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Hydro-Wind Synergies: promoting sustainable development through system co-ordination

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Abstract

Renewable energy is widely recognised as an important contributor to global efforts to develop sustainable energy solutions. The cross-sectoral benefits of renewable energy have significant potential to increase quality of life and prosperity, particularly in developing countries. Hydropower has long been a source of clean and reliable electricity. More recently, wind turbines have emerged as a leading renewable energy technology. Substantial increases in the uptake of wind power will be restricted by the intermittent nature of the wind resource and other factors. This paper explores the synergies between hydro and wind power that enable high levels of wind penetration. Responsive hydro power plant has the ability to work in synergy with wind developments which are intermittent in production to provide the required ancillary services to maintain grid stability and energy storage.

1 Introduction

Nearly one third of the world's population has no access to electricity and by 2025 close to 50% of people will be facing water scarcity[1]. Without access to modern energy supplies substantial time and physical energy are spent on subsistence activities such as collecting fuel wood and carrying water. Energy poverty is closely linked with poor education, poor health, and poor living standards. Provision of energy services is essential for sustainable development and is also fundamental to achieving global objectives such as the United Nations Millennium Development Goals[2] which include halving the number of people living in poverty by 2015. To meet this need the International Energy Agency has estimated that energy demand will grow by an average of 1.7% annually until 2030. Meeting energy demand from oil, gas and coal will only increase the problem of global warming – the world's most pressing environmental problem.

According to the Intergovernmental Panel on Climate Change (IPCC) concentrations of carbon dioxide in the atmosphere have been steadily increasing since the Industrial Revolution in Europe. This has been confirmed from ice core samples that show that CO_2 has increased by 31% since 1750.

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[1] World Summit on Sustainable Development, 2002; *A Framework for Action on Water and Sanitation,* WEHAB Working Group.

[2] UN Millennium Development Goals (MDG); http://www.un.org/millenniumgoals/index.shtml

In the past 20 years, three-quarters of this increase has been the result of burning fossil fuels. Indeed in the last 12 months concentrations have increased from 376 parts per million (ppm) to 379 ppm - a rate which is very much faster than the average increase over the past decade. This acceleration is of concern to climate scientists and puts pressure on us all to look for alternatives.

Against this background the World Summit on Sustainable Development (WSSD) in Johannesburg in 2002, and Renewables 2004 in Bonn this year, have called for an increase in the amount of energy supplied from renewable resources[3/4]. This presents an opportunity for developing countries to consider taking a different route to the provision of water and energy services. They do not have to make the mistakes of the past with over reliance on fossil fuels for the provision of energy. Rather, they can take advantage of rapidly developing renewable energy technologies.

In this context there are two major renewable energy resources that are commercial today - hydro and wind. Hydropower already supplies 19% of the world's electricity, and wind power is the fastest growing renewable energy resource, with the market doubling every two years. Whilst renewable energy will rarely be able to meet all the local energy needs of the world's expanding population (currently 6 billion but forecast to reach 8 billion by 2050), the use of renewable energy can significantly improve local outcomes by reducing air pollution associated with the burning of coal and fuelwood, creating local employment, reducing dependence on imports such as oil with its associated price risk, and increasing domestic energy security.

In addition to local benefits from the use of renewables, the global benefit of reducing greenhouse gas emissions will increasingly result in an income stream from emissions trading based on Certified Emission Reduction (CER) opportunities under Kyoto's Clean Development Mechanisms (CDM). Emissions trading has the potential to benefit both business and the environment, as well as providing profits for developing country participants. An example of this developing opportunity is the first trade in CER's between three sugar cane refineries in Brazil and a European company that took place on 11th October 2004.

Development of renewable forms of energy also provides further benefits in the form of increasing energy security. Unlike fossil fuels, the distribution of renewable sources of energy are wide-spread. This paper will focus on the opportunities associated with hydropower and wind power rather than other forms of renewable energy such as biomass and solar. The concentration is on the use of hydro and wind in combination to maximise wind energy penetration. The Tasmanian Case Study is used to explore the synergies between these two technologies in order to provide tangible evidence of the

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[3] World Summit on Sustainable Development, 2002; *A Framework for Action on Energy,* WEHAB Working Group.

