31 March 2011

Simon Bartlett
Chairperson, E S Cornwall Scholarship Advisory Committee

Dear Mr Bartlett,

Re: ES Cornwall Scholarship – Sixth Quarterly Report

Please find enclosed my sixth and final quarterly report during my tenure of the E S Cornwall Memorial Scholarship, as required by the scholarship rules.

This report covers the period from April 2010 until concluding the scholarship in September 2010. During this time, I was employed by National Grid in the United Kingdom and tasked with working on a fundamental review of Great Britain's transmission planning criteria. Additionally, I was able to visit a number of companies (Fingrid, ABB, Alstom, Psymetrix, Axpo, and HydroOne) and attend the 2010 Cigre Session. The report documents my impressions from each of these activities.

I welcome feedback or questions from the committee or other interested parties on anything I have discussed in my report.

Yours faithfully,

Jonathan Dennis

Enclosures:

- E S Cornwall Scholarship 2008-2010 – Jonathan Dennis – Sixth Quarterly Report

Sixth Quarterly Report

Introduction

I have used my tenure of the E S Cornwall Memorial Scholarship principally to gain experience in the measures being applied internationally by transmission companies to manage three significant complicating aspects of large centralised renewable generation, being:

- variability of renewable power generation over time,
- low inertia, poor fault ride through capability, and
- remote location necessitating long distance radial connections.

However, as previously indicated, my overwhelming impression since commencing the scholarship is that the obstacles to the increased use of renewable generation are multi-faceted, and that the technical difficulties listed above must be considered alongside the political, regulatory, and commercial challenges. I have therefore sought to investigate and report on all of the transmission related obstacles to increased use of renewable generation.

This is the final quarterly report required by the scholarship guidelines and relates to the period from April to September, 2010. During this time I continued my employment with National Grid's UK electricity transmission network investment planning team. Additionally, I was able to visit a number of companies (Fingrid, ABB, Psymetrix, Axpo, and HydroOne) and attend Cigre Session 2010. This report documents my impressions from each of these activities.

Fundamental Review of GB Network Planning Criteria

My main responsibility during my final period with National Grid was to help develop modifications to the transmission planning criteria to account for the fundamental changes taking place to the British power system.

A common transmission planning and operational criteria is used by the throughout Great Britain, called the National Electricity Transmission System Security and Quality of Supply Standard (NETS SQSS). The NETS SQSS is very comprehensive, specifying information such as:

- the design of generator connections
- limits on the amount of generation infeed which can be lost for credible contingencies, with implications for both the design of the transmission system and the maximum generator unit size
- the variable level of reliability to be provided to different levels of demand, both with the system intact and during planned outages
- a methodology to determine the minimum permitted capacity of network boundaries (i.e. cutsets) following different network contingencies
- the range of background conditions which should be studied and for which the criteria is applicable, including forecast demand cycles, typical power station operating regimes and typical planned outage patterns
- restrictions on the configuration of substations, and the number of ends a transmission circuit can have

In 2008, a fundamental review of the standard was initiated to take account of the significant changes expected to occur in coming years, including:

- UK government plans to facilitate investment in approximately 35GW of new renewable generation in Great Britain between now and 2020.
    - The location of this generation will mean that significant network reinforcement is needed, perhaps including the development of an interconnected offshore transmission network.
    - Much of this renewable generation will be intermittent in nature, and given that the peak demand in Great Britain is presently only 60GB (and falling slightly), this intermittency will have a significant impact on the operation of the GB power system.

- It is expected that new nuclear power stations will have larger capacity generating units than is presently permitted by the SQSS.
- There are significant new interconnections to external systems under construction and more are planned. Interconnectors can result in large changes in flows within short timescales across the transmission system, and this needs to be taken account of in the planning process.

The workload for the fundamental review was divided between a number of topical working groups, with the terms of each working group set by a central review committee. Membership of the working groups included representatives from the three British onshore Transmission System Operators (TSOs), generators and academia.

In early 2010 the review committee decided that a public report of the working groups' progress to date should be compiled, and those proposals which were ready should be consulted on with the wider industry. My initial responsibility was to work with each of the working groups to produce a summary report of their findings, along with presentation material for an industry workshop. Interacting with each of the working groups enabled me to better understand the thinking behind their proposals as well as the merits and practicalities of alternative options. Participating in the industry workshop helped me to see the issues from the perspective of different industry participants: various generators, distribution companies, academics, and other lobby groups.

