Supplying the bulk of electricity in Western Australia by wind generation

This paper explores the limits of the amount of wind generation that can be installed on the South West Interconnected System or SWIS.

Load versus Accumulated Hours a Year

Timestamp data for the South West Interconnected System (SWIS) as shown in Figure 1 was obtained from Western Power for one year, April 05 to March 06, at half hour intervals, to calculate the graph in Figure 2.

Date and Time	SWIS	Rounded MW
1/04/2005 0:00	1,262	1,300
1/04/2005 0:30	1,222	1,200
1/04/2005 1:00	1,193	1,200
1/04/2005 1:30	1,173	1,200
1/04/2005 2:00	1,167	1,200
1/04/2005 2:30	1,154	1,200
1/04/2005 3:00	1,163	1,200
1/04/2005 3:30	1,166	1,200
1/04/2005 4:00	1,193	1,200
1/04/2005 4:30	1,216	1,200
1/04/2005 5:00	1,282	1,300
1/04/2005 5:30	1,356	1,400
1/04/2005 6:00	1,514	1,500
1/04/2005 6:30	1,635	1,600
1/04/2005 7:00	1,792	1,800
1/04/2005 7:30	1,881	1,900
1/04/2005 8:00	1,917	1,900
1/04/2005 8:30	1,922	1,900
1/04/2005 9:00	1,937	1,900
1/04/2005 9:30	1,926	1,900
1/04/2005 10:00	1,920	1,900
1/04/2005 10:30	1,923	1,900
1/04/2005 11:00	1,927	1,900
1/04/2005 11:30	1,921	1,900
1/04/2005 12:00	1,916	1,900
1/04/2005 12:30	1,897	1,900

Figure 1, Sample of Timestamp data for the SWIS

The load in MW was graphed against accumulated hours a year for WA's electricity consumption on the SWIS - just under 15,000 GWh.

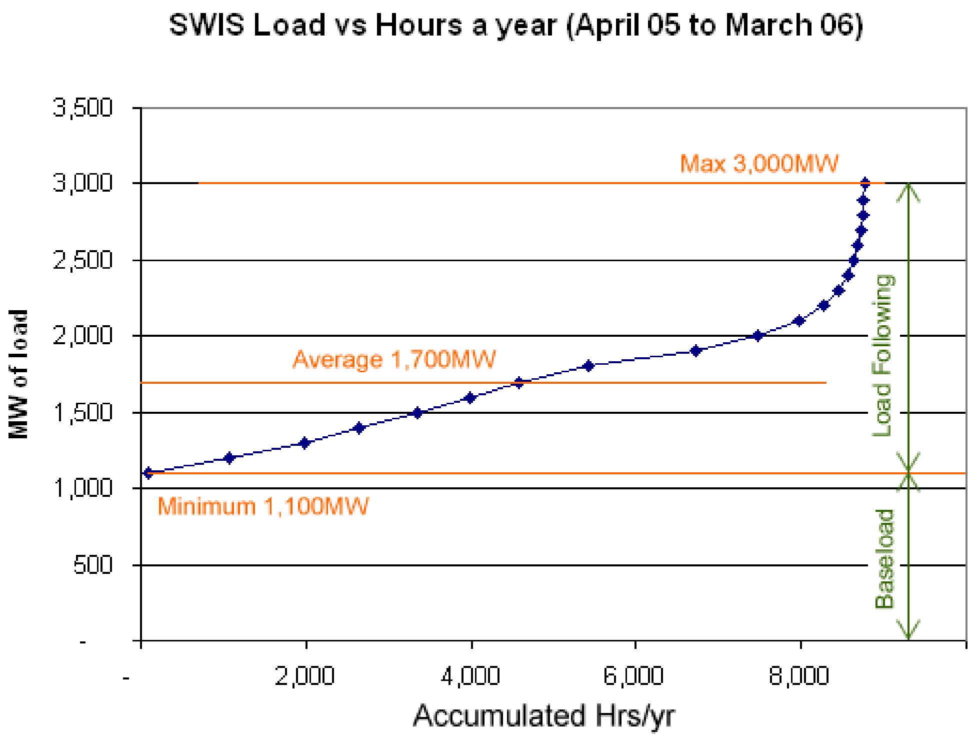

Figure 2, SWIS versus Accumulated Hrs/yr

From this graph, we can see that the baseload was just over a third the maximum load, and the average just over half the maximum. This means that the system already has load following capability of two thirds the maximum load, ie just under 2000MW.

Windspeed Distribution and Power from Wind

Based on the 800kW Enercon E48 wind turbine, a typical powercurve - if somewhat smaller than most modern machines.