[4] See Renewables 2004 , and the Political Declaration which calls for renewable technologies to be to be increased with a sense of urgency <http://www.renewables2004.de/en/2004/outcome_declaration.asp>

opportunities available to other regions of the world that have wind and hydro potential.

2 Technical Challenges with Large Scale Wind Development

A number of technical challenges are faced by those integrating a large percentage of wind into electricity grids. The key issues include:

- Compliance with electricity code requirements to continue to operate during transmission faults i.e. "Fault Ride Through";
- Management of the variability of wind production power system frequency; and
- Management of power system voltage.

In Tasmania recent work has demonstrated that there are significant synergies in combination of wind and hydro-electric development to provide solutions to technical constrains on wind development.

Hydro generators are very robust power generation equipment and do not face technical constraints on levels of development.

3 The Tasmanian Example

Tasmania is located in the "Roaring Forties" where winds move unabated across the Atlantic and Indian Oceans to the State's west coast. Tasmania, Australia's island state, built its economy on the basis of a period of hydro-industrialisation in the 20th century. Hydro Tasmania has supplied power for Tasmania for over 80 years, with over 95% of the Island's electricity supplied from hydro-electric power. Hydro Tasmania represents 60% of Australia's renewable energy production.

Hydro Tasmania is a government owned generation business that has designed, constructed and now operates 2262 MW of generation equipment including 27 hydro power stations and a 64.75 MW wind farm and a 240 MW thermal power station (recently been converted from oil to gas). A map of the Tasmanian power system including the transmission system, power stations and catchments is provided as Attachment 1 along with an Australian map.

The Gordon Power Development shown in the illustration below is an example of the hydro-electric facilities owned and operated by Hydro Tasmania. The storage provided by this scheme represents 35% of total Tasmanian hydro storage and the power station has 430MW capacity. Lake Gordon was created by the building of a 140 metre high concrete arch dam across the Gordon River.

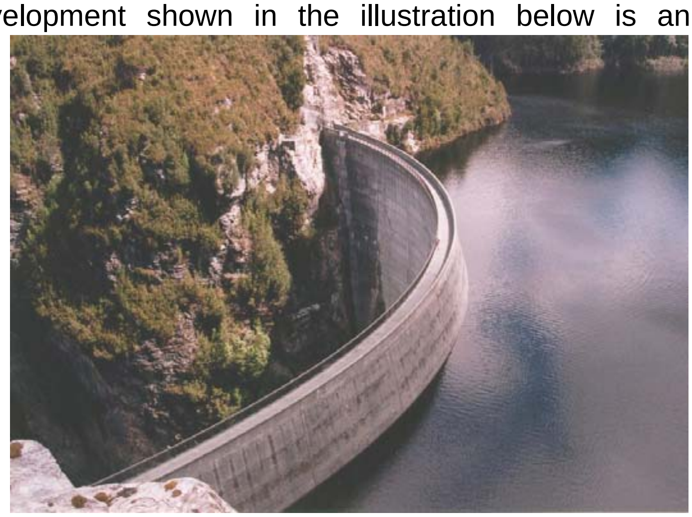

Figure 1 – Gordon Dam

Tasmanian hydro-electric development substantially concluded in the mid 1990s with the King and Anthony Power Developments (John Butters and Tribute Power Stations). In 1998 Hydro Tasmania's wind development interest emerged with the King Island Wind Project (a remote area power supply).

A Direct Current (DC) transmission connection (Basslink) is under construction between Tasmania and mainland Australia. Basslink is due to be complete in November 2005 and will have a 600MW export and 300MW import capacity.

Hydro Tasmania is committed to sustainability, and is confident that its focus on sustainable energy developments within a global context will enable the company to reach its vision "to be Tasmania's world renowned renewable energy business."

