important benefit claimed by the proponents of distributed generation is that it can potentially defer large investments in the transmission/distribution infrastructure.

A simulation model was used to investigate the impacts of distributed wind and solar generation on transmission network expansion costs. The transmission network expansion problem was modelled as a cost minimisation problem subject to system reliability and AC power flow constraints. Generation investments were implemented using the nodal prices obtained from power flow studies. Power system security constraints, which are also becoming a concern to policymakers, are also carefully considered in our model. The model has been applied to the Queensland market. In the Queensland market, solar PV would have a stronger effect on transmission investment deferral compared to wind power, since it can be deployed evenly in all areas of Queensland, while wind power can only be concentrated in north-east areas.

In practice, the transmission network operator is responsible for investing in voltage support facilities – the cost of voltage support is also considered as a part of transmission investment. Therefore, a wind turbine with a doubly-fed induction generator (DFIG) is a better DG option since it can reduce the voltage support cost. Solar PV panels can also improve voltage stability. This is because solar PV panels are deployed in all areas of the market, and they can therefore reduce the local active and reactive power demand, thereby helping to maintain the voltage level.

4. INTELLIGENT GRID SOCIAL IMPACT– PROJECT 5

Project 5 - The Intelligent Grid Social Impact was undertaken by Diane Costello from the Research Centre for Stronger Communities, based at Curtin University in Western Australia. The central aim of this project was to assess the implications of deploying decentralised energy technologies in an intelligent grid against human, social, economic, political, cultural and environmental considerations. The research involved evaluating the feasibility and impact of a variety of DE technologies sited in regional communities to manage peak loads and promote sustainable energy use from a range of stakeholder perspectives such as the community, small to medium enterprises (SMEs) and the energy networks.

The most significant theme to emerge is the high level of acceptance among energy (residential and SMEs) consumers and other stakeholders. The stakeholders accepted that an intelligent grid or 'smart grid' with embedded decentralised energy measures offers a genuine alternative to a centralised grid supply. Concerns about economic viability are a crucial issue, and so proving that an intelligent grid can shift from theorised benefits to a sound investment opportunity is essential.

Another significant finding is that most stakeholders believe governments have the ultimate responsibility for policy direction, regulatory reform and coordination and for providing incentives for energy stakeholders to move towards a low carbon future. The paradox, however, is the lack of trust placed in governments' capacity to implement the intelligent grid – decentralised energy (IG-DE) vision. While government leadership is desired, there is also the recognition of personal responsibility, where all sectors of society including community, business and the energy networks drive a low emission vision through a combination of top down and bottom up processes.

The research was conducted in three main stages with different energy stakeholders. The research method is outlined below:

Stage 1 provided insight into the socio-economic barriers faced by community members and the extent to which institutional collaboration and community activism can facilitate the planning and deployment of DE, including community-owned DE initiatives.

Stage 2 developed and conducted an energy attitude survey with the small and medium Enterprises (SMEs) sector in the regional Western Australian communities of Denmark and Albany to gain their perspective of the issues and impacts of DE deployment.

Stage 3 involved interviews with representatives of Western Australia's energy industry network to gain their perspective on the challenges, barriers and drivers of a transition to a more intelligent grid, and to determine if they had a preference as to whether a 'smart grid' transition should include 'distributed generation' capacity.

4.1 Drivers of Decentralised Energy

The potential for network efficiency gains and cost savings of DE will lead to industry recognition of its value. Energy utilities are driven to implement smart grid solutions for a variety reasons: to reduce the peak demand; to avoid paying higher prices during peak times; to meet Renewable Energy Targets (RET) and Renewable Energy Certificates (RECs) liability obligations; to offer customer choice for green energy; to provide energy security and to reduce emissions. Approximately 90 percent of industry stakeholders surveyed believe that "*network efficiency*", "*cost savings*" and "*peak demand reductions*" are key motivations for the industry to pursue IG-DE. Another key driver is the efficient use of scarce commodities and the need to ensure the capacity of the industry to meet the growing customer demand for DE.

The incentives driving DE, from a householders' perspective, include the rising cost of electricity, aspiring to a more sustainable lifestyle, energy security and mitigating greenhouse gas (GHG) emissions. Members of the community with strong sustainability values embrace DE because of their desire to reduce our reliance on fossil fuels. Those not concerned about climate change still support the development of renewable DE, but oppose community DE projects, due to the perception that they will hinder economic growth. The application of decentralised energy systems is appropriate in the community of Denmark in Western Australia as energy reliability is a major issue. Of the stakeholders surveyed, only 40 percent believed that IG-DE is less reliable than centralised supply.

4.2 Impediments to the widespread deployment of DE

Through interviews and surveys the research found that the communities in Denmark and Albany have a strong desire to be energy independent and to live sustainably. However, the affordability of DE technologies is a key impediment as only a minority of regional residents can afford to access government subsidies for technologies such as photovoltaics. Similarly, small and medium enterprises (SMEs) are keen to promote their green business credentials and/or attain energy security, yet economic viability is regarded as the key impediment. The other challenge is that energy is a low priority for SMEs. However, given sufficient economic incentives, SMEs would consider installing DE technologies.

Economic considerations and a lack of energy expertise among policy makers are key impediments facing the industry. However there is optimism that technological advances and consumer demand for DE will drive policy and regulatory reform. Surveys from the iGrid forum that was held in Perth in March 2010, found the majority of respondents highlighted institutional and economic impediments as significant industry barriers. As the stakeholders highlighted, firstly the network is not regulated to accommodate all residential solar power on the grid and secondly retailers are not obliged to purchase renewable energy credits (RECs) in WA. In view of these issues, the call from the community is for political leadership and coordination to drive a smart grid transition that will be in the interests of the WA’s energy industry.

