Frequency Control Ancillary Service Requirements with Wind Generation - Australian Projections

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***Abstract*--This paper reports on detailed modelling to project the size and cost of Frequency Control Ancillary Service (FCAS) requirements in two Australian markets in 2019-20 upon implementation of the 20% Renewable Energy Target. One minute resolution wind and demand data was used in conjunction with a system frequency model and a market dispatch model. In the National Electricity Market (NEM) the Regulation requirement was found to increase by around 10% of the added wind capacity. However, in the much smaller South-West Interconnected System (SWIS), the Load Following requirement was found to increase by around 30-40% of the added wind capacity. FCAS (Regulation + Slow Contingency) costs are projected to increase substantially in response, increasing by a factor of 20 in the NEM, and a factor of 11 in the SWIS. While these settlements remain small by comparison with energy settlements, if these cost increases are allocated to wind generators they could be prohibitively large, being $6-8 /MWh in the NEM, and $30-60 /MWh in the SWIS.**

***Index Terms*-- Australia, Frequency Control Ancillary Service, Load Following, National Electricity Market, NEM, Regulation, South-West Interconnected System, SWIS, Wind Generation.**

I. Introduction

Australia has two significant electricity markets; the National Electricity Market (NEM), and the South-West Interconnected System (SWIS). The NEM incorporates all the eastern states and serves the majority of electrical load in Australia, with a 2009-10 peak demand of 33.8 GW. The SWIS is a much smaller system, located in Western Australia, with a 2009-10 peak demand of 3.8 GW.

1781 MW of wind is installed in the NEM at present, with the majority located in South Australia (attracted by the strong wind resources in this region). These wind farms provide around 3% of the energy in the NEM.

Three wind farms are installed in the SWIS at present, totalling 202 MW, and providing around 4% of the energy in the SWIS. Collgar wind farm (206 MW) is currently being commissioned, and when completed will more than double the capacity of installed wind in the SWIS.

There is significant interest in continued wind development around Australia, driven by the 20% by 2020 Large-scale Renewable Energy Target (LRET). This scheme creates a market for Renewable Energy Certificates, each representing 1 MWh of renewable generation. The price of certificates is capped by a "shortfall charge" of AUD$65 (defined in nominal terms).

A. FCAS in Australia

Frequency Control Ancillary Services (FCAS) involve adjusting supply and demand to ensure that they match at all times, and the system frequency remains stable. Two broad categories are identifiable:

1. Regulation (Load Following); and
2. Contingency (Spinning Reserve / Load Rejection).

Regulation (Load Following) is the service of constantly adjusting supply minute to minute to match the variations in the load (or intermittent generation). In the NEM this service is termed "Regulation", and is split into raise and lower components, supplied individually via the ancillary services market. In the SWIS this service is termed "Load Following", with both raise and lower components supplied by the government owned corporation Verve Energy.

Contingency services (Spinning Reserve / Load Rejection) are those related to adjusting supply in the event of the sudden and unexpected trip of a large generator or load, such that a large quantity of generation must be rapidly replaced (or removed) from the system to compensate. In the NEM this is split into six services: 6 second raise, 60 second raise, 5 minute raise, and the equivalent lower services. The timeframes refer to how quickly the response must be implemented in the event of a contingency. In the SWIS two services are defined: Spinning Reserve relates to the sudden loss of a generating unit (and hence is a raise service), while Load Rejection relates to the sudden loss of a large load (a lower service). Both are provided by Verve Energy plant, or in some cases by other plant via contractual arrangements.

An increase in installed wind capacity to around 20% by 2020 is expected to affect the capacity of Regulation service required, since an increase in intermittent generation is likely to increase the magnitude of minute to minute generation deviations. The LRET is not expected to substantially affect the capacity of Contingency services required. In this study, sudden large events such as high wind speed cut-outs have been taken into account in the calculation of Regulation services, and have therefore not been 'double-counted' with the Contingency services. However, a different framework may be possible, allowing some rapid wind change events to be treated as Contingency events rather than included under the Regulation service.

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In both the NEM and the SWIS, Regulation services are considered to simultaneously contribute Slow (5 minute) Contingency services. As the capacity of Regulation required increases (with increased wind penetration) this therefore decreases the capacity of additional Slow Contingency services required. Eventually, the Regulation requirement exceeds the Slow Contingency requirement and no further Slow Contingency service is required. In this situation it is therefore sensible for participants liable for the costs of Contingency services to be partially liable for the costs of Regulation services, and both the NEM and the SWIS have complex settlement equations to this effect. In this study the costs of these two services are considered in a combined fashion to allow appropriate comparison from year to year.

