CSIRO Intelligent Grid Cluster

Interim Report 1

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Key Words

Distributed Generation; Economies of Scope and Scale, Renewable Generation; Greenhouse Gas reduction;

1 Introduction

1.1 PROJECT BACKGROUND

Market and Economic Modelling of the impacts and benefits of Intelligent Grid and Distributed Energy.

With the Australian governments' recent commitment to the Kyoto protocol and introduction of a National Emissions Trading Scheme (NETS), the need for significant innovation in generation technologies is becoming more urgent. A key component in realising the Government's commitment to its emissions reduction target will most definitely include low emissions distributed generation and demand side management.

This project will examine the case for distributed generation and demand side management as a framework for emissions reduction and improvements in network efficiency. Furthermore, this project will produce an extensive economic analysis of the benefits and potential drawbacks, with respect to the optimal placement of distributed environmentally friendly generating units.

The direct economic benefits of distributed generation have only just been touched on by the economics literature, with varying stand points on the merits of individual technology types and implementation frameworks. The economic justification for distributed generation within the Australian electricity network has yet to be performed. This provides our project with a distinct advantage.

The engineering and economics literature, while sparse, indicates that the benefits of implementing distributed generation are as follows:

- Reduction of energy losses by installing new generating units close to demand, compared with locating large power stations in remote areas close to fuel sources.
- Emissions reduction via installation of renewable generation technologies.
- Planning, infrastructure, transmission and distribution cost deferral.
- Mechanisms for managing system stability and demand augmentation.
- Deferral of large plant installation resulting in over capacity and the lumpy nature of the investment cycle for new plant.

This project will integrate several Macro and Micro level studies which seek to develop regulatory and economic frameworks to enhance the deployment of distributed generation. These are as a follows:

Macro-level studies:

- Distributed generation and economies of scale
- Examination of the true cost of generation
- Market regulation
- Transmission infrastructure and planning requirements
- Risk management of generation portfolios, following the introduction of distributed generation

Micro-level studies:

- Modelling and system dynamics
- Demand side management and the economies of scope
- Costs of optimal placement of distributed generation

1.2 RESEARCH OUTCOMES

The economic analysis and modelling project at UQ, will provide an economic framework for the policies needed to effectively transform Australia's energy sector into a climate friendly industry. This will include the following topics:

- The economic benefits of the deferral of network infrastructure investment and maintenance upon the introduction of distributed generation.
- New investments in a variety of electricity and other energy systems.
- Flow on effects of the network wide implementation of distributed generation on the greater economy.
- Provide support for the deployment of distributed generation via policy and regularity recommendations on market design and structure.
- Development of supply and demand side price response mechanisms that will provide both system and end user level economic benefits and/or cost reductions.
- Specifications for the Carbon Pollution Reduction Scheme (CPRS) and other greenhouse gas trading frameworks.
- Extensive cost benefit analysis framework to enable key energy sector investors to make clear and informed investment decisions.
- Provision of system wide and individual component modelling frameworks to assist key decision makers.
- Market risk management models and software algorithms for operations that conform to emissions reduction targets

1.3 CLASSIFICATION OF MILESTONES

Milestones will be classified according to the following 6 classes of outcomes:

1. Case study: An application of a model or methodology developed in the project/cluster to a specific concrete example in the Australian energy system.
2. Methodology: A document outlining an approach or set of approaches and algorithms to determine a certain economic quantity or measure related to DE.
3. Model: A specification, design and potentially an implementation in software of a computational model for calculating or simulating a set of relevant economic measures of interest to DE, e.g. price of carbon etc.
4. Report: A document destined for internal cluster distribution or for circulation to relevant academic, regulatory or industry bodies.
5. Paper: An academic paper destined for a refereed conference or journal.
6. Database: A data set of key data useful for the cluster and project implemented in Access or MySQL etc. E.g. Network data including topology, components such as sub-stations and lines, component costs of maintenance and upgrading etc. or the NEMMCO Info server/NEM data database.