In 2000 the Australian Government introduced the Renewable Energy (Electricity) Act 2000 (known as the Mandatory Renewable Energy Target or MRET). The legislation requires electricity retailers to source an additional 9500 GWh of renewable energy, or 2% of the electricity supplied to the national energy market, by 2010.

3.1 Tasmanian Wind Power Development

MRET has provided significant stimulus to renewable energy development in Australia and in combination with the Basslink development and the abundant wind resource present in the "Roaring Forties" (Latitude 40^{o} South) has underpinned Hydro Tasmania's ambitious 450 MW wind development program in Tasmania as well as upgrading of ageing Tasmanian hydro-electric power stations. The projects include:

- Woolnorth Wind Farm – 140 MW (64.75 MW installed to date)
- Heemskirk Wind Farm – 160 MW
- Musselroe Wind Farm – 120 MW

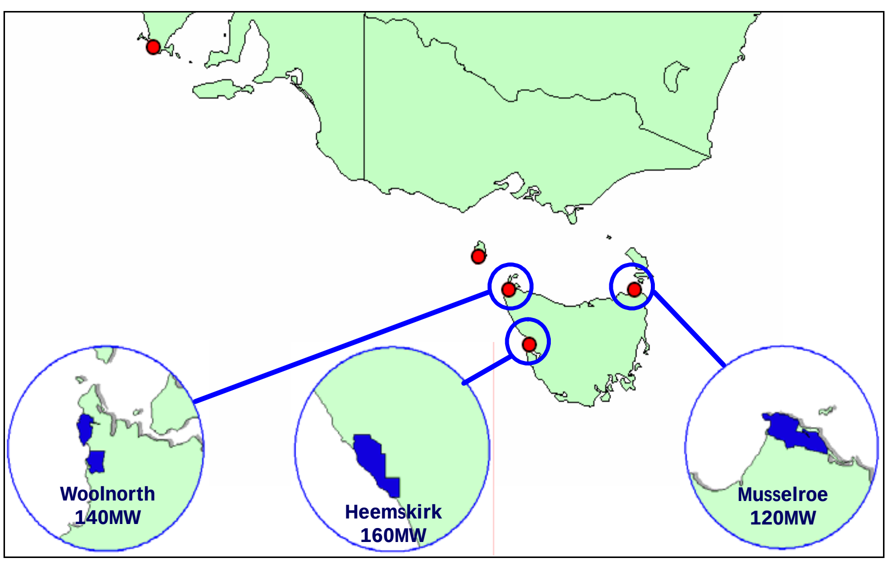

Figure 2 – Hydro Tasmania's Planned Tasmanian Wind Farms

Hydro Tasmania recently completed the second stage of the Woolnorth Wind Farm which now consists of 37 x 1.75MW Vestas V66 wind turbines (64.75 MW installed).

Figure 3 – Woolnorth Wind Farm

Tasmania provides an excellent case study for hydro/wind synergies and is providing early indications of the benefits that can be achieved.

3.2 Limits to Wind Development in Tasmania

In addressing the technical challenges described in section 2, two threshold levels became apparent.

The first issue that had to be overcome in Tasmania was the need for large wind farms to continue to operate during transmission faults. This requirement became important even for the second stage of the Woolnorth Wind Farm - 64.75MW installed capacity. This requirement was met by purchasing wind turbines with fault ride through capability. Vestas were able to provide this technology. Section 4.1 on fault ride through explains this requirement in more detail.

The second issue that was identified was compliance with Tasmanian frequency standards. As with the fault ride through requirement, this requirement was met through wind turbine capability improvement.

After a comprehensive review of technical constraints on wind development in Tasmania it was found that up to approximately 140MW of development (the full Woolnorth Wind Farm) could be achieved as long as location specific transmission connection issues were addressed.

Beyond this 140MW level wind development must be complemented by dispatch of additional inertia and additional voltage support (fault level contribution) under some load/generation scenarios. Findings from work on inertia and fault level contribution are described in sections 4.2 and 4.3.