Neither the NEM or the SWIS features day-ahead scheduling. In the NEM dispatch is calculated each five minutes, and generators are responsible for managing unit commitment via appropriate bids in each period. A pre-dispatch forecast is published each half hour for the upcoming trading day, but generators bear any costs of deviations from pre-dispatch.

In the SWIS, Independent Power Producers are dispatched to their submitted operating plans (based around bilateral contract positions), and the Government owned Verve plant must be dispatched around this. System Management communicates with Verve about unit commitment, but Verve bears any costs associated with deviations from expected unit commitment.

Therefore, although there are economic costs associated with deviations from expected unit commitment, these are not included in ancillary service settlements in either the NEM or the SWIS. For this reason, in this study only the balancing costs associated with increased minute to minute variability (as required to maintain the defined frequency standards of each system) has been estimated.

II. Methodology

The FCAS requirements and costs in 2019-20 were determined using the following methodology.

The generation of individual wind farms in each minute in 2019-20 were projected from a reference year of historical wind data (2009-10) from Bureau of Meteorology weather stations, adjusted to produce realistic wind generation profiles at hub height using average annual wind resource values from the Australian Renewable Energy Atlas. These wind traces were summed to produce one minute resolution aggregate wind traces for each of the NEM and the SWIS.

One minute resolution demand traces for each of the NEM and SWIS were determined based on an historical reference year (2009-10, the same year as the wind data was used to ensure accurate correlation between wind and demand). ROAM Consulting's Load Trace Synthesizer tool was used to grow this reference trace according to the peak demand and energy targets forecast in 2019-20.

For each of the NEM and SWIS the wind trace was subtracted from the demand trace to produce the total 'disturbance' in each minute to be met by the Regulation raise and lower services.

A system frequency model was constructed and calibrated individually to each of the NEM and SWIS to calculate the frequency response to each one minute disturbance, taking into account system inertia and frequency response of each dispatched generator at the time. For the NEM, the frequency responses were modelled on a minute-to-minute basis for the entire year to ensure that the frequency was maintained within the required ±0.25Hz at all times [1]. For the SWIS, the Rules require the frequency to be within ±0.2Hz for 99.5% of the time [2]. Therefore the distribution of the minute-to-minute changes of demand and wind was examined, and periods representing the bottom (for raise requirement) and top (for lower requirement) 0.25 percentiles were selected for analysis in the System Frequency model.

The amount of Regulation raise and lower services applied in each system was increased until the frequency was maintained within the required limits defined by the relevant Rules.

A half hourly dispatch model that co-optimises the energy market with the eight ancillary service markets (ROAM Consulting's *2-4-C*) was used to calculate FCAS costs. The increased Regulation raise and lower requirements were used as an input with historical FCAS and energy market bids. For comparison, the model was run with the Regulation raise and lower requirement that would be required in the absence of the LRET in 2019-20.

The SWIS does not presently have an FCAS market, but is in the process of implementing one. Therefore, FCAS services were modelled in two ways: 1) All FCAS was provided by government owned Verve energy plant (existing Rules), and 2) All FCAS was provided by the most efficient plant (FCAS Market). Total system costs were calculated based upon individual generator fuel and fixed and variable operations and maintenance costs, and compared in each case.

III. Scenarios

FCAS requirements and costs were considered under the scenarios listed in Table 1. It was assumed that the 20% by 2020 renewable energy target was met in the scenarios where it applied.

In the SWIS, the entry of the committed Collgar wind farm (206 MW) is sufficient to satisfy the local proportion of the LRET, so no further wind is installed in the absence of the carbon price. This leads to the same capacity of installed wind in the SWIS in the Reference and Counterfactual scenarios.

TABLE I
SCENARIOS MODELLED FOR THIS STUDY

Scenario Name	Renewable Energy Target	Carbon Price (Real 2011 $AUD)	Installed wind capacity in 2019-20 (MW)	
			NEM	SWIS
Reference	20% by 2020	None	8231	408
Counterfactual	None	None	2627	408
Carbon Price	20% by 2020	$34/tCO2 in 2019-20	8196	679

IV. Results

A. Regulation Requirements

As illustrated in Table II, the Regulation requirement in the NEM was found to increase from ±120 MW at present to

+840, -700 MW in 2019-20 with the addition of 6450 MW of wind generation to meet the 20% by 2020 Large-scale Renewable Energy Target (LRET). In the absence of the LRET a smaller quantity of new wind is installed (846 MW), and the Regulation requirement increases only moderately to ±200 MW. These scenarios indicate that for the NEM, Regulation requirements are likely to increase by around 10% of the added wind capacity.