1.4 OUTPUTS/DELIVERABLES

- Publications in international journals.
- Presentation of results at national and international conferences.
- Engagement with industry via briefings and forums.
- Yearly reporting on project outcomes outlining market and economic modelling.
- Participation in Australian public policy debate to engage with key decision makers via:
  - Recommendations on energy market rule changes.
  - Carbon market design and implementation
  - Industry briefings throughout the life of the project.
  - Training of PhD and Honours students throughout the project.
  - Economic models, with software implementation, examining the impacts of distributed energy technology on the Australian economy to be completed by the 3rd year of the project.
  - Risk management methodology policy documents which can used by energy market participants to manage distributed energy portfolios.

2 Macro level study overview

2.1 ECONOMIES OF SCALE AND DISTRIBUTED GENERATION

One of the classic problems with energy efficiency in large centralised electricity market regulation is the possibility of lost revenues for utilities companies [1]. Electricity generators are considered to approximate large monopolies that exhibit such strong economies of scale [2] that it would detract from their viability to allow competition from a large number of smaller less-efficient suppliers [3].

Given the behaviour of large monopoly generators, the abuse of market power is avoided by a competitive wholesale spot market [4]. Regulatory approaches in Australia have previously impeded policies intended to expand distributed generation because of the threat that utilities might loss revenues. A common hypothesis in the literature [1, 5, 6], is that generators have deliberately raised barriers to counter the inter-connection of self-generation and to discourage energy efficiency investments because of possible consequences for their revenues and profits [7-9].

Generators have also expressed concerns that, if large amounts of energy availability are rolled out onto the market, it would result in excess capacity and the so called "Blood Bath Scenario" [10]. This scenario has been observed several times on the spot market in Queensland when installed excess capacity resulted in generators only being able to bid/recover their short-run marginal costs.

However, with Australia's recent ratification of the Kyoto protocol and its commitment to the introduction of an emissions trading and a renewable energy target, the barriers to investment in distributed generation are slowly being removed. An example of new policy frameworks being developed is New South Wales's recent commitment to provide a feed-in tariff for electricity generated by solar power onto the grid.

2.2 EXAMINATION OF THE TRUE COST OF GENERATION

To establish the economic benefits and costs of installing distributed generators across the grid we will need to define the true cost of electricity production and distribution. A major study into the true cost of generation within Australia has yet to sufficiently quantify all of the components of the vertical cost structure for electricity [11]. We will examine the following costs in our investigation:

- Connection charges
- Transmissions and Distribution costs
- Marginal losses from resistive power flows
- Emissions intensity factor analysis [12]
- Distribution Network Operations
- Demand Side Management/Response

This study will allow the project team to formulate a comprehensive portfolio of data to enhance our modelling and economic analysis of the viability of distributed generation.

2.3 MARKET REGULATION

The iGrid's goal is to overcome the technical, engineering, social and economic barriers to the deployment of distributed generation to reduce greenhouse gas emissions and improve network and system security. When the technical barriers have been overcome the main challenge will be to mount credible business cases for distributed network operators [13].

For distributed generation to become a viable and competitive option in Australia, utilities must be given market access. Market access for distributed generation plants within the NEM will require:

- Network access to the wholesale spot market in each State.
- Integration into the Frequency Control and Ancillary Services market.
- Establishment of new distributed generation capacity market.

The National Electricity Rules require a minimum rated capacity of 30MW for access to the wholesale spot market which may not be the optimal situation in the future. The implementation of distributed generation across the national electricity market will require it to be a competitive investment opportunity for generators in a range of different contexts, involving different regulatory specifications.

Several possible changes to the NER will need to be developed to encourage strategic investment in distributed generation:

- The aggregation of DG assets to form portfolios of substantial size (e.g. 1000MW)
    - Off take to be traded by distributors, such as Energex in South East Queensland.
    - Off take to be traded by generators
- Alternate specifications for distributed generators to be tradable at smaller rated capacity.

2.4 TRANSMISSIONS INFRASTRUCTURE AND PLANNING COSTS

With the implementation of distributed generation across Australia, it is expected that there will be a significant deferral of transmission capacity which would have normally linked centralised and remote generation assets. Distributed generation is expected to be installed close to load centres requiring smaller investment in network transmission costs [14].

One of the most contentious structural aspects facing the development of distributed generation (particularly in the NEM), is the absence of incentives. Energy only markets provide little support for technologies which can reduce infrastructure and planning costs [8].

The South West Interconnected System (SWIS) offers not only dispatch payments for generation, but capacity payments for installed generators which provide stability for the network. Distributed generation would greatly benefit from access to capacity or security payments above the current frequency control and ancillary services payments of around $2/MWh received by NEM generators.