It was found that there are ways to provide the additional inertia and fault level contribution to allow the planned 450MW of Tasmanian wind development even under quite testing load/generation scenarios. The most testing scenario was found to be:

- full production from 450MW of wind power;
- minimum Tasmanian overnight load of 900 MW; and

- full import over the DC interconnect (Basslink) of 300 MW.

Under this extreme scenario wind penetration will be 50% of system load but 75% of local generation.

3.3 The Tasmanian Example - Fault Ride Through

One of the key requirements of the Australian National Electricity Market Code is that generators are required to have the capability to sustain operation through a transmission fault where system voltage falls to zero volts for 0.175 seconds.

This capability is required so that a short circuit in the transmission system does not cause a substantial reduction in generation output and result in a system collapse.

Conventional generators found in thermal or hydro generators have utilised synchronous generator technology for many years. This synchronous generator technology is generally capable of meeting National Electricity Code fault ride through requirements.

Modern wind turbines now generally utilise variable speed technology and partial or full duty power electronics. This technology was developed with the objective of maximising energy production and was not initially developed with fault ride through capability. Whilst small wind development is possible even without fault ride through capability, for large scale wind development to be achieved, fault ride through capability is critical. This capability has now been developed by a number of wind turbine manufacturers and is being supplied in Tasmania by Vestas Wind Systems – Hydro Tasmania's wind turbine supplier.

This capability does not draw on the synergy between hydro and wind power.

3.4 The Tasmanian Example - System Frequency

A key role of the National Electricity Market Management Company (NEMMCO) is to manage the system frequency within an acceptable band. In Tasmania the frequency band is 47.5 Hz to 55 Hz. This band is unusually wide in Tasmania due to the presence of hydro plant and compares with mainland Australia where the band is 48 to 52 Hz.

Wind turbines are typically designed to operate within the 48 – 52 Hz range but recent work has proven lower frequency operation. As will be seen later, loss of generation at high frequency is a positive contributor to frequency management as long as it is controlled or staged to some degree.

Power system frequency is managed through a number of actions:

- Short term inertial response from generation and end use equipment (the fly wheel effect of spinning machines). Inertia in the power system dampens the rate at which frequency rises if load suddenly reduces or falls if generation suddenly reduces. System inertia provides an immediate damping response to frequency changes;
- Scheduled load shedding. If system frequency reduces to a threshold level, an automatic system sheds system load. It takes some time for the

system frequency to reach threshold levels and then more time for the load shedding to occur due to communication timeframes; and

- Generator governor response. The generator governing response is required in order to adjust the level of generation production to match demand. This response takes some time and typically acts over a longer timeframe than the load shedding response.

Whilst high levels of wind penetration do not impact on load shedding capability, it can have an impact on system inertia and generator governing response.

Short Term Inertial Response - Wind turbine variable speed technology generally isolates the inertia of the rotating mass of the wind turbine from the power system. This means that for each MW of wind operating on the system, there is a corresponding reduction in the system inertia due to the displacement of synchronous generation.

In the Tasmanian system, studies have shown that if wind turbines are not able to contribute to system inertia, large scale wind penetration will at times require the dispatch of synchronous hydro generators either as spinning reserve (part loaded generators, with fractional water flow) or as synchronous condensers (generators “motoring” on the network but only supplying reactive power). It was found that under some relatively infrequent circumstances, for each MW of wind power operating an equivalent amount of hydro installed capacity must be operating unloaded. The circumstances that are most testing are periods of low Tasmanian demand, when Basslink is operating in import and wind production is high. Basslink is not expected to contribute any inertia.

There is a low cost associated with operating hydro generators as synchronous condensers during these infrequent system circumstances.

Studies of the power system have shown that there is a relationship between the Tasmanian load and the minimum amount of hydro plant that must be operating to maintain system inertia.