4.3 Solutions to impediments

Greater deployment of DE is viewed positively by stakeholders, as the benefits are considered to outweigh the costs in the long term. There is overwhelming support for community energy initiatives and better community engagement with intelligent grid technologies. Stakeholders were also overwhelmingly in favour of institutional support for community DE initiatives and a more inclusive energy governance model to enable more widespread participation. Other enabling processes include government leadership, greater financial incentives, and policy and regulatory reform. Collaboration between state agencies and between state agencies and the energy industry are also considered necessary to ensure an economically viable sector.

Community engagement – There is support for community energy initiatives, however the lack of knowledge among energy consumers is considered a key barrier. Public education is vital to inform consumers of the benefits of intelligent grids and DE technologies. More opportunities for genuine community engagement via training and education are needed to ensure consumers benefit from the application of smart meters and time-of-use (TOU) pricing mechanisms. Stakeholders advocated a number of promising processes to facilitate a smart grid transition. Firstly, development of '*community decentralised energy'* is considered a significant bottom up process, in which community members drive the community-owned energy generation initiatives and also bear the associated costs. Also highlighted is Western Power's pilot *community engagement* process to plan sustainable energy visions with regional communities as a key model to advocate for smart grid solutions. Consumer education is fundamental to motivating the transition toward a low carbon community.

The role of government – Government leadership and coordination are seen as key enablers. The state government and the energy utilities are seen as having the ultimate responsibility for energy supply. Despite these expectations, study participants had a profound lack of confidence in the ability of government to tackle climate change issues. Instead, trust was placed in bottom up leadership with community and environmental activists playing a key role as advocates for change at policy and community levels. SMEs tend to operate in isolation without support, hence strong regional leadership, combined with institutional facilitation, is important for this sector.

Consistent government policy was suggested vital in **addressing policy and regulatory impediments** to ensure that DE can be better accommodated on the grid**.** This requires reform in a number of areas. Market reforms are needed to encourage the purchase of DE and to prioritise low emissions generation over more carbon intensive sources. Market rules which deal with liability issues for network impacts caused by residential generators also need to be reviewed. A key measure recommended for surmounting institutional barriers facing developers of community DE initiatives was the establishment of supportive regulatory and institutional structures that prioritise community funded DE projects. Policy changes are needed to facilitate a smoother and speedier institutional process for small-scale DE generators. In their qualitative feedback stakeholders called for a triple bottom line approach. With this in mind they called for institutional drivers and enablers that incorporated regulatory reform. SMEs want regulatory incentives such as mandatory energy efficient buildings to drive deployment of DE. Regulatory reform is also considered vital to secure the recognition of networks and the regulator for cost savings derived from IG-DE. The consensus is that a supportive energy regulatory and policy context is vital to increased penetration of DE initiatives.

The enormous economic pressures inherent in transforming the electricity grid can be addressed through **government leadership**, appropriate policy direction, and collaboration with the energy industry to ensure it can operate as an economically viable sector. From a network perspective, the deployment of DE will require demonstrating the economic viability of IG-DE and establishing the right price signals to enable industry support. Energy stakeholders believed that promoting cost effectiveness and creating a fair and predictable investment environment are vital for transforming the energy industry. Innovative energy policies and programs are vital to enable an IG-DE transition. Land developers are demanding energy innovation to promote the construction of energy efficient commercial buildings and residential eco-villages and homes to gain a market edge. In addition, innovative business models such as the roof space rentals are also seen as a way to drive DE deployment at both the residential and SME level.

Financial incentives such as feed-in tariffs are considered a key incentive for increasing penetration of some DE technologies such as PV. Stakeholders expressed concern that economic incentives could lead to sectoral inequality, as disadvantaged SMEs could not afford access to rebates. The challenge for policy makers is to structure incentives to ensure all energy consumers can access them regardless of socio-economic status. A key recommendation involves utilising the revenue raised from the carbon tax to incentivise DE deployment among disadvantaged energy consumers. Government subsidies and the higher Feed in Tariffs, Renewable Energy Credits, the Renewable Energy Buyback Scheme and state government subsidies were also noted as providing strong financial incentives. The WA State Government's $30 million Low Emissions Energy Development (LEED) fund for research and development of a variety of RE technologies was also seen as a key driver for DE.

Collaborative strategies to change consumer behaviour – Strategies are needed to reduce peak energy demand in edge-of-grid communities. Strategies for behavioural change include consciousness raising, and initiating social norms, social equity, and market and policy incentives to drive green energy investments. For those who are driven by external motivations, emphasis is placed on the social, economic and environmental benefits of technological advances. Policy and economic incentives are used to motivate all stakeholders.

4.4 Case Study: Western Power behaviour change initiative

In addition to implementing education and training schemes, Western Power based in WA has deployed a number of demand side management (DSM) strategies at no cost to consumers these strategies help residents to reduce energy consumption and electricity costs. In Western Power's Green Town project collaborative engagement with community members is a key driver for IG-DE because consumers are informed about the benefits of this technical innovation. Western Power's Demand Side Management (DSM) strategies are a pertinent example of how institutions can encourage residents to adopt smart grid solutions. While Western Power's planning process has been significantly influenced to consider IG-DE solutions for regional communities, it has also evolved with undertakings of social policy programs to provide incentives for economically disadvantaged residents to engage with DSM solutions.