A variety of studies have been performed on the establishment of connection costs for the integration of distributed generation within the grid [6], resulting in a wide range of scenarios for future connections charge [15]. However, we will consider the following scenarios in this project:

- Scenario 1: Business-as-Usual
    - Generators pay deep connection charges.
    - Demand side pays "*shallowish*" connection charges.
    - Reinforcement costs met through consumer tariff charges.
- Scenario 2: Shallow generator connection costs.
    - Reinforcement costs met through consumer tariff charges.
- Scenario 3: Shallowish generator connection costs.
    - Reinforcement costs shared between all parties.
- Scenario 4: Shallowish generator connection costs with site specific charges.
- Scenario 5: Incentives for development.
    - Shallow generator connection costs.
    - Site specific charges.
    - Incentive based payments post connection for demand side management and at call availability, requiring a new market for DG operations.

3 System Modelling and Dynamics

The development of a modelling framework to examine the impact of distributed generation and its effects on wholesale spot market dynamics is a major requirement for the success of this project. These frameworks will be developed to perform simulation and analysis tasks at the technology type, regional, and system wide levels to compliment the macro and micro level studies to be examined in this project.

Technology type modelling and assessment will examine the broad spectrum of generation types waiting to be deployed to reduce emissions by stationary energy production. Before we can develop regional and system wide modelling frameworks we will require detailed analyses of:

- The costs for deployment
- Technology uptake
- Innovation and technology improvement

The technology type modelling will initially examine the following generation types [5]:

- Solar-Photovoltaic [16, 17]
- Solar Thermal
- Micro-turbines (using Methane, [18])
- Stirling engines (proposed by [6])
- Wind turbines

Regional and system wide modelling will be carried out using data obtained from both the macro and micro level research in this project. Our modelling platforms will include Plexos, the electricity market simulation package used by industry to perform forecasting of electricity network conditions. Currently the Plexos database we have established has extensive economic and technical details on every generating unit across the NEM. We have also constructed a 30-node bus test bed for regional/community level analysis for the optimal placement of distributed generators.

The project investigators have already completed studies using the above modelling tool which reinforces our expertise in this area. Our research will now evolve to focus on the specific requirements of modelling a range of technology types for incorporation of DG into the Australian electricity grid.

3.1 Risk Management

For markets resembling the structure of the NEM, the effect of installing distributed generation on wholesale spot market prices has yet to be investigated [7, 19]. Investment in large generation assets has been shown previously by [10], to reduce average spot price by creating excess capacity. By installing small DG units the incremental increase in demand for energy can be met, which will ensure an adequate reserve plant margin[20].

The reserve plant margin has been used as a measure of supply/demand balance while it has also been used as a predictor of spot price spikes behaviour [10, 21]. The reduction of the incidence of price spikes and general price volatility reduces portfolio risk for generators. A high incidence of price spike behaviour was observed in the NEM in 2007 because of constrained generation availability due to water shortages in Queensland. Conceivably, if distributed generation had been implemented across the NEM, the average spot price in June of 2007 would not have been at the 6^{th} standard deviation of all time. Continued volatility for sustained periods has had serious consequences for retailers (e.g. Energy One in New South Wales) with inadequate hedging and portfolio risk management.

A reduction in portfolio risk will have a variety of economic impacts, including the reduction of the costs associated with managing price volatility risks via lower hedge contract premiums [22, 23]. Volatility risk reduction will lower the barrier for new entry of perspective financial intermediaries such as investment banks [24]. These potential intermediaries have become wary of trading significant volumes of electricity derivatives because they do not possess the physical generation assets which provide the natural physical hedges to mitigate the risks associated with these contracts [2].

Another added benefit of price volatility risk mitigation will be increased derivative market liquidity which leads to improved market efficiency in credit risk management. This improvement can occur through mechanisms such as potential increased use of d-cyphaTrade. A central exchange traded product on d-cyphaTrade eliminates credit risk for intermediaries due to its central clearing/settlement mechanisms. In the current climate, managing credit risk has significant real costs as well as opportunity costs.