Since a similar capacity of wind is installed in the Reference and Carbon Price scenarios, a similar outcome is determined for the Regulation requirement (to within the granularity of the modelling).

TABLE II
FORECAST REGULATION REQUIREMENTS IN THE NATIONAL ELECTRICITY MARKET (NEM)

Scenario		Installed Wind Capacity (MW)	Regulation Requirement (MW)
Existing (2009-10)		1781	±120
2019-20	Reference	8231	+840, -700
	Counterfactual	2627	±200
	Carbon Price	8196	+800, -700

As listed in Table III, in the SWIS the Load Following requirement is found to increase from ±60 MW at present to around ±120 MW with the addition of Collgar wind farm (in the Reference and Counterfactual scenarios), or to ±260 MW with the addition of 480 MW of wind generation by 2019-20 (in the Carbon Price scenario). These scenarios indicate that in the smaller SWIS system, Load Following requirements are likely to increase by 30-40% of the added wind capacity. This is larger than in the NEM, likely related to the fact that the economically viable size of a new wind farm (100-300 MW) is relatively large compared with the size of the SWIS. This means that to achieve wind penetration up to 20%, a relatively smaller number of individual wind farms have been installed in the SWIS than in the NEM. The output of each wind farm is internally highly correlated, leading to larger minute to minute 'disturbances' relative to the size of the system. This suggests that FCAS is likely to be a much more challenging issue for small power systems.

TABLE III
FORECAST LOAD FOLLOWING REQUIREMENTS IN THE SOUTH-WEST INTERCONNECTED SYSTEM (SWIS)

Scenario		Installed Wind Capacity (MW)	Regulation Requirement (MW)
Existing (2009-10)		202	±60
2019-20	Reference	408	±120
	Counterfactual	408	±120
	Carbon Price	679	±265

B. Regulation Settlements in the NEM

FCAS and energy settlements calculated for the NEM in 2019-20 using the co-optimised *2-4-C* half-hourly dispatch model are listed in Table IV. Energy settlements increase from present levels in all scenarios due to significant load growth projected over the next decade. The increase is largest in the Carbon Price scenario, due to pass-through of the carbon price (AUD $33.80 /$tCO_2e$) to the energy market. The increase is reduced in the scenarios with the LRET, since wind generators (with very low short run marginal costs) are expected to bid low values into the market, depressing the average pool price.

FCAS settlements are reduced from present levels in the Counterfactual scenario for two reasons. Firstly, load relief increases substantially (due to the increase in the load), so the slow contingency requirement is reduced. Secondly, this modelling does not include some types of possible contingency events (such as transmission contingencies), so some exceptionally high priced periods are not included. This means that these forecasts are likely to be at the lower bound of expectations.

TABLE IV
FORECAST FCAS SETTLEMENTS IN THE NEM

Scenario		Real 2011 AUD$ millions pa	
		Regulation + Slow Contingency Settlements	Energy Settlements
Existing (2009-10)		$10	$6,900
2019-20	Reference	$204	$12,418
	Counterfactual	$5	$17,853
	Carbon Price	$177	$20,347

FCAS settlements are substantially increased in the scenarios featuring the LRET, driven by the much higher Regulation requirement. However, FCAS settlements remain small compared with energy settlements.

It should be noted that these settlement outcomes for the NEM are based upon the projection of historical FCAS market bids for each generator. However, with such a large increase in the Regulation requirement this market will undergo a dramatic change, meaning that generator bidding strategies relating to FCAS are likely to change. With the growth in the market size more generators may participate more actively, seeking ways to provide these services more efficiently. Alternatively, the growth in the market may allow generators more market power, giving them the ability to bid higher prices in many periods and increase FCAS costs.

C. Load Following Costs in the SWIS

FCAS and energy costs calculated for the SWIS in 2019-20 using the *2-4-C* half-hourly dispatch model are listed in Table V.

The SWIS features a Wholesale Electricity Market (WEM), into which generators are required to bid their short run marginal costs. Functioning as a net pool, the majority of settlements are made outside of the market via contractual arrangements. Given the limited transparency of this process, energy settlements provided in Table V for the SWIS are indicative only, calculated assuming gross pool trading by proxy.

The Reserve Capacity Mechanism (RCM) provides further generator revenue through a two year ahead auction process. These settlements have not been included in the energy settlement values listed in Table V.