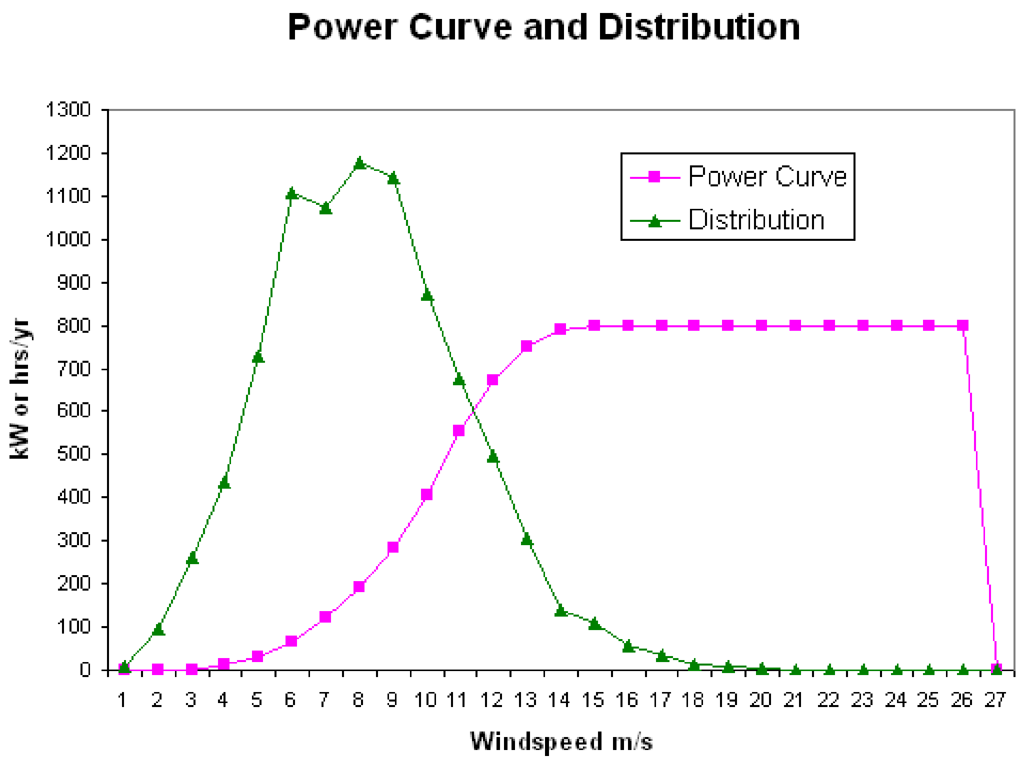

Figure 3, Windspeed versus Power Output and Distribution

Wind distribution is based on a year's worth of wind data from a mast on top of Mt Barker Hill, 70km north of Albany (and the coast) on the highway. The electricity generated by the wind turbine is the product of these two curves. The windspeeds have been doctored to give a modest Capacity Factor, CF, of 0.35 ~ around 2,300 MWh/y. Now, we can combine the two curves by recalculating the distribution curve as accumulating hours a year and graphing it against the corresponding power output for that windspeed. Ie at 6m/s, the distribution is 1075 hours a year, including the hours at windspeeds lower than 6m/s, we get 3716 accumulated hours, the output at 6m/s is 120kW.

At 12m/s, the accumulated hours are 8391 hours and the power output is 750kW.

Combining the distribution curve and the power curve provides a single curve for a single turbine ie output for one turbine will look something like this. This is a single turbine supplying electricity to roughly 500 people.

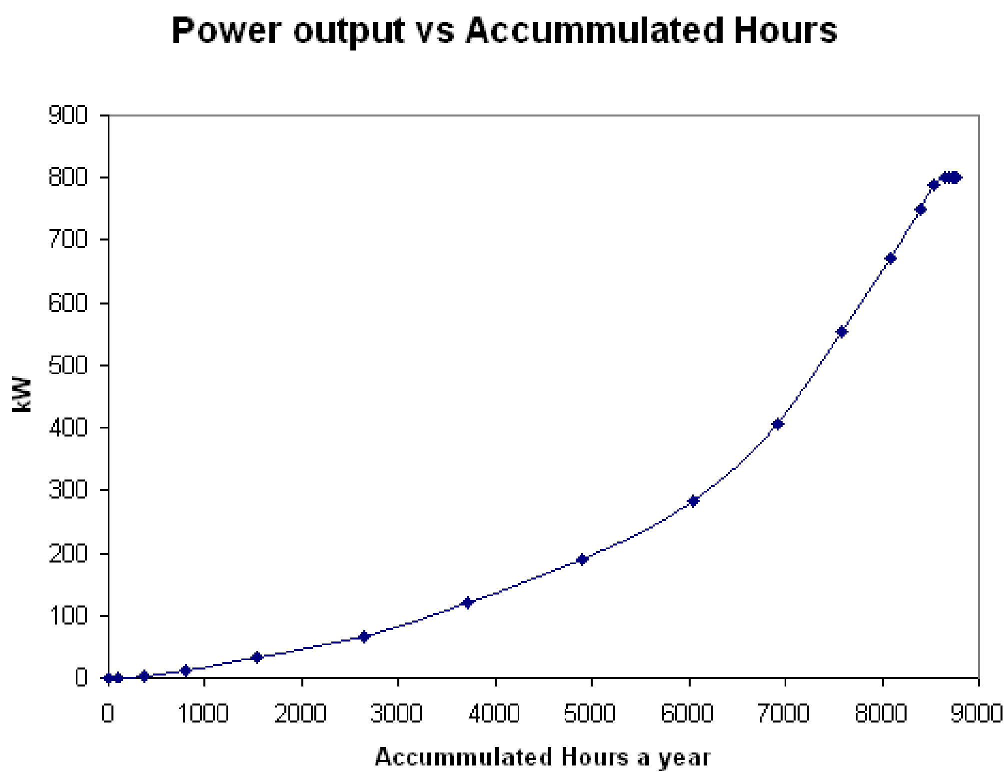

Figure 4, Power versus Accumulation Hrs/yr

Of course, more turbines, more windfarms more geographically spread will give a flatter curve, it will be rare that the wind will be strong or weak, everywhere.