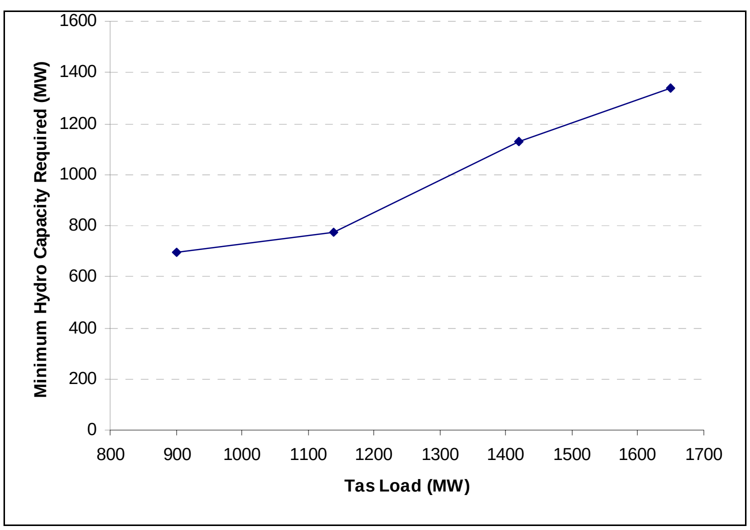

Figure 4 - Minimum Hydro Operation vs Tasmanian Load (to meet minimum acceptable system inertia levels)

It can be seen from the above graph that with low Tasmanian load, the operation of 450MW of wind will result in lower than acceptable levels of hydro generation. For example, if load is 900MW and 450MW of wind is operating, whilst only 450MW of hydro production is needed to meet demand, 700MW of hydro machines are required to at least spin to provide inertia.

In a report by the Large-Scale Wind Integration Working Group (a group of specialist interests commissioned to study the integration of wind into the Tasmanian grid) it was estimated that the Tasmanian system had adequate inertia to replace approximately 150 MW of hydro generation by the wind generation (using current technology) with minimum effect on the grid[5].

System simulations can be undertaken to determine how frequently these requirements occur. The following table show the results of such a simulation and demonstrates that it is relatively rare that system load is low at the same time as high levels of non-inertia generation (Basslink and wind).

	Probability Matrix - Hours of Operation														
	Tas Demand (MW)														
Non-Interial Gen (MW)	*960*	*1020*	*1080*	*1140*	*1200*	*1260*	*1320*	*1380*	*1440*	*1500*	*1560*	*1620*	*1680*	*1740*	***Sum***
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37.5	0	0.01	0.15	0.49	0.73	0.81	0.77	0.68	0.56	0.41	0.25	0.12	0.05	0.01	5.04
75	0	0.01	0.11	0.43	0.78	1.05	1.06	0.87	0.70	0.57	0.37	0.19	0.08	0.02	6.24
112.5	0	0.02	0.16	0.59	1.07	1.37	1.34	1.09	0.87	0.68	0.44	0.23	0.09	0.03	7.98
150	0	0.02	0.20	0.75	1.37	1.78	1.80	1.45	1.16	0.92	0.58	0.28	0.11	0.03	10.46
187.5	0	0.02	0.22	0.77	1.34	1.81	1.76	1.40	1.15	0.88	0.56	0.27	0.10	0.03	10.32
225	0	0.02	0.23	0.73	1.20	1.54	1.52	1.22	0.95	0.72	0.45	0.23	0.09	0.02	8.94
262.5	0	0.02	0.22	0.66	1.07	1.35	1.29	1.02	0.83	0.64	0.40	0.21	0.08	0.02	7.81
300	0	0.04	0.27	0.72	1.02	1.20	1.13	0.92	0.74	0.56	0.34	0.17	0.06	0.02	7.18
337.5	0.00	0.14	0.76	1.13	1.09	1.08	0.91	0.68	0.50	0.34	0.21	0.10	0.04	0.01	7.01
375	0.01	0.19	0.94	1.28	1.16	1.04	0.78	0.56	0.40	0.28	0.17	0.09	0.04	0.01	6.96
412.5	0.01	0.19	0.92	1.21	1.06	0.95	0.71	0.47	0.34	0.22	0.13	0.07	0.03	0.01	6.30
450	0.01	0.16	0.80	1.08	0.91	0.76	0.55	0.34	0.22	0.14	0.08	0.04	0.02	0.01	5.10
487.5	0.01	0.12	0.63	0.87	0.71	0.61	0.44	0.28	0.18	0.11	0.06	0.03	0.01	0	4.08
525	0	0.08	0.43	0.58	0.48	0.43	0.32	0.19	0.12	0.08	0.05	0.02	0.01	0	2.81
562.5	0	0.06	0.28	0.37	0.34	0.30	0.22	0.14	0.09	0.06	0.03	0.02	0.01	0	1.92
600	0	0.03	0.16	0.22	0.21	0.20	0.15	0.09	0.06	0.04	0.02	0.01	0.01	0	1.20
637.5	0	0.01	0.04	0.07	0.08	0.08	0.06	0.04	0.03	0.02	0.01	0	0	0	0.43
675	0	0.00	0.02	0.03	0.03	0.03	0.03	0.02	0.01	0.01	0.00	0	0	0	0.18
712.5	0	0	0	0.01	0.01	0.01	0.01	0	0	0	0	0	0	0	0.05
750	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
Sum	0.05	1.15	6.55	11.99	14.65	16.41	14.85	11.45	8.91	6.67	4.16	2.09	0.82	0.22	