5. CONTROL METHODOLOGIES FOR DG FOR ENHANCED NETWORK STABILITY AND CONTROL – PROJECT 1

The Project 1 research was conducted by the School of Information Technology and Electrical Engineering at the University of Queensland. It has focused primarily on the enhancement of stability of medium-voltage (MV) and low-voltage (LV) power systems in the presence of distributed generation (DG) units. Fundamentally, it is important that power quality and protection issues for higher penetration of DG units in distribution systems are fully investigated. Shunt compensation devices such as capacitor banks, Static VAR Compensator (SVCs) and static synchronous compensators (STATCOMs) are normally installed to enhance voltage stability. However, the placement of such compensating devices can have an big influence on small signal stability. DG units installed with appropriate control modes in a network can be utilised to enhance small signal stability of the network. This project has developed a number of methodologies to determine the optimal location and size of synchronous and induction generator-based DG units and a new index was formulated for steady state and post-fault voltage recovery.

Decentralised Energy brings new challenges for power systems because operators need to integrate distributed generators into the existing distribution system. The challenges include: bi-directional power flow, less high-inertia generation and unregulated/intermittent behaviours. These challenges mean that instability is a key issue for the operation of the electricity grid. DG's can affect reliability, power quality, stability and safety. DG units embedded with different technologies, and with different steady state and dynamic characteristics, can improve or impair system stability depending on how the challenges they pose are dealt with.

This research focused primarily on the enhancement of voltage stability and small signal stability of MV and LV power systems in the presence of DG units. The overall objectives of the project were to:

- investigate the impact of distributed generation units on voltage regulation and dynamic stability
- determine the optimal size and location of the static and dynamic compensation devices and DG units in order to enhance system stability and reduce losses

- coordinate DG with available voltage control devices in order to ensure that the system retains the appropriate voltage regulation and to mitigate the possible negative effects of DG placement on stability
- develop appropriate control methodologies for the robust and flexible integration of DG units without violating system constraints.

5.1 Voltage stability

The integration of distributed generation has a number of advantages like voltage support, power loss reduction, opportunity to utilise local energy resources and better peak load management. However DG may give rise to some instability issues because of the nature of sources and loads related to DG units. Voltage instability is often considered to be a local area phenomenon associated with the lack of reactive power in a significant part of the power network. Therefore the location and sizing of DG units has become one of the most important concerns for power system stability. The augmentation of both static and dynamic stability was researched. The connection of DG requires the use of voltage and reactive power control equipment to ensure that the system maintains proper voltage regulation. Before a DG unit can be connected to an existing power system, the low voltage ride through (LVRT) capability must be assessed.

The study of voltage stability in this project involved the following steps:

- investigating effective voltage stability indices
- improving static voltage stability margins by proper DG placement
- enhancing static and dynamic voltage stability in view of present grid standards.

The research found that capacitor banks, SVC and STATCOMs are key components for improving the voltage stability.

Reactive power margin

The reactive power margin of a particular bus indicates how load the bus can manage before its loading limit is exceeded and voltage collapse occurs. A 16-bus distribution system was used extensively in this study, and a wide variation of load composition was simulated through different sets of load models, which included both extreme and intermediate conditions. Irrespective of load composition, the reactive power margin index provides a reliable index for identifying the weakest and strongest buses in a system. Ranking of buses was performed by calculating their reactive power margins and voltage sensitivity factors (VSFs). When an amount of reactive power equal to the reactive power margin is drawn from a bus by an applied load then the system may experience voltage collapse.

Selecting the proper locations for synchronous and induction generators

Weak buses with low reactive power margins are already operating with a deficiency in reactive power. If some DG units which consume reactive power are placed on these buses, voltage problems and instability will occur. However, we can use the large reactive margins of ‘strong buses’ to help improve the stability of these types of DG units.

A methodology was developed for the determination of the optimal location and size of synchronous and induction generator-based DG units, considering their reactive power capabilities. The methodology was based on a reactive power margin index which was found to be reliable for identifying suitable locations for various DG units. Placing synchronous generators (SG) on weak buses improves voltage stability and increases the loadability of the distribution system. The rate of the increase of loadability with SG is greater at a weak bus than at a strong bus. To avoid reductions of loadability and to improve voltage stability, induction generator-based DG units need to be placed at strong buses. This methodology can be used by distribution companies in planning the most suitable locations and sizes of DG units along with other practical considerations.

Determining the size of induction generators

The inclusion of an induction generator in the distribution system usually results in significant losses. The optimal size of the induction generator corresponds to maximum loadability as the loadability of the system starts to decrease after a certain machine size. Also, the reactive power consumption through the grid tends to increase as machine size increases. With an induction generator connected to the system, if the volatile primary resource (e.g. wind and solar) becomes zero then the real power injection also becomes zero. However, the reactive power consumption is still there, this creates a significant amount of grid loss which is greater than the base case. To ensure the loss is always lower than the base case loss, it is important to provide reactive power compensators on buses with induction generators, which can support the worst case. Results from this study show that for the enhancement of the static voltage stability margin, synchronous generators need to be placed at a weak bus and induction generators need to be placed at a bus near to a substation which is strong enough to support the reactive power requirements of the IG. In recent years grid requirements and standards have been developed to shape conventional control strategies and maintain static as well as dynamic voltage stability throughout DG-integrated systems. The technical regulations or specific standards define the maximum permitted variation of every bus bar voltage under both transient and steady state conditions.