Geographical Dispersion

An idea of how much flatter is given by looking at data from four different sites. In this case, 1 years worth of half hourly data at Bureau of Meteorology (BoM) sites around the SWIS, the wind speeds were multiplied by a single factor selected to give a capacity factor of 35% with an E48 power curve. It is assumed that the variation in windspeed at the BoM sites will be representative of what would be expected from a windfarm.

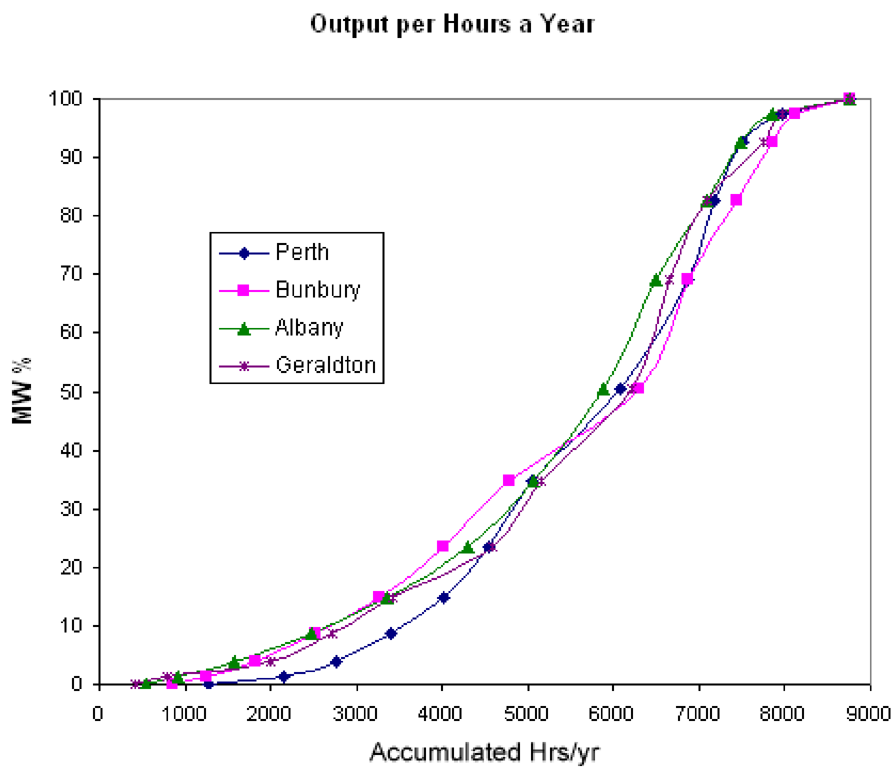

Figure 6, % Power versus Accumulated Hrs/yr

The average for all sites is shown below, however, we ought be looking not at the average, but at the average of all the wind farms every half an hour;