Given the two independent markets in the SWIS (the

WEM and the RCM) Load Following settlements are recovered through a combination of "Availability Costs" (associated with the changed dispatch of plant in the WEM due to Load Following service) and "Capacity Costs" (associated with the allocation of generation capacity under the RCM to Load Following service). To forecast Availability Costs, total system costs were calculated via dispatch simulation and compared with simulation results from identical scenarios with no FCAS implemented to determine the additional cost associated with FCAS. Load Following "Capacity Costs" were calculated assuming the Reserve Capacity Price remains at the average of 2010-11 to 2012-13 prices.

TABLE V
FORECAST FCAS COSTS IN THE SWIS

Scenario		Real 2011 AUD$ millions pa	
		Load Following + Spinning Reserve Costs	Energy Costs
Existing (2009-10)		$18	-
2019-20	Reference	$58	$1,964
	Counterfactual	$58	$1,964
	Carbon Price	$203	$1,923
	Carbon Price with FCAS Market	$160	$2,097

As for the NEM, FCAS costs are found to increase substantially in response to the larger requirement, but remain small compared with energy costs. The large increase in FCAS costs for the SWIS is due to several factors. Firstly, the increased Load Following requirement means that a larger capacity of gas-fired plant must be operated at a midpoint to provide sufficient raise and lower capacity. Secondly, the gas price assumed for Verve in the existing settlement calculations is around $4 /GJ [3]. However, it is likely that Verve will need to negotiate new gas contracts prior to 2019-20, and will face significantly higher gas prices ($7.60 /GJ was assumed). This significantly increases the cost to Verve of operating the gas-fired plant required to provide fast-acting Load Following services. Finally, in the scenario featuring a carbon price, this increases the cost of Verve's gas-fired generation that is operating to provide Load Following.

D. Allocation of Regulation Costs in the NEM

In the NEM the recovery of payments for Regulation Services is based on the 'causer pays' methodology. Under this methodology, the response of measured generation and loads to frequency deviations is monitored and used to determine a series of causer pays factors. These factors are calculated each four seconds, averaged to 5 minute intervals.

For this analysis, it was assumed that since the entry of new wind generation is the driver of increases in the Regulation requirement, wind generators are likely to bear the majority of the increase in Regulation costs. It was assumed that half of the existing Regulation costs are borne by wind generators, with the other half being borne by loads and other generators. The proportion borne by other Market Participants (non-wind farms) was projected to continue at a constant level, while the entire increase in Regulation costs was assumed to be borne by the installed capacity of wind farms. These assumptions allow an upper estimate of the Regulation costs for which wind generators could be liable. The resulting cost estimates are listed in Table VI.

TABLE VI
ALLOCATION OF REGULATION COSTS TO WIND GENERATORS IN THE NEM

Scenario		Regulation cost liability for wind generators ($/MWh, Real 2011 AUD)
Existing (2009-10)		$0.40
2019-20	Reference	$8.30
	Counterfactual	$0.17
	Carbon Price	$6.18

The addition of these costs to the long run marginal costs of wind generators could have significant implications for whether sufficient wind generation is installed for the LRET to be met (especially in scenarios that do not feature a carbon price, and where the LRET shortfall charge is not increased).

E. Allocation of Load Following Costs in the SWIS

In the SWIS the recovery of payments for Load Following Services is divided equally according to the metered schedules (MWh) consumed and generated by loads and intermittent generators. On this basis, wind generators (and loads) could expect Load Following costs similar to those listed in Table VII in the first column ("Existing Rules"). Costs would likely be reduced below this, since some of the liability would be paid for under Spinning Reserve services.

However, a Rule Change has been proposed that will change the settlement equations for Load Following [4]. The proposed methodology estimates the capacity of Load Following that would be required to meet the variability of loads (in the absence of intermittent generation) as a proportion of the total Load Following requirement, and attributes that proportion of the Load Following cost to loads. Intermittent generators are then liable for the remaining cost. Since the majority of the increase in Load Following requirement is due to the entry of new wind generation, this means that wind generators will bear the majority of the increase in Load Following costs.

In 2009-10 the fluctuations caused by loads alone lead to a Load Following requirement of -32/+26 MW [5]. This is anticipated to increase gradually over time in response to load growth. A value of ±40 MW was assumed for 2019-20. Allocating the remaining proportion of Load Following costs to wind generators leads to the costs listed in the right column in Table VII.