A copy of this summary report and presentation slides are available online[1], and so I won't repeat them here in full. However, there were a couple of findings which may have some relevance to Australia and are worth pointing out:

- A review of transmission system faults over the past 10 years highlighted a surprisingly high occurrence of double circuit faults (76 in England and Wales). Approximately half of these were due to weather conditions (predominantly ice and lightning), while the other half were due to a fire or other emergency related to the easement. Interestingly, although the rate of single circuit faults was much lower on 400kV and 275kV circuits than on 132kV circuits, the double circuit fault rate was unaffected by the voltage level of the line. On this basis, the working group concluded that the loss of a double circuit line should continue to be treated as a credible contingency in Britian. In Britain, there is only one instance where two transmission lines are constructed on the same corridor. Even when a new transmission line was constructed in the 1990s in parallel with an existing line, it was built on a new corridor several miles away from the existing corridor. Given the relative high cost of transmission in Australia (a function of long distances which need to be traversed), I don't expect that it would be economic to normally consider the loss of

[1] Available online at:
http://www.nationalgrid.com/uk/Electricity/Codes/gbsqsscode/fundamental/April+2010+Consultation/

double circuit lines as credible. Nevertheless, I believe that the exposure of multi-circuit transmission corridors to fires, landslides or other easement emergencies – regardless of their voltage level – is a factor which should be seriously considered when planning the transmission system. Ideally, it would be best to use diverse transmission paths for different transmission lines to avoid the situation where a single mode of failure could affect multiple lines (potentially 3 or 4 circuits). This concern must obviously be weighed against political and community considerations.

- The SQSS specifies the manner in which generation should be connected to the grid, and presently does not differentiate between baseload power stations and those powered by intermittent sources, or between different capacities of plant. One of the working groups proposed altering the criteria to specify a connection whose reliability is related to the contribution the generator makes to wider system security. For instance, a large thermal generator would require a multi-circuit meshed substation connection, while a small radially-fed windfarm might only merit a single-circuit single-breaker connection. Although there was general industry agreement with the principle of the proposal, there was disagreement regarding how the difference in the quality of service offered to smaller/intermittent generators should be reflected in the transmission charging methodology. The aggregate effect on system security of connecting large numbers of intermittent generators by non-firm connections was also questioned. The working group's proposal was consistent with the findings of a separate study a few years earlier which developed the planning criteria for offshore transmission networks. That study concluded given the cost of offshore infrastructure and the absence of demand connections, it was not cost effective to provide redundancy offshore but merely to limit the amount of generation which could be lost following a contingency (refer to my second quarterly report for more information about this). In Australia, where infrastructure costs are generally higher and renewable resources can be a significant distance from the existing network, there may be economic merit in allowing the non-firm connection of *remote* intermittent forms of generation (perhaps up to a certain MW cap, linked to the amount of FCAS typically run). As in Britain, the financial and operational implications of such a change would need to be resolved.

Review of the Required Boundary Capability Criteria

There were a number of areas in which the fundamental review working groups failed to reach definitive findings, largely owing to their very wide remit, the unfamiliar nature of the problems they were tackling, and strongly-held differences of opinion. One particularly important area in which no conclusion had been reached was on the methodology use to define the minimum permitted capacity of network boundaries.

The existing criteria was conceived in the 1930's and consists of a deterministic procedure by which the minimum allowable capacity of each boundary (i.e. cut-set) can be determined in terms of the generation and demand on each side of the boundary. The technique has been the subject of much academic research over the years, and despite the technique's simplicity, it has been found to be very effective at maintaining a consistent loss of load probability throughout the British power system, as well as facilitating a cost-effective energy market. Having a simple formulaic criteria has provided power industry participants with clear idea of the performance they should expect from the grid, and provided the TSOs with an unambiguous mandate to expand the transmission network as needed.

However, the following changes taking place on the power system have called the ongoing suitability of the criteria into question:

- increasing generator plant margin
- intermittent nature of generation
- economic distortion applied to the market by incentive schemes
- much greater interconnection with neighbouring countries

Given the lack of progress of this issue to date, coupled with the importance of the criterion to a number of key transmission augmentations being considered, a special working group was established to resolve this issue. Membership of the working group included representatives from each of GB's TSOs. I was grateful to be one of National Grid's representatives on the working group as it afforded me the opportunity to gain first hand experience grappling with the macro impact of intermittent generation on the operation and development of power systems, provided some insight into the Scottish TSOs' perspective on the issues (which were not always the same as National Grid's), and enabled me to have a hand and shaping the future development of Great Britain's transmission system.