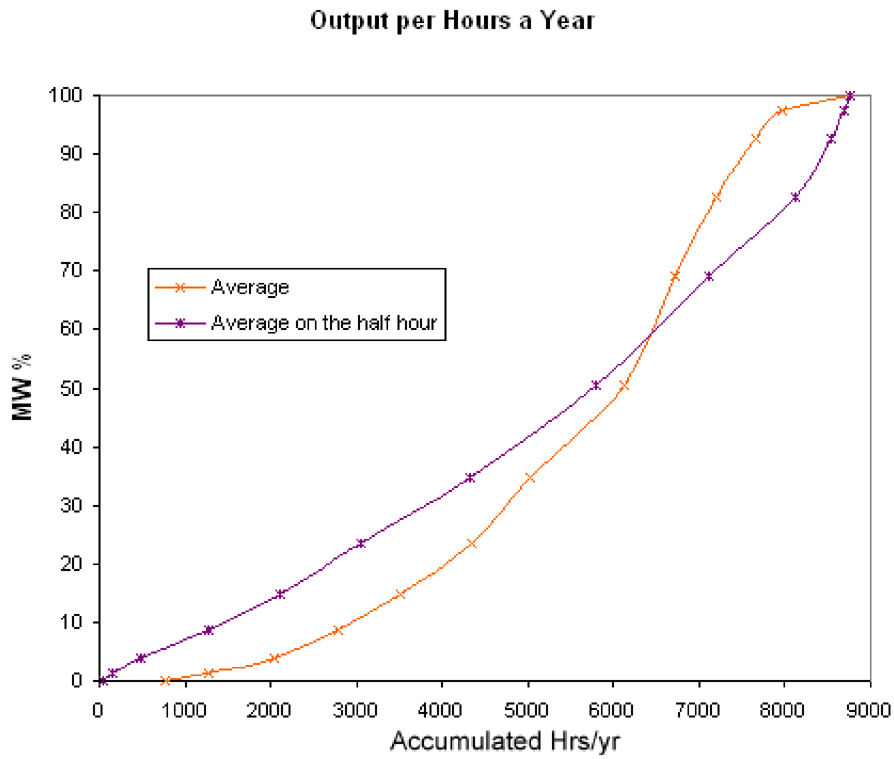

Figure 7, Average and Real Time Average

The resulting curve is somewhat different, and this illustrates what we mean be geographical dispersion. Adding the production from windfarms at all four sites at the same time gives a flatter curve, as fronts pass through, one windfarm will be producing when the other is not, similarly, it will be also rare for both to be producing at full power or not at all. What is really interesting are the very few hours above 80% of full output.

From a study of Nordic countries by H. Holttinen, *Hourly Wind Power Variations and Their Impact on the Nordic Power System*, 2003, Helsinki University of Technology, come very similar looking curves;

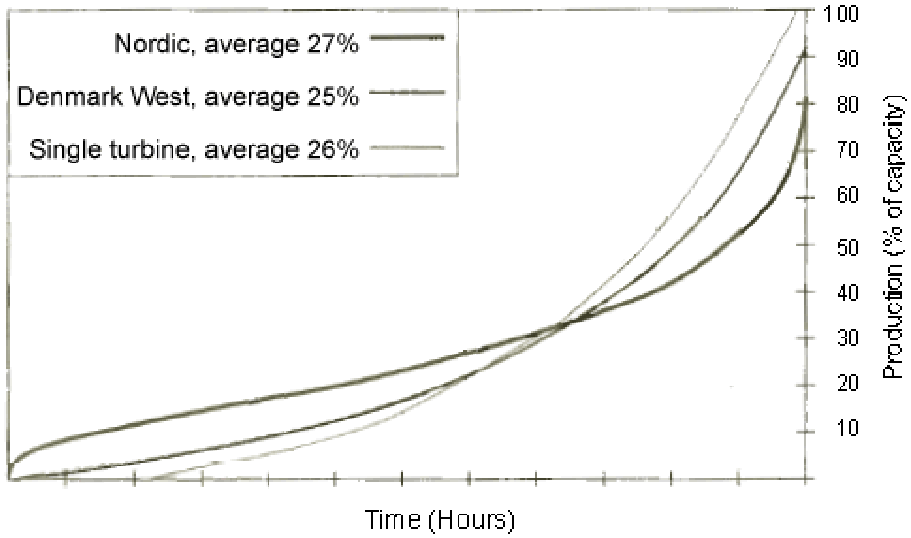

Figure 8, Nordic curves of wind production vs accummulated hours

2000MW of wind plant

Back to the SWIS, from Figure 2 we see the system can cope with nearly 2000MW of variable load. But 2000MW intermittant supply of energy by the wind?! 2000MW is greater than our minimum of 1100MW so there will be times of the year when the wind plant will need to be derated. How often and how much will the wind be excessive?

The difference between the load and the energy generated for each half hour for the year April 05 to March 06 is calculated.

Date and Time	SWIS Load	2000MW Wind Plant	Difference	Rounded
1/04/2005 0:00	1261.51	1160.49	101.02	100
1/04/2005 0:30	1222.40	1086.42	135.98	100
1/04/2005 1:00	1192.62	1086.42	106.20	100
1/04/2005 1:30	1173.16	1259.26	-86.10	-100
1/04/2005 2:00	1167.08	1185.19	-18.10	0
1/04/2005 2:30	1154.30	1135.80	18.49	0
1/04/2005 3:00	1162.71	1086.42	76.30	100
1/04/2005 3:30	1166.23	1135.80	30.43	0
1/04/2005 4:00	1192.64	1259.26	-66.62	-100
1/04/2005 4:30	1215.51	1407.41	-191.90	-200
1/04/2005 5:00	1282.29	1506.17	-223.89	-200
1/04/2005 5:30	1356.07	1358.02	-1.95	0
1/04/2005 6:00	1513.85	1358.02	155.82	200
1/04/2005 6:30	1635.21	740.74	894.46	900
1/04/2005 7:00	1791.79	1283.95	507.84	500
1/04/2005 7:30	1880.72	1012.35	868.38	900
1/04/2005 8:00	1916.83	1506.17	410.66	400
1/04/2005 8:30	1921.51	1629.63	291.88	300
1/04/2005 9:00	1937.27	1851.85	85.42	100
1/04/2005 9:30	1926.41	1259.26	667.15	700
1/04/2005 10:00	1920.16	1333.33	586.83	600
1/04/2005 10:30	1922.66	2000.00	-77.34	-100
1/04/2005 11:00	1927.15	2000.00	-72.85	-100
1/04/2005 11:30	1920.63	1407.41	513.22	500
1/04/2005 12:00	1916.30	1506.17	410.13	400
1/04/2005 12:30	1896.82	1506.17	390.65	400

Figure 9, SWIS Load vs 2000 MW of Wind Plant in 'Real Time'