Enhancement of static and dynamic voltage stability in view of present grid standards

Determining the optimum location and size of static compensators (such as capacitor banks) is one of the foremost tasks in reactive power planning. When they are of the correct size and when they are in the correct position, SVCs and STATCOMs have the inbuilt potential to offer both dynamic reactive power compensation for transient voltage stability improvement and steady state voltage regulation. A methodology was developed for the placement of reactive compensation devices with the objectives of minimising grid losses and satisfying grid code requirements. A sensitivity-based approach to deciding the appropriate location and size of high-cost dynamic compensators such as STATCOMs has been proposed. This novel approach not only reduces system losses but also ensures faster recovery time and thus improves reliability. The feasibility of the methodology was demonstrated on two distribution systems with different network and load configurations.

5.2 Small signal stability assessment with DG units

The increasing penetration of distributed generation (DG) sources and other controllers for enhancing power quality is transforming traditional distribution systems into more active systems, where there are more dynamic interactions among DG units and controllers. The dynamic interactions may lead to low damped - low frequency oscillations, raising the issue of small signal stability. In this project, participation factor and eigenvalue sensitivity approaches were used to determine the maximum level of renewable energy penetration that can be applied without losing small signal stability. This helped in the selection of the best generator to control in order to effectively suppress unwanted oscillations in the distribution system.

Many countries aim to supply at least 20 percent of their load demand by renewable energy within the next 10 years. Based on this, our research investigated three cases for small signal stability analysis:
1) The base case: 2) 20 percent wind and 3) 20 percent solar.

The increased penetration of wind and solar power was found to have a positive impact on the oscillation damping of the voltage controlled synchronous generator. However, the given DG penetration is not always sufficient to ensure the stability of the system and in such cases an additional controller for a DG unit can be designed for system stability enhancement.

5.3 Control methodologies for distributed generation

There are a number of approaches for enhancing the network stability of DG systems such as designing a shunt controller for a selected capacitor bank and designing additional controllers for DG units such as Photo-voltaics and doubly-fed induction generators (DFIGs). A coordinated control approach for different DG units is also proposed and discussed in this study. First, the research team developed an approach to control a shunt capacitor bank in order to adjust the damping of the critical modes. Next, a supplementary control for PV generators for augmenting small signal stability was proposed. We then presented a robust control algorithm for DFIGS for enhancing small disturbance stability. A robust decentralised control approach for different types of DG including DFIGs, PV generators and direct-drive wind generators (DDWGs) was designed to enhance both dynamic voltage and transient stabilities for the flexible integration of DG units.

5.4 Robust coordinated control of DG units

The controllers designed by classical control techniques have their validity restricted to a nominal operating point at which the system is linearised. But a power system constantly experiences changes in operating conditions due to variations in load generation patterns and variations in transmission networks. Moreover, some uncertainty is introduced into the power system model due to inaccurate approximations of the power system parameters, neglecting high frequency dynamics and assumptions made in the modelling process. Hence, it is desirable to have a robust damping controller to ensure adequate damping under various system operating conditions.

The use of DG units could be significantly enhanced if they operated in a voltage control mode instead of the unity power factor recommended by the IEEE 1547 standard. Transient voltage variations and dynamic voltage instability can also limit DG penetration, although voltage rise is a major constraint when accommodating DG units. The simulation results show that the proposed robust control method can augment the potential penetration of DG units without requiring network reinforcements or violating the system operating constraints.

6. OPTIMAL SITING AND DISPATCH OF DISTRIBUTED GENERATION – PROJECT 3

6.1 The challenges of integrating DG into the grid

Project 3: Optimal Siting and Dispatch of Distributed Generation was a collaboration between researchers at the Queensland University of Technology and Curtin University of Technology. The research aimed to find solutions to a number of technical challenges that arise from integrating DG into existing distribution networks. The key technical challenges investigated include: voltage rise, protection issues, under-frequency load shedding considering DGs and dealing with different types of DG that have different impacts upon the grid. The research project also quantified the benefits provided by DG technologies such as reduced losses, voltage control and the ability of DG to defer costly network investment.

6.2 Benefits

This project quantified the value of improvements in the reliability of the network. The key benefits of DG that have been identified include:

- DG can reduce network loss reduction by avoiding long-distance transmission
- DG can improve voltage control in the remote terminal of feeders
- DG can significantly improve reliability and defer network investment in lines and transformers.

Benefits to networks

This research quantifies the benefits to networks in terms of voltage support and reliability, and determines an appropriate level of investment in DG to achieve these benefits compared with other network investment options. DGs can provide network functions such as voltage support and line-loss reduction. To realise these benefits the DG units need to be owned by, or controlled by, the distribution service provider (DSP).

In urban areas reliability of supply is achieved by having cross connections to nearby feeders. However in rural areas there are no nearby feeders, and reliability can be poor with outages exceeding 700 minutes per year. Outages can cost as much as $70,000/MW/hr, and loss values at the level of $8,000/MW/hr could be sufficient to drive investment in backup supply. If local generation is able to continue supply when the main line is faulted, the increased reliability could yield substantial benefits. In edge-of-grid areas the costs of the network can be very significant. Therefore, DG's can reduce the network investment and therefore edge-of-grid is one of the most viable places to install DG.

Optimising network investment

This project assists with determining the optimal level of network investments over the planning horizon for the distribution system. DE can reduce the growth of peak demand or supplement the supply of energy needed during peak times, which would defer the need for investment in network upgrades. This project contributes to the development of tools to determine the optimal investment planning of distribution networks. The considerations include: the power lost in the transmission lines; the capital and running costs of DG; and whether to meet load-growth issues by augmenting of the network (using conductors and transformers), or by deploying DG. This conclusion is supported by the research in Project 2 and Project 4. For further details please see the final report for Project 3.