Analysis

The final proposals of the working group are the subject of an ongoing review by the regulator, so I will not comment on them beyond what is already in the public domain. I can however discuss in general terms how the problem was approached and the issues which the working group encountered – both in the analysis of results and interaction with wider industry.

In my third quarterly report I discussed some research which found there to be insufficient wind diversity in the UK to be able to rely upon wind generation to secure much demand. On the basis of this finding, a decision was taken to split the criteria into two:

1. One criteria to determine the minimum transmission capacity required to maintain demand security with low levels of wind generation. This was achieved by applying the existing criteria to the system with a low contribution from intermittent generation.

2. Another criteria to determine any additional transmission capacity needed to cost-effectively integrate wind generation into the power system:

Identifying what amount of transmission is cost-effective becomes much more complex and subjective when a significant volume of intermittent generation is introduced:

- With a significant increase in the plant margin, far more generation patterns are possible and the network's capacity may be exceeded during a wide variety of peak and off-peak conditions. The justification for a transmission reinforcement therefore has to be made on the basis of an extensive range of conditions, where each individual condition has a very low probability of occurring. This means that the likelihood of each situation occurring and the operational costs that would be incurred should it happen need to be quantified for each possible state – so that the weighted average can be determined.
- The incentive schemes put in place to encourage the development of renewable generation significantly distort the normal operation of the market – especially when coupled with Great Britain's market structure that compensates generators affected by transmission constraints. Although modern wind turbines are technically some of the most flexible plant on the system, the very high value of the credits earned from producing green energy means that in practice they are extremely inflexible and will always run to their maximum extent when wind is available. When the penetration of wind generation is high this can lead to some 'abnormal' effects - such as very high constraint costs or displacing firmly baseload generation (which has its own operational costs and impacts). Even though a situation may only occur very infrequently, if the costs incurred during it are sufficiently high, it can just justify large scale transmission augmentations. However, a need case based on extreme operating conditions is invariably going to be highly sensitive to input assumptions which are very difficult or impossible to defend objectively. This inflexible operating behaviour would be a reasonable economic outcome if the value of the green credits earned by renewable generators was equivalent to the value of the carbon pollution that they are avoiding. If however, as is presently the case, the value of support they receive is greater than the value of carbon displaced, it would seem uneconomic to constrain off other generation and construct new transmission on the basis of their artificially elevated constraint costs.
- It is not just the volume of generation that is significant but also its location. Therefore, generator behaviours need to be set on an individual basis. Often the most difficult generator assumptions to make are which generators are most likely to come offline when wind is abundant – especially in the situation where wind generation can supply much of the off-peak demand and historically baseload generators must come offline to make room. In this case, whether more generators in one region come offline than in another region can greatly affect the interregional flow of power. Setting assumptions is both subjective and commercial sensitive. As generation firms may be exposed to commercial damage if it becomes known that the utility considers their generators more likely to be displaced by wind than a competitor's fleet, it is unlikely that the input assumptions could

be published, making the process non-transparent. A workaround would be to use the same profile for all generators of a particular type – but there would still ambiguity in setting the profile for each type of generator. Ultimately the validity of the answers produced by a study is based on the quality of the data input to the study - generic data inputs are likely to result is sub-optimal outcomes.