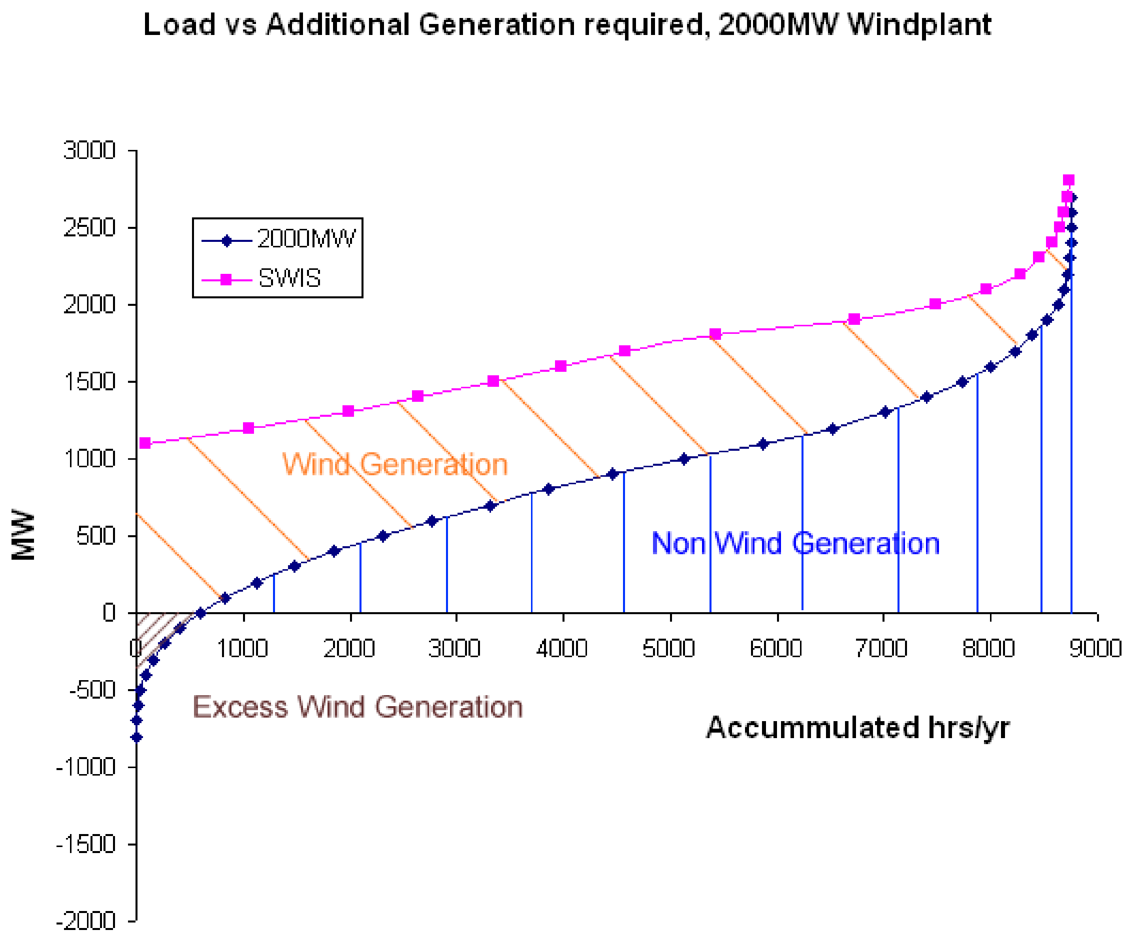

Figure 10, SWIS and 2000MW Wind Generation

From the above graph, the area between the two curves is the wind energy generated. This is about 41% penetration. The area above the blue curve and below the Accumulated Hrs/yr axis is excess wind energy which occurs when the load is less than the wind plant produces - this is around 1% of the overall wind generation. The remaining electricity generation required is under the rest of the blue curve.

Why the tiny excess?

Why, when the lowest load is almost half the 2000MW of wind plant, is only 1% of the electricity generated by the wind in excess?