Optimal siting and sizing of distributed generators in distribution systems

Inappropriate siting and sizing of DGs could lead to negative impacts on a distribution system with regard to relay system configurations, voltage profiles and network losses. The chance-constrained programming (CCP) framework provides a new mathematical model to handle some uncertainties in the optimal siting and sizing of DGs. These uncertainties include: the stochastic output power of Plug in Hybrid Electric Vehicles, renewable DGs and solar generating sources; volatile prices of fuels used by some DGs; and uncertain future load growth. The project developed a software program which, through cost-based technical analysis, identifies the most beneficial installed capacity for a particular distribution network with increased integration of DG. For further details on this research refer to Chapter 5 of the final Project 3 report.

Sizing the distributed generation with life-cycle costing

Optimal planning algorithms are required for determining the best type of generating technology to use for determining the machine ratings that will satisfy the demand, and to operate the system at minimum cost under constrained operating conditions. Modelling shows that the most economical combinations of various DGs with critical support of diesel units are wind–PV–diesel, followed by

PV–diesel. The priority ranking of life cycle cost and greenhouse gas (GHG) emissions can be used by network regulators and policy makers to set incentives, or to penalise. It also facilitates benchmarking distribution networks for the incentives as appropriate.

6.3 Technical challenges and solutions of DG deployment

This section addresses the technical barriers that arise from an expansion of DG, and pathways to overcoming these barriers. The technical barriers include:

Voltage rise

The potential for a rise in voltage due to an increase in the penetration of DGs is recognised as a challenge for distribution utilities. The increased penetration of solar photovoltaics (PV) is especially challenging as the PVs trip off when the voltage exceeds the acceptable range. The solution lies partly in using the ability of inverters to operate at a leading or lagging power factor; to operate with some capacitive or in a partly inductive mode. However, this could be a problem if multiple independent units are each trying to control the line voltage. The "voltage droop" concept, which is used for voltage-sharing in large power stations where the reactive power injection is proportional to the voltage drop, provides a practical solution.

Protection

DGs in a distribution system can reduce the ability of conventional protection systems to reliably detect high impedance faults on the network. Protection systems are necessary to prevent power-line damage resulting from faults; they are designed to switch off circuits when power lines fall to the ground, and hence reduce risks to public safety from live power lines. A method is presented in this project that provides precision detection of line high-impedance faults in the presence of DGs by developing the admittance relay. This method is similar to conventional overcurrent relays and can be used in conjunction with them. This makes the relays sensitive to faults even when the voltage drops. Further investigation is proceeding on the connection of earths for three-phase generation, but a clear picture of this situation has not yet become evident.

If we are to gain the reliability benefits for distributed generation, we need to be able to operate in microgrid or grid-connected mode, and this requires changes in the earth referencing of generation. For additional information about microgrids please refer to Section 1.4 of the Project 3 final report. For a more comprehensive analysis refer to the Project 7 final report which is outlined in section 7.

Under-frequency load shedding considering DGs

Normal power-system operation keeps the system frequency very close to 50 Herts (Hz). Controls are required to add generation capacity if the frequency is falling, or to reduce generation when the frequency is above 50Hz. If there is a rapid drop in frequency one solution is to shed load, causing the system frequency to increase until the load is less than the remaining generation. With the ever-increasing size of the power system and the extensive penetration of DGs in power systems, the development of an optimal under-frequency load shedding (UFLS) strategy presents new challenges. These include avoiding the isolated operation of DGs when the UFLS strategy is executed and loads are shed; and exploring the use of DGs to reduce the load amount to be shed or even avoid the need to shed load. The research objective of this project was to develop an optimal UFLS strategy in a distribution system containing DGs and considering load static characteristics.

The strategy proposed by Project 3 consists of a basic round and a special round. In the basic round, the frequency emergency can be alleviated by quickly shedding some of the load. In the special round, the security of the frequency can be maintained and the operating parameters of the distribution system optimised by adjusting the output powers of DGs and some loads.

Scheduling generation with non-dispatchable distributed generators

Generation scheduling with non-dispatchable distributed generators can be challenging as generation from intermittent sources such as wind turbines cannot be relied upon to dispatch power on demand. This can lead to increased scheduling costs since the system must provide more reserves than a power system with conventional generation units. Existing generation scheduling is generally based on deterministic models, and usually ignores the likelihood and the potential consequences of variable contingencies. Addressing this limitation, Section 1.6 of the Project 3 final report proposes generation scheduling methods suitable for fluctuating wind power. This is also applicable to other intermittent power generation scenarios.

This research has developed a probabilistic model for the power output of wind generators. The Direct Current probabilistic power flow is calculated with the combined use of cumulants and Gram-Charlier series. Three risk-controlling strategies are then introduced to enhance the system defence against security risks, given uncertainty such as the probability of not violating each branch power flow limit (PBL); the probability of not violating system power flow limit (PSL); and the probability of the security margin of system power flow (PSM).

7. OPERATION CONTROL AND ENERGY MANAGEMENT OF GRID CONNECTED DISTRIBUTED GENERATION BASED ON A MICROGRID – PROJECT 7

A number of DG technologies can be integrated to form an independent electric grid to supply local loads in the absence of the main utility grid. Small electric grids like this are called microgrids. Microgrids are capable of operating when connected to the main utility grid (grid-connected mode) or operating without the presence of a utility grid (islanded or autonomous mode) without compromising power quality. DGs, especially those based on renewable energy sources such as solar and wind, can be effectively integrated into a microgrid to cater for rapid growth in demand.