Figure 5 – Probability Of Requiring Inertia Support (Percent) – 450MW Wind Installed

There is a limit to how much hydro plant can be dispatched as spinning reserve due to minimum acceptable loading levels (~50% loading). On this basis in Tasmania, spinning reserve limitations would restrict wind production to 300MW under the most testing operating conditions (low load, and high Basslink import).

However, the operation of hydro generators as synchronous condensers overcomes this constraint, and enables the full integration of the planned 450MW of wind.

The overall cost of dispatching hydro machines as synchronous condensers to compensate for the lack of inertia can then be readily estimated based on this data and was found to be quite low in the case of Tasmania. This primary

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[5] Transend, 2004, Integration of Large-Scale Wind Generation: A report by the Large-Scale Wind Integration Working Group to the NEM Entry Coordination Group

cost associated with synchronous condenser operation is the power required to motor the generator at grid frequency.

Load Shedding – Load shedding arrangements are typically triggered by system frequency dropping to a threshold level. These arrangements are not expected to substantially change with the introduction of large scale wind development but some tuning of settings may be needed.

Governing Response – Reducing generation output in the event of a sudden reduction in demand is readily achieved with conventional hydro machines and can be achieved with recent developments in wind turbines controllers. This governor capability is typically referred to as the “Lower” Frequency Control Ancillary Service. The term ancillary service reflects the way these services are viewed as ancillary to the energy market.

In order to increase generator output, partially loaded spinning plant must be available. This spinning reserve is ideally provided by hydro plant which can operate at part load with minor loss of efficiency. Part loaded hydro generators are ideally suited to responding rapidly to the need for increased production. This capability is typically referred to as the “Raise” Frequency Control Ancillary Service.

Whilst it is technically possible with modern wind turbines to provide the raise service, it can only be achieved by deliberately operating the wind turbine at reduced output unless called upon to increase or “Raise” production. Providing this service from wind turbines would be wasteful as energy is lost in the process.

Hydro plant have the unique ability to operate at less than full capacity while using a minimal amount of fuel (water) and a small loss of efficiency. In comparison, thermal generation cannot sustain operation at low output, and even small reduction of output is associated with significant loss of efficiency.

Historically the flexibility of hydropower has been utilised to provide regulating reserves to meet the fluctuating gap between supply and demand.

Wind turbine production is characterised by significant variation in production as wind speeds vary. The term “intermittency” is now commonly used to describe this characteristic. Whilst this effect is reduced with large wind developments due to the diversity of the output of many machines and several wind development locations the large scale development of wind power will increase the need for both Raise and Lower Frequency Control Ancillary Services.