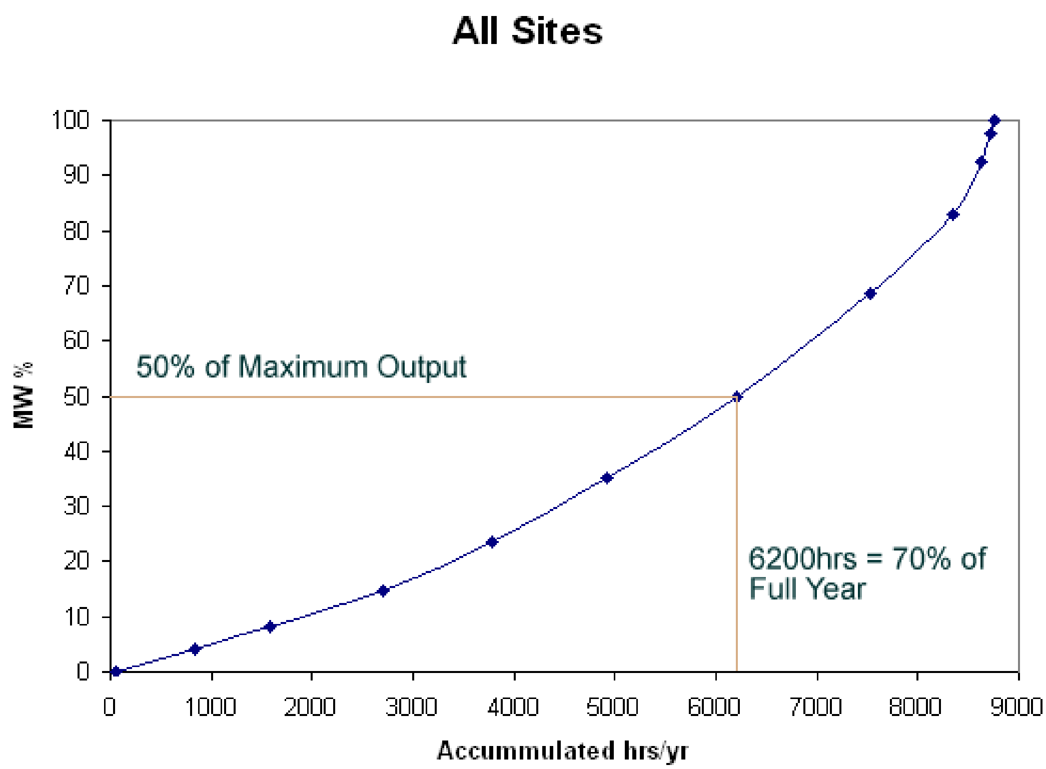

Figure 11, Combined Output vs Accummulated hrs/yr

Consider the curve of the combined output of the 2000MW of windfarm vs the accummulated hours a year, despite the leveling impact of geographical distribution, for 70% of the year, the total output is still less than 50% of maximum, ie for most of the time, the impact of the 2000MW is less than 1000MW.

In addition, a look at the time of day curves, shows that, on average, the output roughly matches the load.

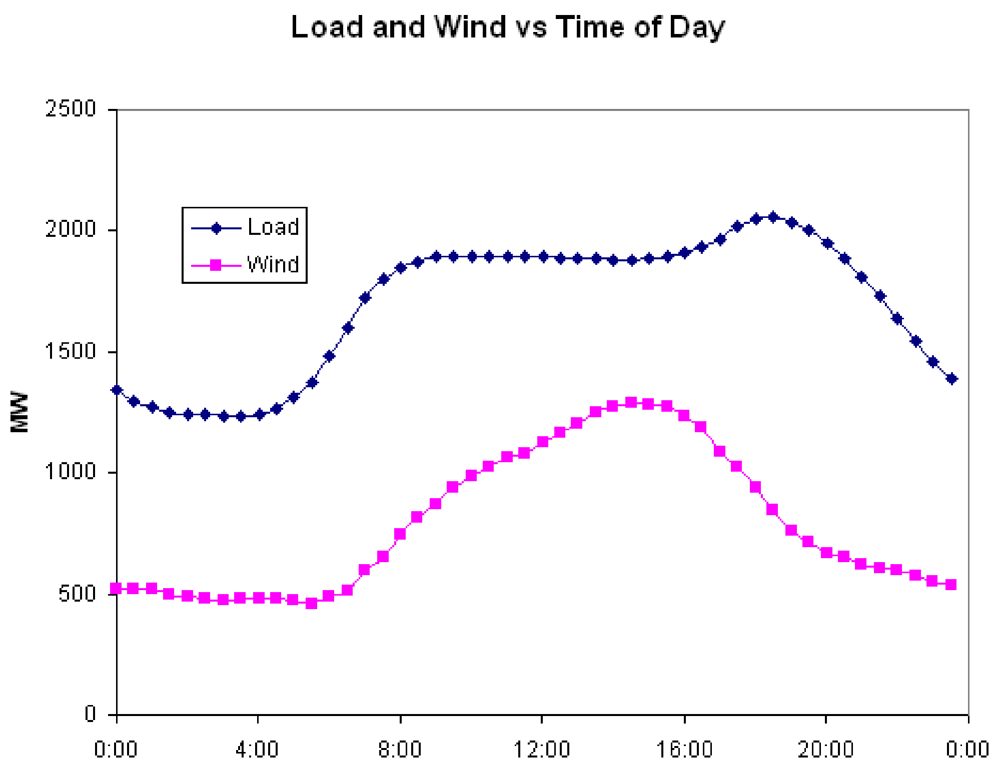

Figure 12, SWIS and 2000MW Wind Generation Time of Day

What does 2000MW look like?