This final report for Project 7 discusses the challenges of microgrid operation such as grid stability, power management and protection. Solutions to overcome these challenges include new control, power management and protection strategies for a safe and reliable microgrid operation. The key findings of this project include:

- using a modified droop control strategy to improve the transient stability of a microgrid
- power management strategies for a microgrid containing dispatchable DGs, non-dispatchable DGs and energy storage
- control strategies for converter-controlled DGs
- improved power quality of microgrids using filters for converter-interfaced DGs
- techniques to analyse microgrid stability in the presence of multiple DGs
- protection strategies for a microgrid (both radial and meshed) to ensure safe and reliable operation in both grid-connected and islanded modes of operation.

7.1 Inertial and Non- Inertial Distributed Generation

The DG sources can be classified as inertial or non-inertial. Inertial DGs such as biodiesel generators and synchronous type wind turbines are run by synchronous generators with their rotating inertial masses. These DGs respond very slowly during transient events in the microgrid. DGs connected through converters such as PVs, fuel cells and batteries are non-inertial since their output quantities (voltage, current, frequency) can be changed almost instantaneously. Power management strategies are required to incorporate non-dispatchable (renewable energy-based) DGs and battery storage into a microgrid.

7.2 Dispatchable and Non-dispatchable Distributed Generators

The DG sources in a microgrid can be also classified as dispatchable or non-dispatchable in terms of power flow control. The output power of DGs such as micro-turbines, fuel cells, and biodiesel generators can be controlled on request and are known as dispatchable DGs. The output power of DGs such as wind turbines and PVs cannot be directly controlled since primary sources associated with these DGs are intermittent. The output power of these DGs cannot be dispatched to meet load demand, and are known as non-dispatchable DGs. It is desirable to control the non-dispatchable DGs in maximum power point tracking mode, thereby harnessing the maximum available power.

The conventional operation, control and protection strategies applied to an electric power distribution grid cannot be used in a microgrid, especially when it operates in islanded mode. More importantly, the standard frequency and the voltage of an islanded microgrid should be maintained within predefined limits to avoid problems with the operation of the DGs and customer loads. Fluctuations of system frequency and voltage should be minimised to maintain system stability.

7.3 Controlling system frequency and Voltage

Frequency and voltage droop controls are the most common methods used to control system frequency and voltage in the presence of multiple DGs in a microgrid. Frequency and voltage droop control the real and reactive power outputs of a DGs by changing the frequency and the voltage magnitude respectively. However, when both inertial and non-inertial DGs are present in the microgrid, their response rates during transients are different and this may cause transient oscillations in the system. To dampen these oscillations new control strategies need to be developed. The project researchers have found that an angle droop control is capable of minimising the frequency and power fluctuations during transient events in a microgrid, making it possible to share real and reactive power effectively.

Primary sources of DGs such as PV or micro-turbines need converters to provide a safe interconnection. These converters cannot produce pure sinusoidal waveforms due to their switching operations. As a result, the output waveforms of converters usually contain odd harmonics and this may create power quality issues in the microgrid. The power quality in this case means both voltage and current quality which in the case of deterioration may reduce equipment lifetime or damage equipment. To avoid this, new converter control filters such as inductor-capacitors or inductor-capacitor-inductors can be used for smoothing the output waveforms.

When operating two or more DGs in parallel in the islanded mode, stability is of concern. If higher gains are used in droop controls, this will cause instability in the system. A stability analysis should be performed with DGs to ensure a safe and reliable microgrid operation.

7.4 Protection schemes

Protection schemes are also vital to ensure personnel and equipment safety in a microgrid. To harness its maximum benefits a microgrid should be allowed to operate in the islanded mode. New protection strategies are required to ensure the safe islanded operation of microgrids. Firstly, a protection scheme for a DG-connected radial network is proposed using overcurrent and communication channels. Secondly, a new inverse time admittance relay characteristic is presented that can detect and isolate faults irrespective of the fault level current in the network. Finally, the protection of a meshed microgrid using current differential relays discussed.

7.5 Summary

The major challenges associated with microgrids are:

- microgrid transient stability in the presence of inertial and non-inertial DGs
- real and reactive power control of DGs and load power sharing in microgrids
- power quality (i.e. filter capabilities) of DG converters and the stability of microgrids in the presence of multiple DGs
- microgrid power management to incorporate non-dispatchable and energy storage devices
- microgrid protection in both grid-connected and islanded modes of operation considering radial and meshed configurations.

In this project, the operation, control and protection issues in microgrids were thoroughly investigated to propose new solutions. Better strategies to incorporate DGs in microgrids were developed. The key findings of this study are discussed below:

- improved transient stability of microgrids using proposed droop control strategies
- power management strategies for microgrids containing dispatchable DGs, non-dispatchable DGs and energy storage
- control strategies for converter-controlled DGs
- improved power quality of microgrids using filters for converter-interfaced DGs
- techniques to analyse microgrid stability in the presence of multiple DGs

- protection strategies for microgrids (both radial and meshed) to ensure safe and reliable operation in both grid-connected and islanded modes of operation.

These key findings can be effectively used in implementing future microgrids in Australia.

8. INTELLIGENT GRID IN A NEW HOUSING DEVELOPMENT – PROJECT 6

The University of South Australia (UniSA) worked on Project 6 – Intelligent Grid in a New Housing Development. The project investigated the impacts of the introduction of energy efficiency measures and distributed generation on energy use patterns, on greenhouse gas emissions, on the electrical grid and on consumers. The research also investigates the issues of ownership and control of distributed energy resources (i.e. local generation and loads) in residential houses as well as occupants' attitudes towards this new type of energy generation.