The following diagram shows predicted wind production (a Danish example). Predicted variation can be managed through scheduled operation of generators on the system whereas spinning reserve needs to be dispatched to cover the uncertainty in production. Hydro generation is ideally suited to the role of spinning reserve, providing both Raise and Lower Frequency Control Ancillary Services .

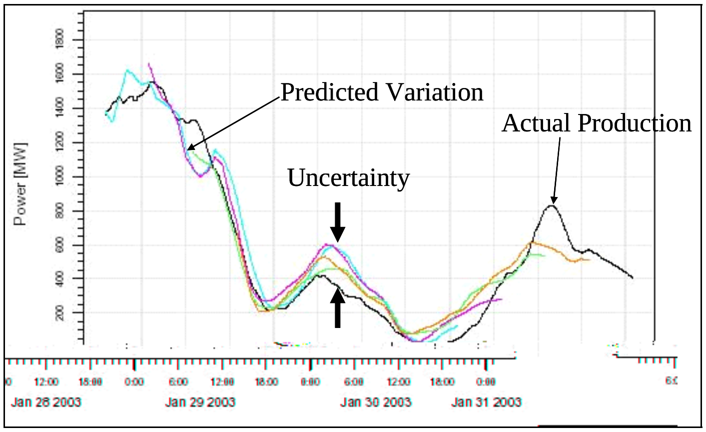

Figure 6 – Predicted Variation vs Production Uncertainty "Zephyr" wind power forecasting system - Risø National Laboratory

Both wind power and run of river hydro plant are intermittent generation, although run of river hydro varies less in the very short term. Ideally hydro systems have a combination of run of river hydro generators and hydro generators with large reservoirs. Hydro generators with a storage reservoir can provide a balancing role for wind in the same way they do for run of river hydro.

Installed hydro capacity typically exceeds average production by a factor of around two. This enables hydro plant to be operated at high output to either meet peak load or to capture available water without excessive spill.

By reducing hydro output when wind production is high, energy can effectively be stored in hydro reservoirs.

3.5 The Tasmanian Example - Management of power system voltage

The National Electricity Code (NEC) requires management of transmission voltage across the power system and stable system operation. This results in direct requirements being placed on generators connecting the system but also creates a need for whole of system consideration of voltage management.

In the Tasmanian situation the introduction of the DC interconnection (Basslink) will result in frequent switching of components within the Basslink AC/DC converter station. This switching will result in frequent voltage disturbances that must be managed by generators contributing reactive power to smooth out voltage fluctuations to within acceptable levels.

Current wind turbine designs typically have limited capability to provide voltage support in these circumstances. As the amount of wind installed on the power system increases, the need for additional voltage support correspondingly increases.

In the case of Tasmania it was found that the solution to the inertia issue described earlier also addresses the voltage support requirement. In supporting the system voltage however, it is important that the synchronous condensers that are dispatched are located in areas of the system that require voltage support.

3.6 Relevance of Tasmanian Case Study

The Tasmanian case study is relevant to other areas in the world where hydro and wind power can be developed together. The synergy between wind and hydro power is strong, with hydro generator being able to provide important support to wind generation. In Tasmania, the synergy enables a much greater wind penetration than would otherwise be possible. Hydro generators operating as spinning reserve or synchronous condensers can play a key role in maximising wind penetration.

4 International Opportunities

In Johannesburg, the 2002 World Summit on Sustainable Development (WSSD) called for an increase in the use of renewable energy in developed and developing countries. Both industry and government accepted the challenge posed at the WSSD, and many renewable energy initiatives were subsequently launched in Bonn at Renewables 2004. The Bonn Conference also led to a Political Declaration supported by 154 countries. The Declaration reaffirmed a commitment to increase the global share of renewable energy in the total energy supply. An action plan was also tabled by a large number of governments, international organisations, the private sector and other stakeholder groups aimed at increasing the global supply of renewable energy[6].

It was specifically noted at the WSSD, and in Bonn, that the most significant increase in global energy demand would come from developing countries. Further, that sustainable energy supplies in these countries were a vital component of ensuring global sustainable development.