TABLE VII
ALLOCATION OF LOAD FOLLOWING COSTS TO WIND GENERATORS IN THE SWIS

Scenario		Load Following cost liability for wind generators ($/MWh, Real 2011 AUD)	
		Existing Rules	Possible Rule Change
Existing (2009-10)		$0.42	$5.75
2019-20	Reference	$2.24	$29.17
	Counterfactual	$2.24	$29.17
	Carbon Price	$7.51	$72.86
	Carbon Price with FCAS Market	$5.92	$57.47

These costs constitute a very significant increase in Load Following costs for wind generators. The addition of these costs to the long run marginal costs of wind generators is likely to be prohibitive for any further wind generation installation in the SWIS in the absence of substantial additional subsidies.

F. Comparison to previous studies

In systems such as Finland, Sweden, Ireland, UK, Germany and Minnesota, the increase in reserve requirement for balancing has been previously predicted to be in the range 1-10% of the installed wind capacity, and increases in balancing costs are typically predicted in the range 0 - 4.5 Euros/MWh of wind [6]. The results derived in this study for the NEM are of a similar order.

The results derived in this study for the SWIS are much larger than those predicted for other systems (with respect to increase in reserve requirement and balancing costs). This is likely due to a combination of reasons:

- The relatively small size of the SWIS system (17,300 GWh pa, 3.8 GW peak demand) compared with the size of typical installed wind farms (80-200 MW) means that 20% wind penetration is met with a relatively small number of individual wind farms (4, or 7 in the Carbon Price scenario). This leads to a high degree of wind correlation, and a higher incidence of large rapid wind generation changes. Other systems with a more distributed wind arrangement are likely to demonstrate more geographical smoothing.
- There is a lack of available one minute resolution wind data; only four weather stations in the SWIS are located in the vicinity of the modelled wind farms and have recorded sufficient historical data of the required time resolution. This necessitates aggregation of wind farms in the model and leads to reduction in the degree of geographical diversity that may exist. In order to provide an upper bound on the load following requirement no artificial geographical diversity smoothing was applied to the data. This issue will be improved over time as more data becomes available.
- Neither the SWIS or the NEM has any transmission interconnection to any other grid. This limits the system size from which balancing services can be provided.
- With imminent rapid expansion of Australia's Liquid Natural Gas (LNG) export industry, gas prices in the SWIS are projected to double, and act as a multiplier on load following costs.
- In this study the full cost of the load following service was allocated to wind farms; in reality a proportion of this cost will be allocated to plant liable for contingency (spinning reserve) services, since the load following plant simultaneously provides this service.
- No improvements in wind forecasting were assumed.
- No improvements in the technologies available for load following were assumed. For example, if high efficiency gas turbines designed for load following service were installed, this could reduce load following costs. Alternatively, new operational modes may reduce the load following requirement (for example, with appropriate control systems aggregated wind farms may be able to reduce the incidence of large rapid wind generation increases, minimising the load following lower requirement with minimal associated wind curtailment).

G. Conclusions

The increased penetration of wind generation in electricity systems is likely to increase the Regulation requirement, especially in smaller systems. This is likely to substantially increase the cost of this ancillary service. If this cost is solely attributed to wind generators it could be prohibitive to the installation of further wind generation. This highlights the necessity of reviewing the procurement of Regulation ancillary services and ensuring that they are sourced at the lowest possible cost. Research into the self-provision of Regulation services by wind farms should also be continued with a high priority.

As mentioned in the introduction, a different framework may be possible, allowing some rapid wind change events to be treated as Contingency events rather than included under the Regulation service. Investigation of alternative frameworks of this nature should be considered a priority.

V. References

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VI. Biographies

Jennifer Riesz is the Principal of Renewable Energy and Climate Change at ROAM Consulting. She joined ROAM Consulting in October 2007, and models and advises on topics related to climate change, such as carbon pricing, the Renewable Energy Target, and the anticipated impacts of these on electricity systems (including pool prices, transmission congestion, and changes in dispatch). In addition, Jenny is constantly developing ROAM's expertise in detailed modelling of renewable technologies including wind, solar, biomass and geothermal energy. Prior to joining ROAM Jenny completed a PhD in the field of biophysics at the University of Queensland, employing techniques such as theoretical quantum mechanical modelling, advanced spectroscopy and nuclear science. In 2007 Jenny was selected as the Queensland Young Achiever of the Year in recognition of her scientific contributions. Jenny spent the latter half of 2009 working with the government of the Solomon Islands on international climate policy, culminating in joining their delegation for the critical climate negotiations at the United Nations meeting in Copenhagen.