The focus of the research is the Lochiel Park Green Village, a master planned community that seeks to demonstrate that urban, medium density housing developments can have sustainable living as their core principle. The 106-dwelling development has installed solar PV cells, recycled water systems, gas-boosted solar hot water systems and systems have a minimum 7.5 star thermal performance rating. It also features energy-efficient lighting and appliances, a load management system to control peak demand, energy and water use feedback monitors, rainwater water harvesting, and the recycling of stormwater for toilet flushing.

A target was set for a 66 percent reduction in energy use and a 74 percent reduction in greenhouse gas emissions in comparison with the average Adelaide household. UniSA provided technical advice in developing and adhering to environmental guidelines to enable the achievement of the set targets. A comprehensive energy and water monitoring program has been developed and implemented which will provide details of energy and water quantities and patterns of use, as well as peak demands for individual homes as well as for the overall development. The monitored energy saving was around 25 percent, however the development successfully introduced many passive solar and energy-efficient technologies and practices to the local building industry. For further details on Lochiel Park see Section 2 of the Project 6 final report 'The Intelligent Grid in a New Housing Development'.

8.1 Energy use in the building sector

In Australia, the operation of buildings is responsible for over 27 percent of national greenhouse gas emissions, and when combined with emissions embodied in the materials used throughout the building's lifecycle, the impact is estimated to be between 32 and 40 percent of national emissions. Household energy consumption is predicted to increase by 56 percent from 299 PetaJoules (PJ) in 1990 to 467 PJ in 2020. Annual energy use per household in Australia was estimated to be around 13,500 kWh in 2010/2011, although regional differences are significant and new homes, which on average are larger in floor area, typically have higher energy use.

Australian housing is regarded as having relatively poor energy performance, as compared to those of other developed nations. There are a number of explanations for this. Firstly energy is sold below the full environmental and social cost of its supply, thus artificially reducing the attractiveness of energy-efficient homes. Low energy costs have resulted in significant energy wastage through poor building energy performance, wasteful behaviour by residents and the overuse of inefficient energy-consuming appliances and equipment.

Secondly, in most cases house buyers have insufficient information about the likely ongoing energy and cost performance of a home and are therefore unable to make a fully informed decision. And thirdly, organisational or cultural factors have resulted in skills and knowledge gaps in the building and house design industries, reducing the ability of the market to supply higher-performing homes. Lastly, energy efficiency has not, until recently, been a high priority for the building industry or for new home buyers.

For these reasons Australian governments have sought to address market failures by establishing financial incentives to make renewable energy more attractive, by establishing regulatory standards to eliminate the impact of information barriers, by industry education, and by implementing training schemes to improve the ability of the building sector to supply low-energy housing. Although progress has been made in improving the energy performance of new Australian homes, such as though the Building Code of Australia minimum energy efficiency standards, our building standards are well below those of similar economies. A study of building regulatory standards in force during 2004 in the United States, Canada and the United Kingdom found that the median rating for a sample of homes was 7.5 stars. Other policies could also be applied to address specific barriers. Putting a price on carbon could reduce price barriers, and mandatory energy performance disclosure could reduce information-related barriers.

8.2 Monitoring in Lochiel Park

Monitoring was conducted at the individual and apartment level. Each of the 106 houses incorporates a touch screen computer and an in-home display called Ecovision, and an array of intelligent meters and sensors, which comprehensively measure and display general electricity, water and gas usage, in real time. The monitors also enable householders to monitor their own energy and water use so that they can reduce their consumption. Ecovision monitors are one of the ways that it is envisaged that living in Lochiel Park will lead to more sustainable use of energy and water. The premise of the monitors is that householders will be able to gauge their energy use by seeing how much they use with particular appliances.

While all homes at Lochiel Park are being monitored for total energy use and renewable energy generation, a small number of houses are also being monitored at a more detailed level, allowing researchers to gain a thorough understanding of where the energy is used, when it is used. For these houses, separate monitoring is being carried out for lighting, heating and cooling, water heating, laundry services, refrigeration, cooking equipment, renewable electricity generation, and general plug loads. Monitoring of all homes at Lochiel Park is to continue for nine years. Please refer to Section 3 of the final report for further details of the monitoring system.

Key findings

Approximately 35 percent of all energy consumed within Lochiel Park was consumed by gas appliances, and the remaining 65 percent total energy was consumed by electrical devices. Of the electrical energy consumed, a significant portion is generated locally by the roof-mounted photovoltaic (PV) systems. Peak energy usage occurs during the winter months. This peak consumption is mainly caused by smaller solar gain in winter which results in a greater need for gas boosting of solar hot water systems, and the use of gas space heating; however this only occurred in a small minority of houses.

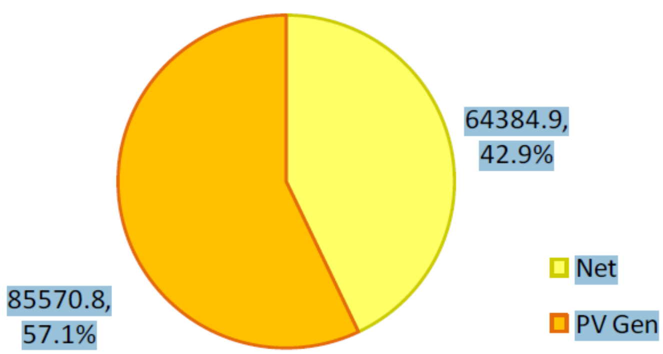
8.3 Key distributed energy technologies

Photo-voltaic system

The average size of PV systems is 2.2 kWp, with the smallest being 1.8 kWp, and the largest system having power rating of 4.2 kWp. Approximately 40 percent of all systems use amorphous cells, whilst the remaining 60 percent use crystalline cells. The majority of houses have their PV systems installed with an inclination angle of between 15 and 45°. Most PV panels face north to northwest, which should allow the system to perform marginally better in the mid-late afternoon compared to a system that is facing directly north or northeast. Please refer to Section 4 of the final report for further details of the PV array.