3.2 Economies of Scope and Demand Side Management

Economies of scope, in the form of demand side management (DSM), will form another component that this project will focus upon. Micro-grids and distributed generation provide a new paradigm for defining the operation of electricity networks [25]. The operation of a micro-grid assumes that a cluster of loads and micro-sources are operating as a single controllable system[26]. To the distributed network operator this cluster becomes a single dispatchable load, which can be delivered in seconds.

Wherever possible, it is more efficient for markets to resolve congestion and supply/demand balance shortfalls than to involve side-markets for demand management [27]. Distributed generation units may offer cost savings for distributed network operators with respect to side markets/demand management contracts with high volume consumers.

One key element of using demand side management contracts as an incentive to operate distributed generation is in the economic value of the interruptible energy at each location across the grid [28]. Existing power flow solution methodologies can be used to calculate the true economic cost/value of interrupting demand [26].

Economic efficiency is a major concern of distributed generation customers. Various technologies are available for distributed generation, including sterling engine/generators, micro-turbines, photovoltaic/ solar thermal units and wind turbines. Furthermore, with the implementation of distributed generation, a comprehensive analysis of demand side management will be performed as follows:

- Optimal placement of distributed generation units within regional boundaries
- Economic benefits to customers and utilities for install DG units
- Distributed generation vs. demand management contracts
- Interruptible value of energy demand within a regional framework

4 Summary/Conclusions

Distributed generation will be one of the key methodologies for reducing CO_2 emissions, which will greatly facilitate Australia's reduction targets. In this report and literature review the key aspects of the project's scope, research tasks and planning have been presented. In summary, the project will examine the following topics:

- Distributed generation and the Economies of Scale
- Examination of the true cost of generation
- Market regulation
- Transmission infrastructure and planning requirements
- Risk management for generation portfolios following the introduction of distributed generation
- Modelling and system dynamics
- Demand side management and the Economies of Scope
- Costs of optimal placement of distributed generation

Research is currently underway on a variety of projects which are relevant to the energy industry and distributed generation:

- Plugin Hybrid Vehicles and their effects on the South-East Qld Grid.
- Grand-fathering of electricity generators under the national emissions trading scheme.
- Electricity spot market price spike events
- System modelling using Plexos to establish baseline forecasts for the NEM for use throughout this project.

It should be noted that the project's lead investigator has also been successful in winning an ARC Linkage project:

LP0883650: Prof John Foster, Prof John Charles Quiggin, Dr Paul Simshauser, Mr Craig Nalder

Assessing the impacts of proposed carbon trading and tax schemes on the Australian electricity industry and the overall economy

Because of growing international concerns about global warming, Australia is considering both carbon taxation and tradeable quota (e.g., carbon trading) schemes. In this project we seek to address two key research questions: First, what are the likely medium and long term impacts of different carbon abatement policies on electricity supply and demand and how will the power generation industry respond? Second, what are the likely medium and long term impacts upon the economy, and its industries and regions, more generally? Currently, research on these questions remains very limited so we expect to produce findings of international significance.