Fu-Sheng Shiao specialises in the modelling and analysis of electrical systems. With a strong engineering background coupled with experience in complex systems modelling, Fu-Sheng has been the lead engineer on a number of projects targeted at finding solutions to complex problems related to network power flows, transmission congestion, connection point loss factor estimation and system frequency transient response. Furthermore, Fu-Sheng is also actively involved in the development of innovative models to forecast short and long term electrical demand patterns as a key input to ROAM Consulting's flagship modelling software 2-4-C. Fu-Sheng joined ROAM Consulting in March 2007 after completing his university studies in Electrical and Electronics Engineering at the University of Canterbury in New Zealand. Fluent in English and Mandarin, Fu-Sheng has had work experience in both New Zealand and Taiwan. In 2005, he was awarded the Golden Key International Engineering/Technology achievement award for his outstanding achievement in the field of Engineering.

Joel Gilmore is a member of ROAM's team of energy market modellers, specialising in renewable energy technologies and applications, and greenhouse gas emissions forecasting. Since joining ROAM in November 2008, he has conducted a number of major modelling exercises in the NEM related to renewables, including work on the proposed 1GW of solar power for the Commonwealth Government, and work for AEMC on the changes resulting from the introduction of the CPRS and RET. He has also conducted a major study on the effect of variability in wind generation on the WEM to 2020. Joel received a PhD in physics from the University of Queensland in 2007, where he developed models to describe complex biological processes such as vision and photosynthesis. He then worked for two years as a science communicator with the University of Queensland, heading a team promoting public understanding and appreciation of science across the country to diverse audiences.

David Yeowart is intensively involved in developing advanced algorithms for ROAM's electricity market models including energy and ancillary service markets and hydro thermal optimisation. David holds a Bachelor degree in IT from the Queensland University of Technology. He has worked with ROAM Consulting since 2003.

Andrew Turley is ROAM's principal market forecasting analyst. He has conducted many of ROAM's probabilistic generation scenario modelling studies and was responsible for the revisions of the methodology in the last five years. He has been responsible for key forecasting studies throughout Australia. Andrew joined ROAM Consulting in March 2005, prior to which he was employed as an IT consultant at a software development house in Brisbane and in the United Kingdom. He has significant experience in user interfaces and web based products, as well as product design and development from conception to delivery. Andrew also has over two years experience as an academic staff member in the University of Queensland's Business and Economics Departments.

Ian Rose co-founded ROAM Consulting in 2000, and is principal power systems consultant. He has more than 35 years of electricity network modelling software development and application experience in Australia, New Zealand, Canada, the USA and China, and has been involved in generation and transmission operations and planning throughout that period. Throughout the 1980's, Ian was responsible for development of all power system software and then for daily dispatch of all Queensland power generation for four years from the state control centre, now AEMO's northern control centre. This included commissioning the Tarong and Wivenhoe power stations and associated changes to spinning reserve policy for the state. For the following six years he was requested to plan Queensland's fuel requirements for all thermal power stations, in conjunction with hydro stations, including Wivenhoe, Barron Gorge and Kareeya. This included commissioning of the Callide B and Stanwell power stations which commenced in 1988 and 1993 respectively. For several years he was also the key technical adviser for the sale of Gladstone power station and associated contractual arrangements. He was Queensland's technical representative on the three state (NSW, Vic, SA) Interconnection Operating Committee investigating interconnection between Queensland and the southern states for several years during this period, leading to setting the major parameters for the future QNI interconnector. When the Queensland Electricity Industry was disaggregated in the mid-1990's he was appointed Manager Planning and then General Manager Technology for the Queensland Generation Corporation, responsible for all GOC generation, until founding ROAM. He was responsible for planning several stations now in operation, including Kogan Creek, Swanbank E and Callide C, and for establishing the market trading activities of QGC. Ian also held operational positions in generation and transmission in North Queensland during the 1970's, covering Collinsville, Kareeya and Barron Gorge power stations and the associated transmission systems, followed by several years of high voltage measurement and testing including commissioning the 300km Bouldercombe to Nebo lines, which joined North Queensland to the rest of Queensland for the first time. He has published papers on a variety of power system issues including reliability of multi-area systems, dispatch of generation and spinning reserve. His special interests include: Demand Forecasting, Integrated Resource Planning, Linear Programming for Dispatch of generation in electricity markets, composite generation and transmission reliability assessment, power flow modelling, marginal loss factor modelling and congestion analysis.