The average electrical energy consumed monthly is about 460 kWh, of which only 195 kWh comes from the grid (net electricity). The solar systems effectively have a combined average saving of 265 kWh per month, which represents an average reduction of grid-bought (net) electrical energy of 57 percent.

Figure 5: Percentage of total electrical energy used at Lochiel Park, i) generated by the PV systems (PV Gen), and ii) supplied by the grid (Net). Note that the values shown have units of kWh.



Load management

An electricity load management trial was designed to allow residents to lower their electricity demand and reduce their electricity bills. By electing to keep the total household electrical peak load below a certain threshold, participating residents were charged for their electricity under a "capacity-based tariff", which was lower than the standard rate. To assist with this process, a load limiting device was installed in all houses at no cost, with the limit chosen by a resident being easily set on the Ecovision display. Householders could elect the appliance circuits to be shut down when the load limit was exceeded, and in what sequence. As part of the trial, if the maximum load chosen proved to be too problematic for the household, then the resident could choose to either change the limit or disable the load management system altogether via the in home display (IHD).

8.4 The economics of low energy homes

Low-energy homes provide several key direct and indirect energy-related economic benefits. Firstly, they use much less energy to maintain human thermal comfort and health, to provide artificial lighting, and to heat water. This provides significant cost savings. The research has established that thermally comfortable homes can decrease the impacts of extreme weather events such as heat waves, on human mortality and morbidity, reducing the demand on often overloaded health systems. Secondly, the excess renewable electricity generated on-site is typically sold at a premium to the local energy market, producing an ongoing revenue stream. Thirdly, the energy required by zero-energy homes in times of climate-related peak energy demand such as heat waves is significantly less than that of the average home. This reduces the need for expensive peaking infrastructure and results lower energy costs to the regional economy .

Residential housing is largely responsible for the escalating peak electrical power demand. The reduction in energy consumption at Lochiel Park should be accompanied by a reduction in peak demand, which is linked to air-conditioning use during hot summer conditions. This reduced reliance on grid energy is also expected to ease the peak demand problems faced by electricity utilities in South Australia and therefore help reduce the need for peaking plants. This corresponds with the research from Project 4 – Institutional Barriers, Stakeholder Engagement and Economic Modelling.

8.5 Awareness, attitudes and behaviour

It is common knowledge that people's awareness, attitudes and behaviour affect the way they consume energy in dwellings. The success of any program aiming at reducing or minimising energy use and the consequent greenhouse gas emissions will depend largely on people's attitudes and behaviour. The UniSA team conducted a survey on the attitudes and behaviour of owners/occupants of the housing development. The results of the survey are summarised below:

- The residents' self-assessment of their own understanding of the greenhouse effect and energy conservation issues is moderate.
- They ranked the environment as the third-most serious issue after education and health, and as more serious than crime, unemployment and poverty.
- Knowledge of energy conservation information was derived from the media and from their own personal experience. The internet was the least influential source.
- Most respondents indicated that their decisions to purchase each different type of appliance was influenced by energy-efficiency star ratings, but a significant proportion of residents used relatively low energy efficiency appliances.

Key findings

The desire for thermal comfort has a big impact upon the consumption of energy and water. All interviewees wanted their houses maintained at a temperature that avoided extremes of heat or cold. Many of the Lochiel Park residents, or intending residents, were knowledgeable about ways of keeping their homes cool in hot conditions and exercised considerable initiative in using these methods before resorting to air-conditioning. Despite the homes being very well insulated, 83 percent of residents considered that in hot weather the upstairs rooms were moderately or very uncomfortable without air-conditioning. The predominant reasons for using the air-conditioner were, in descending order:

- help with sleeping
- getting the house to a comfortable temperature
- for the welfare of visitors
- for the welfare of children
- enabling usual activities to be undertaken.

Comfort is a multi-dimensional concept. Any attempt to understand patterns of energy use in households needs to encompass the many meanings that people attach to ‘comfort’ and to comprehend the place of comfort in routine household practice. Despite the residents exhibiting a strong commitment to pro-environmental behaviour and high levels of knowledge, environmentally related behaviour were not always given the highest priority if the consequences were impaired comfort and convenience.

9. SUMMARY

While much of the recent debate about transforming Australia's energy industry has focused on the big end of power stations and taxes, there's an immediate potential for a rapid reduction in greenhouse gas emissions at the smaller end. The final series of reports released by the Intelligent Grid (iGrid) Research Cluster provides the justification for a low-waste, high-efficiency electricity network. The reports are the culmination of a significant body of research into the economic, environmental and social impacts and benefits of the large-scale deployment of intelligent grid technologies and decentralised energy in Australian electricity networks.

Decentralising electricity generation, introducing smart technologies in the electricity grid, improving energy efficiency and managing demand are effective measures within easy reach according to the key findings this three-year multi-disciplinary research project. The iGrid research has as rigorously assessed the technical challenges of integrating distributed energy into the existing grid as well as the economic, environmental and social impacts and benefits.

To download all of the final reports please visit the Intelligent Grid website www.igrid.net.au