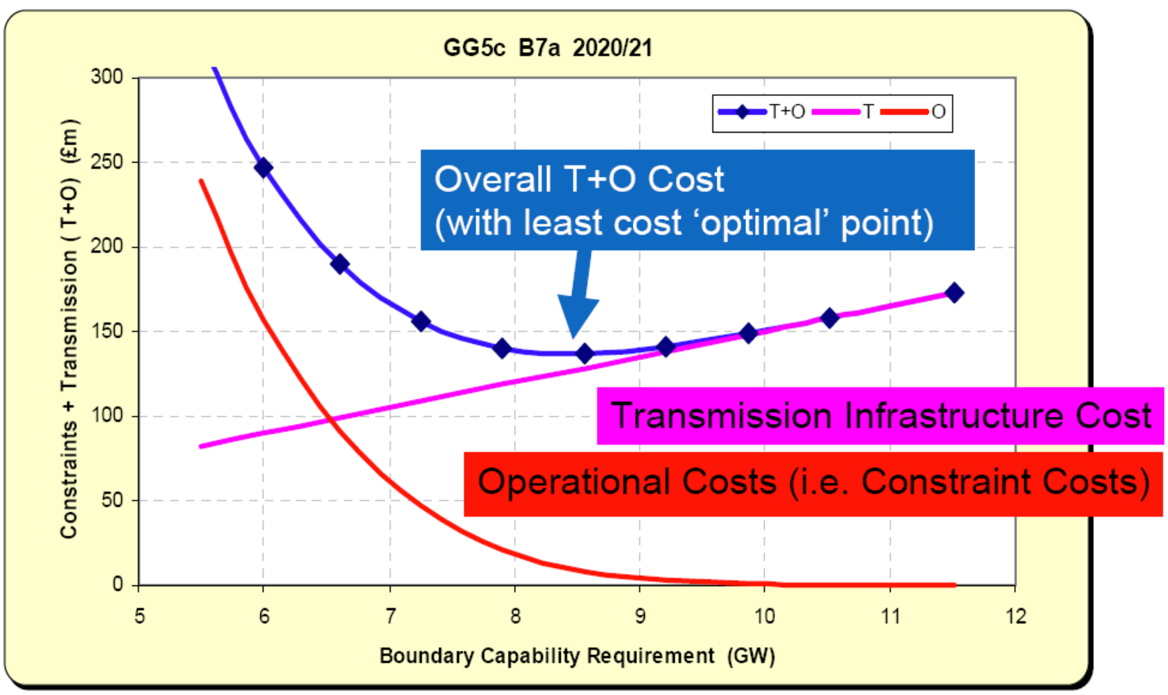
- Unlike conventional generators, the behaviour of wind, wave, solar and tidal generators is highly correlated due to the scale of the weather systems which affect their output. This very-real and very-influential effect needs to be taken into account, and for accuracy and defendability, ought to be based on historical measurements recorded over a long period of time.
- There are many uncertain external factors which could significantly impact the future operation and economics of the power system:
    - Demand changes over time
        - efficiency improvements vs. more loads being powered by electricity (e.g. electric space heating/cooling)
        - different consumption patterns (e.g. charging electric cars overnight)
    - Different power generation/storage technologies (CCS, solar thermal with storage)
    - Future commodity prices and availability
    - Political decisions about carbon reduction levels, acceptable fuel sources, inter-regional connectivity
    - Assumptions regarding how users will value electricity into the future
- Given all of the dimensions to the problem, simplifications and trade-offs need to be made in the assessment process to ensure that the problem is still solvable. Judgement is therefore needed to discern which factors are most influential. Unfortunately, even those 'less influential' factors can still significantly affect the answer. Within the working group we would typically speak in terms of whether a factor was likely to have a 1^{st}, 2^{nd} or 3^{rd} order effect on the overall result.
- Because of all of the un-clear decisions which need to be made, the procedure is likely to produce inconsistent results over time.
- The economic analysis of power systems with a large volume of intermittent generation is internationally an evolving area and as yet there are no well established norms or 'industry best practice' to point to in defence of a particular approach.
- The work requires significant amount of expertise in statistics and computer science. Accordingly, most of the people involved in the detailed economic analysis at National Grid have a mathematics background rather than an engineering background.

The specific approach that I observed to perform the cost benefit analysis:

- was zonal in nature
- studied a particular generation background (i.e. generator openings, closings and behaviours were pre-defined – with the model probabilistically modelling within year operating conditions only).

- required each generator to be classified as a particular 'type' (e.g. low-ranking coal, or mid-ranking coal), which associated it with pre-set probably-distribution reflecting its anticipated availability, merit, bidding and operating characteristics
- used wind-farm output correlation factors calculated by analysis of 8 years worth of wind records
- considered variations in network capability with seasons and outages, including outage likelihoods and durations
- incorporated a year-round demand profile

The model was used to determine how the system operating costs would vary as the capacity of a particular transmission boundary was varied. This curve was then added to another representing how the cost of transmission would vary as the boundary capacity was varied to produce a curve representing how the total cost varied with transmission capacity. The optimal transmission build could then be read by finding the boundary capability which minimised the overall cost. The figure below illustrates this process. Because the analysis was being used to develop new generic planning criteria rather than for a specific project, the transmission costs were represented as a linear cost per MW/km.



This analysis was repeated for a variety of different system boundaries and a number of years.