- At 5MW/square kilometre, we need 400km2
- SWIS covers 322,000km2 (1 ½ size of Victoria)*
- 400km2 could be 2km x 200km which compares with a north south distance of the SWIS of some 1600km

*http://www.wpcorp.com.au/subContent/aboutUs/ourNetwork/Network_Vital_Statistics.html

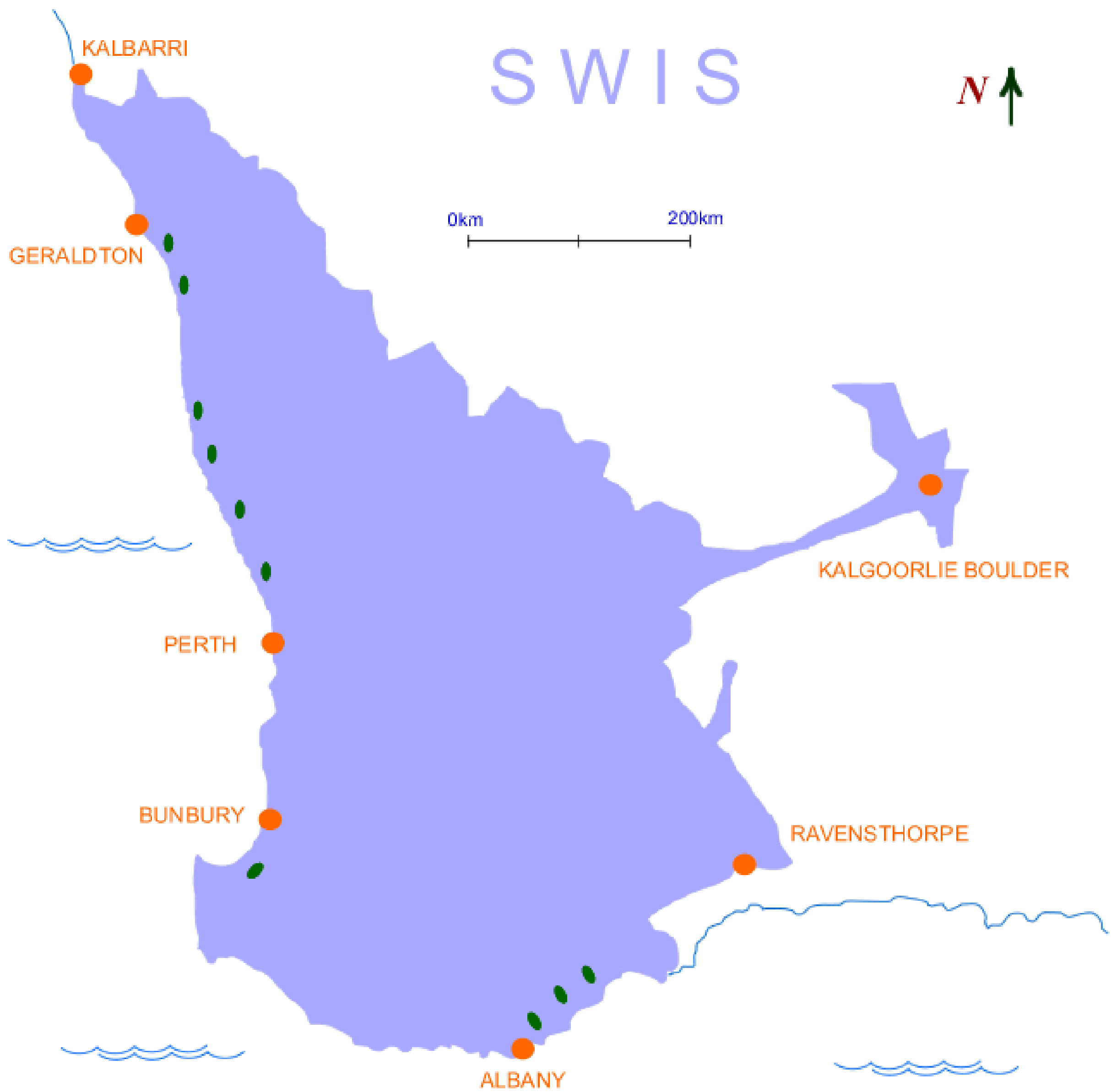

Figure 13, Possible Windfarm Locations, 200MW sites

Other parameters

- Number of jobs in construction, 2,960 jobs for 5 years*
- Number of jobs in operation, 216 permanent jobs**
- Total job years = 16,160
- Equivalent to 733MW of coal (at 90% Capacity Factor)

Based on 20 year life

*assumes 7.4 job years/MW if job 100% local, Dr Robert Passey , March 2003 Driving Investment, Generating Jobs Report, p17
**assumes 37 job years / TWh Dr Robert Passey , March 2003 Driving Investment, Generating Jobs Report, p17

And 3000MW?

Wind generated energy would now supply 56% of what is consumed, an increase of 34% from the increase of 50% in capacity. Excess is now 10% of wind generation but we now have 2000 hours a year where the SWIS is supplied entirely by wind!