A review of international hydro and wind potential shows that there is vast potential for both substantial further hydro development and substantial wind power development. Hydro and wind resources are dispersed widely across the globe. Currently there are ~300 GW of new hydro capacity planned for development across the globe. These plans are only a fraction of the 8,180,000 GWh/year (nearly 2,000 GW) of economically feasible hydro development identified worldwide[7].

World wind energy capacity has been doubling every three years during the last decade, and growth rates in the last two years have been even faster. It is doubtful whether any other energy technology is growing, or has grown, at such a rate. An estimate of potential of wind energy to reduce CO^2 emissions identified a global onshore wind potential of 18,010,000 GWh/year (almost 7,000 GW) at less than 5 c/kWh (US) by 2020[8]. The Greenpeace Wind Force 12 paper identifies the potential for global wind development to meet 12% of global power (1,200 GW) by 2020. These estimates are compiled in Figure 7 below.

Clearly hydro power is many times more developed than wind power in all regions of the world but wind power has been demonstrated to have at least

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[6] International Conference for Renewable Energies, Bonn, 2004

[7] Hydropower & Dams, World Atlas 2004

[8] "The Potential of Wind Energy to Reduce CO2 Emissions" – Garrad Hassan

the same scale potential and possibly much more. There is clearly a great potential for the synergies between hydro and wind power to be utilised on a very wide basis across the globe as the level of wind penetration picks up in different regions of the world.

The fact that substantial hydro facilities are already in place will greatly assist with the rapid adoption of wind power in some regions. Where less hydro is installed, an optimal approach may well be to develop wind and hydro capacity at the same time.

Figure 7 - Installed and Potential Hydro Power and Wind Power

	Hydro Power			Wind Power		
Country/Region	**Installed Hydro 2004 (GW) [1]**	**Economic Potential Hydro (GW) [1] ***	**Technical Potential Hydro (GW) [1] ***	**Installed Wind end 2002 (GW) [2]**	**Wind required to meet 12% global target (GW) [4]**	**Onshore Wind Potential in 2020 (GW) [3] ****
Europe	177	180	260	23.3	360	3,857
Africa & Middle East	21	251	400	0.1	50	1,254
North America	145	208	345	4.9	310	131
Latin America	135	385	678	0.1	100	802
India	30	55 #	151	1.7	included in Asia	19
China*	83	292	488	0.5	170	414
Rest of Asia	134	530	914	0.4	120	364
Pacific	13	21	46	0.1	90	12

Sources
1 - Hydropower and Dams World Atlas 2004
2 - World Wind Energy Association (WWEA) - http://www.wwindea.org/pdf/WWEA_InstallationFigures_World2003.pdf
3 - Garrad Hassan Study - http://www.garradhassan.com/downloads/COP6%20Flyer%20Print.pdf
4 - Windforce 12 - http://www.ewea.org/03publications/WindForce12.htm

Notes
* Economically Feasible Hydropower potential is calculated from energy production estimates using a 50% capacity factor
** Based on converting Garrad Hassan TWh/yr estimates to GW based on an assumed 30% capacity factor
# The Hydropower and Dams World Atlas 2004 report quoted this as a country commitment in the text rather than the table from which other numbers were sourced

There is clearly an opportunity for the co-ordinated development of hydro and wind power resources in several areas globally in a manner that utilises the strong synergies demonstrated earlier in this paper.

5 Conclusion

Hydro and wind power represent a significant opportunity for addressing the shortfall in global energy supply. Substantial community benefits can be expected from such development including, improved quality of life through energy availability, reduced local air pollution, local employment associated with local manufacture construction and economic activity that is made possible through access to electricity.

The work to date in Tasmania has shown that high levels of wind penetration are possible in association with hydro power. The inherent flexibility of hydro plant clearly complements the intermittent nature of and limited ancillary service contribution from wind power.

The scale of global hydro and wind power development is immense and can provide a sizable contribution to meeting future energy needs in a manner that is globally more equitable than is the case with fossil fuel resources.

Attachment 1 - Tasmanian Power System Map and Map of Australia