Given how complex, subjective and non-transperent the assessment process was, the working group concluded that there would be merit in investigating whether we could conceive a more straightforward deterministic process that would consistently produce similar results to the detailed process. If this were possible, the feeling of the working group was that the benefits of having a criteria which was clear for all industry participants could out-weigh the additional ‘accuracy’ of the full Cost Benefit Assessment (CBA) process. The straightforward criteria could be periodically re-tuned by a full assessment to ensure its ongoing accuracy. The working group identified a number of candidate ‘psuedo-CBA’ approaches and presented these in their final report alongside the results of the full CBA process, and sought the industry’s feedback.

Consultation with Industry

Essentially, the consultation with industry came down to finding the appropriate balance between a very complicated, time-consuming and non-transparent process that would arguably produce the most accurate answer (the full CBA every time proposal), and a simplistic approximation that would clearly deliver an answer that was likely to be somewhat sub-optimal (the psudo-CBA proposal).

The industry’s feedback was varied. Most participants were not overly concerned about the proposal per se, but were very concerned about the implications the proposals might have on Transmission Use of System Charges. Whilst many were sympathetic to the infeasibility of the full CBA for normal planning, there was also concern that the ‘pseudo-CBA’ approaches were not a solid basis to perform significant transmission investment. Some of the generators pointed out that they too needed to make large capital investment decisions with an equally uncertain future, and felt strongly that any proposals that would affect their charges should be supported by a comprehensive, robust and transparent analysis. Other participants expressed concern at the already-high constraint costs in Great Britian and indicated that they did not want network augmentations to be further delayed while the criteria was further tweaked/debated.

The debate is of course coloured by the biases of the different parties involved. The TSOs (all shareholder owned) would obviously benefit from an arrangement that gives them a clear mandate to build transmission infrastructure. Conversely, the British market structure compensates generators who are constrained offline and so they are not necessarily disadvantaged by transmission constraints (although the consumer certainly is) and want to minimise their transmission access changes.

At time of writing, the three TSOs have written to the regulator Ofgem, recommending one of the pseudo-CBA options. Ofgem is yet to make a decision regarding how to progress the issue.

Technical Visits

I am grateful to have been able to visit a wide range of companies during my final period of the scholarship. Because of the diverse topics discussed in each of my visits, I have highlighted some key learnings in point form below:

FinGrid

- A key distinctive of Fingrid is their emphasis on good knowledge management – particularly about the condition of their assets. There is nothing particularly special about their record keeping software. Rather, the key to their success has been having clear guidelines to ensure that data is recorded consistently. Having kept good records for 30 years now, the database is a powerful tool on which to base asset management decisions. All maintenance and asset replacement is condition based.
- Fingrid are responsible for owning and operating peak generation as well as transmission, but need to reserve the use of such generation to extreme events so that they do not normally interfere in the market.
- Fingrid is mostly owned by power-intensive Finnish industry participants, and these owners have clearly indicated that they are much more concerned about efficient system operation than profit. Therefore, Fingrid generally does <u>not</u> collect the full revenue that its regulator has allowed them. This behaviour has put them on very good terms with their regulator.
- Fingrid's maintenance activities are all outsourced. The success of this approach in Finland is due to the there being an abundant supply of well-trained formerly-utility-employed technicians working for private companies. Fingrid started its outsourcing strategy in the 1990s and now has a mature arrangement with their contractors based on clear expectations – Fingrid expects high-quality and reasonable-value services, and in return the contractors expect future work.
- Fingrid has a strong emphasis on stakeholder management. An example of this is their 'landscape' towers and substations program, where they invest additional money to develop and install bespoke architecturally designed towers in critical locations. In return, Fingrid benefit from better community relationships and an ongoing ability to install overhead lines and AIS substations in urban areas – saving the cost of undergrounding/GIS.
- Probabilistic planning methods are utilised in Fingrid. A key target the company has been given is to keep the spot prices in Finland the same as in Sweden for at least 97% of the time.

- There is very limited wind power in Finland to date. The government has recently approved the installation of additional nuclear generation to decarbonise power generation.
- Fingrid recently installed 10 phasor measurement units across their network. The engineers remarked that they have been learning new things about their network every day since – characteristics that presumably have always been present but were not observable before now.