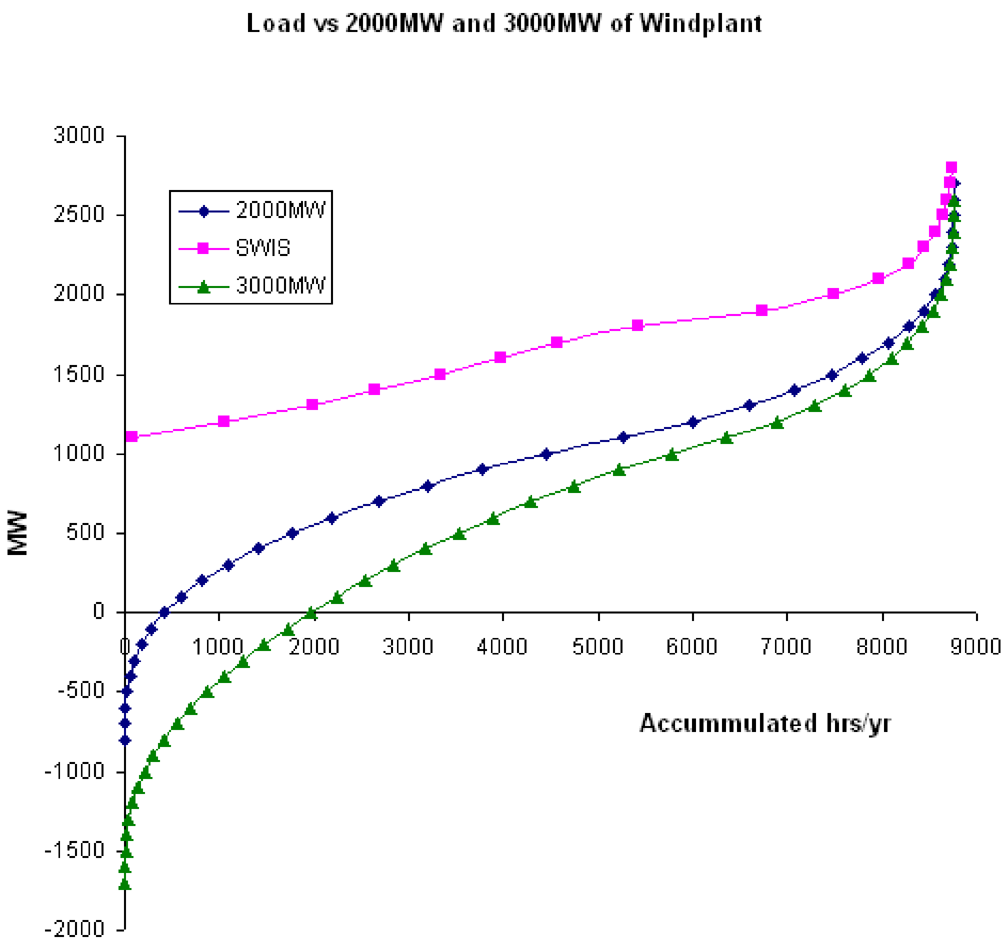

Figure 14, SWIS, 2000MW and 3000MW of Windplant

	2000MW	3000MW	Load
Electricity (GWh/yr)	6047	8282	14,828
% of total Load	41%	56%	100%
% excess	1%	10%	na

Table 1, 2000MW and 3000MW of Wind vs Load

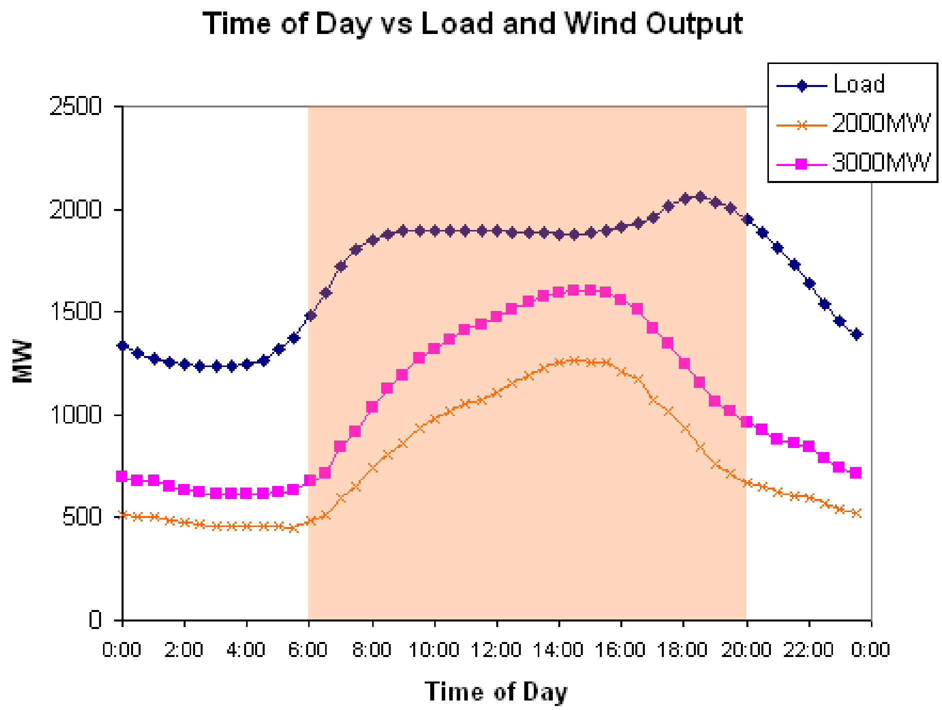

Figure 15, SWIS, 2000MW and 3000MW vs Time of Day

The two wind plant curves have had the excessive energy removed. The shaded area is peak for weekdays. There is NO peak period on the weekend or during public holidays.