5 References

1. Venkataramanan, G., and Marnay, C., *A Larger Role for Mcrogrids.* IEEE power and energy Magazine, 2008(may/june 2008): p. 78-82.
2. Deng, S.J.O., S. S., *Electricity derivatives and risk management.* Energy, 2006. **31**(6-7): p. 940-953.
3. Pepermans G., D.J., Haeseldonckx D., D'haeseleer W., Belmans R., *DISTRIBUTED GENERATION: DEFINITION, BENEFITS AND ISSUES*, in *WORKING PAPER SERIES 2003-8: K.U.Leuven - Energy Institute*. 2003: Leuven (Belgium).
4. Stevenson, M.d.A., L. F. M. Peat, M., *Risk management and the role of spot price predictions in the Australian retail electricity market.* Studies in Nonlinear Dynamics and Econometrics, 2006. **10**(3): p. 24.
5. Marnay, C., et al., *Optimal technology selection and operation of commercial-building microgrids.* Ieee Transactions on Power Systems, 2008. **23**(3): p. 975-982.
6. Leprich, U., and Bauknecht, D., *Policy and Regulatory Roadmaps for the Integration of Distributed Generation and the Development of Sustainable Electricity Networks*. 2004, SUSTELNET.
7. Huber, C., et al., *Economic modelling of price support mechanisms for renewable energy: Case study on Ireland.* Energy Policy, 2007. **35**(2): p. 1172-1185.
8. Shrestha, G.B., et al., *Management of price uncertainty in short-term generation planning.* Iet Generation Transmission & Distribution, 2008. **2**(4): p. 491-504.
9. Hatziargyriou, N., *microgrids [guest editorial].* Power and Energy Magazine, IEEE, 2008. **6**(3): p. 26-29.
10. Simshauser, P., *Microeconomic reform of wholesale power markets : a dynamic partial equilibrium analysis of the impact of restructuring and deregulation in Queensland* in *School of Economics*. 2002, The University of Queensland: Brisbane.
11. Woo, C.K., et al., *MARGINAL CAPACITY COSTS OF ELECTRICITY DISTRIBUTION AND DEMAND FOR DISTRIBUTED GENERATION.* Energy Journal, 1995. **16**(2): p. 111-130.
12. Tsikalakis, A.G. and N.D. Hatziargyriou, *Environmental benefits of distributed generation with and without emissions trading.* Energy Policy, 2007. **35**(6): p. 3395-3409.
13. El-Kordy, M.N.B., M. A.Abed, K. A.Ibrahim, S. M. A., *Economical evaluation of electricity generation considering externalities.* Renewable Energy, 2002. **25**(2): p. 317-328.
14. Xu, J., et al., *Power portfolio optimization in deregulated electricity markets with risk management.* Ieee Transactions on Power Systems, 2006. **21**(4): p. 1653-1662.
15. Xiarnay, C., et al., *Policymaking for microgrids.* Power and Energy Magazine, IEEE, 2008. **6**(3): p. 66-77.
16. Drennen, T.E., J.D. Erickson, and D. Chapman, *Solar power and climate change policy in developing countries.* Energy Policy, 1996. **24**(1): p. 9-16.
17. Shum, K.L. and C. Watanabe, *Photovoltaic deployment strategy in Japan and the USA - an institutional appraisal.* Energy Policy, 2007. **35**(2): p. 1186-1195.
18. Davis, M.W., A.H. Gifford, and T.J. Krupa, *Microturbines - An economic and reliability*

evaluation for commercial, residential, and remote load applications. Ieee Transactions on Power Systems, 1999. **14**(4): p. 1556-1562.

19. Katiraei, F., et al., *Microgrids management.* Power and Energy Magazine, IEEE, 2008. **6**(3): p. 54-65.
20. Asano, H.B., S. *Economic evaluation of microgrids*. in *Power and Energy Society General Meeting - Conversion and Delivery of Electrical Energy in the 21st Century, 2008 IEEE*. 2008.
21. Ehsani, A.R., A. M. Fotuhi-Firuzabad, M., *A proposed model for co-optimization of energy and reserve in competitive electricity markets.* Applied Mathematical Modelling, 2009. **33**(1): p. 92-109.
22. Eydeland, A., and Wolyniec, K., *Energy and Power Risk Management. New developments in Modeling, Pricing and Hedging.* 2003, Hoboken, New Jersey: John Wiley & Sons, Inc.
23. Marnay, C., and Bailey, O.C.,. *The CERTS Microgrid and the Future of the Macrogrid*. in *2004 ACEEE Summer Study on Energy Efficiency in Buildings.* 2004.
24. Liu, M. and F.F. Wu, *Managing price risk in a multimarket environment.* Ieee Transactions on Power Systems, 2006. **21**(4): p. 1512-1519.
25. Fahrioglu, M., Yong, T., Lasseter, R.H., Alvarado, F.L. , *Integrating Distributed Generation Technology into Demand Management Schemes*, in *Working papers University of Wisconsin-Madison*. 2007.
26. Fahrioglu, M. and F.L. Alvarado, *Using utility information to calibrate customer demand management behavior models.* Ieee Transactions on Power Systems, 2001. **16**(2): p. 317-322.
27. Bohn, R.E., M.C. Caramanis, and F.C. Schweppe, *OPTIMAL PRICING IN ELECTRICAL NETWORKS OVER SPACE AND TIME.* Rand Journal of Economics, 1984. **15**(3): p. 360-376.
28. Fahrioglu, M.A., F. L., *Designing incentive compatible contracts for effective demand management.* Ieee Transactions on Power Systems, 2000. **15**(4): p. 1255-1260.