Alstom Grid –Technology Development Centre

- Areva T&D has recently been sold back to Alstom
- Alstom's 1st generation of VSC HVDC has recently been released onto the market, and their 2nd generation is in the early stages of development. It was interesting to observe all of the steps in the technology development and manufacturing process
- With VSC HVDC, there is a continuing trend towards higher capacities, lower losses and more flexible converters using higher capacity IGBTs and more sophisticated scheme architectures. The trade off of this is more components in the scheme and/or greater space requirements
- Historically each HVDC installation has been a bespoke design which necessitates additional time and expense to design and type-test the design (some of which I was able to witness). The latest generation of VSC designs are far more modular with no need to type-test for every project.

ABB's IEC 61850 System Verification Centre

- The objective of the centre is to test the functionality of ABB's intelligent electronic devices (IEDs) when coupled together in a system together with various other IEDs from ABB and other vendors. The centre routinely finds errors of different severities (i.e. from product functionality through to documentation typos), and pass this information back to the design teams for rectification.
- The technicians in the lab expressed concern that IEC61850 is being widely mistaken as plug and play technology and emphsised the need for capable system integrators – especially when mixing equipment from different vendors.
- Configuration change management/verification/commissioning will become a much bigger issue with 61850 – since any changes to the secondary system affect the substation configuration file and should be propagated to all devices in the substation. When changes are made, great care will need to be taken to ensure/verify that existing functions (especially protective functions) have not been affected. Additionally, the IEC 61850

standard is continually being reviewed and new versions are periodically released – so version control of the standard may also become an issue.

- IEC 61850 will require a different skill set for both designers and field technicians, with greater expertise in networking issues and understanding the behaviour of each IED.

Psymetrix

- The use of wide area phasor measurement analysis is becoming more common and has the potential to offer significant additional insight into the operation of the power system. E.g. phasor measurements may be able to be used to refine/certify the accuracy of network models.
- It may be possible to use wide area phasor measurements to coordinate the response of SVCs and/or AVRs to improve power system damping of oscillations, although unpredictable communications latency is a significant complication that is yet to be resolved.

Axpo

- The Swiss power sector has recently been reconfigured to better integrate it with the rest of Europe. A new national TSO has been established (SwissGrid) and transmission assets of European significance belonging to the existing utilities (including Axpo) will soon be transferred into the new company. However, there is still some ambiguity and ongoing debate as to what assets fall into that category.
- Generation is Switzerland is almost exclusively hydro and nuclear. Axpo are not expecting much renewable generation to be built in Switzerland, but are expecting an impact on how their generation will need to operate as Europe's proportion of wind generation increases. Switzerland is in the process of developing more pumped hydro.
- Presently Switzerland is 'shielded' from the effect of large volumes of intermittent generation in Northern Germany and Spain due to transmission bottlenecks in Southern Germany and France
- The Swiss power system is designed to an N-1 level of reliability. As different situations can stress the network differently, both day and night for both summer and winter cases are routinely studied. For the past five years this has been complimented by a probabilistic reliability study. The new national TSO Swissgrid moderates a consultation regarding the input assumptions for each project.
- Axpo has a pilot installation of IEC61850, which has gone smoothly
- It is commonplace in Switzerland for the ownership of infrastructure to be shared between multiple parties, with agreements put in place regarding about how the operating costs

associated with the infrastructure will be allocated. The utility's role is primarily to manage the assets and operate and plan the system.

HydroOne

- Following the announcement of government incentives for renewable power generation HydroOne was inundated with connection applications, many of which were speculative. Managing the resulting connection queue and very large spike in workload has been a significant challenge
- Presently most of the technical challenges presented by renewable generation have been on HydroOne's distribution network – particularly managing the voltage in rural areas with long distribution circuits
- Although Ontario is well interconnected with neighbouring regions, the generation is planned to ensure that Ontario is capable of being self-sufficient
- Smart meters have been widely deployed throughout Ontario. A time of use pricing structure has been introduced, which initially led to some demand reduction at peak times. However, it is difficult to discern how long-lasting this benefit has been, and how much of the present reduction in demands is due to the economic slowdown.

Acknowledgements

I would like to gratefully acknowledge the assistance and patience of those NGET colleagues with whom I worked during the quarter: Jo Zhou, Richard Proctor, Beehun Tan, Hardeep Garcha, Mark Perry, Duncan Hughes, Paul Plumptre, Christian Martins, and Chris Humphries.

I would also like to thank all of the representatives of the companies I visited for the time they gave me and their willingness to share their expertise and impressions with me. I would also like to thank the scholarship chairman, Simon Bartlett for his assistance in organising a number of the visits.

Soli Deo Gloria – to God alone be the glory.