Intermittency of UK Wind Power Generation 2013 and 2014

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April 2015

Executive Summary

This summary covers the principal findings of an analysis of electricity generation from all the UK wind turbines farms which are metered by National Grid, covering the period from January 2013 to December 2014.

The analysis shows:

- Monitored wind turbine output (as measured by the National Grid) increased from 5,894MW to 8,403MW over the period.
- The average capacity factor of all monitored wind turbines, onshore and offshore, across the whole of the UK, was 29.4% in 2013 and 28.8% in 2014.
- The monthly average capacity factor varied from 11.1% (June 2014) to 48.8% (February 2014).
- The time during which the wind turbines produced less than 10% of their rated capacity totalled 3,278 hours or 136.6 days over the two year period.
- The time during which the wind turbines produced less than 5% of their rated capacity totalled 1,172 hours or 48.8 days over the same period.
- Minimum wind turbine outputs averaged 132MW (1.8% of capacity) in 2013 and 174MW (2.1%) in 2014 as measured over 30 minute intervals.
- Variations in output of 75 to 1 have been observed in a single month.
- Maximum rise and fall in output over a one hour period was about 1000MW at the end of 2014 with a trend increase of about 250MW per year as measured over four years.
- There is no correlation between UK wind turbine output and total UK electricity demand, with output often falling as demand rises and vice-versa.

The conclusions to be drawn from the analysis are that the increase in nominal capacity:

- Does not increase the average wind turbine capacity factor.
- Does not reduce the periods of low (less than 10% of installed capacity) or very low (less than 5%) output.
- Does not reduce intermittency as measured by average monthly minimum output
- Does not reduce intermittency or variability as measured by maximum rise and fall in output over one hour period
- Does not indicate any possibility of closing any conventional, fossil-fuel power stations as there is no correlation between variations in output from wind turbines and demand on the Grid.

Therefore, based on the above, there is no case for a continued increase in the number of wind turbines connected to the Grid, or for the associated subsidies for wind energy, since this is an ineffective route to lower carbon dioxide emissions.

Intermittency of UK Wind Power Generation 2013 and 2014

Introduction

In April 2013 The Scientific Alliance published my analysis of electricity generation from all the UK wind turbines which are metered by National Grid, covering the period from January 2011 to December 2012.

This analysis showed:

- The average capacity factor of all monitored wind turbines, both onshore and offshore, across the UK was 33.2% in 2011 and 30.7% in 2012
- The average capacity factor in any given month varied from 16.2% to 50.8%.
- The time during which the wind turbines produced less than 10% of their rated capacity totalled 3,165 hours and the time during which the wind turbines produced less than 5% of their rated capacity totalled 1,200 hours
- The output from wind turbines was extremely intermittent with variations by a factor of 10 occurring over very short periods.

Despite the fact that wind turbines only operate at about 30% of rated capacity on average and are exceedingly variable in their output, leading to long periods of very low output, the wind turbine fleet in the UK has increased significantly since 2012, driven entirely by government policy.

On 5 January 2015 renewableUK (the organisation representing the wind industry) headlined "Electricity needs of more than a quarter of UK homes powered by wind in 2014".

They said that official statistics from National Grid showed that record amounts of electricity were generated by wind power in 2014:

- Wind generated enough electricity to supply the needs of more than 6.7 million UK households last year; a 15% increase on the amount generated in 2013 (up from 24.5 terawatt hours to 28.1TWh in 2014) - just over 25% of all UK homes all year round.
- Wind farms feeding into the grid, as well as smaller sites connected to local networks, provided 9.3% of the UK's total electricity supply in 2014, up from 7.8% in 2013.
- Other records were broken in December, with a new monthly high of 14% of all UK electricity generated by wind, beating the previous record of 13% set in December 2013, as well as a new quarterly record of 12% of electricity from wind in the last 3 months of 2014, breaking the previous record of 11% set in Q1 of 2014.

renewableUK continue to state on the Onshore Wind page of their website, "Onshore wind farms reduce CO_2 emissions, provide energy security, and contribute to the local and national economy. " The page also states, "Onshore wind works well in the UK because of the excellent wind resource. It has also become one of the most cost effective forms of renewable energy, providing over 5,000MW of capacity. A modern 2.5MW (commercial scale) turbine, on a reasonable site, will generate 6.5 million units of electricity each year – enough to make 230 million cups of tea."

On 12 January 2015, the renewableUK home page gave figures "Powered by Wind": Energy Produced 29,190,769 MWh, powering the equivalent of 6,963,447 homes and giving CO_2 reductions (pa) of 12,552,031 tonnes.

These are very impressive figures if taken at face value, but what are the facts behind these statements – can we rely on wind turbines to power our homes and offset the annual release of carbon dioxide from conventional coal and gas burning power stations?

My previous report showed that this could only be true if the wind blew constantly but it does not, it blows very intermittently.

I have continued to analyse the output from the UK wind turbine fleet during 2013 and 2014, as measured by the electricity fed into the grid, in order to determine whether more turbines being brought into operation:

- Improves average capacity factors
- Reduces the periods of low or very low output
- Reduces intermittency
- Makes it possible to close any conventional, fossil-fuel power stations by making up for additional demand on the grid at peak times

and, based on the analysis, to conclude whether wind turbines in the UK are making any significant contribution to a reduction in CO_2 emissions.

Installed and Monitored Capacity

The installed capacity of wind turbines in the UK was quoted as 11,978MW by renewableUK on 12 January 2015 (7,936MW onshore and 4,042MW offshore). By comparison, on the same date the NETA (New Electricity Trading Arrangements) website quoted a capacity connected to the grid of 8,403MW, i.e. only 70% of the total installed capacity quoted by renewableUK.

This ratio has not changed over the years – at the end of 2011 the installed capacity of wind turbines in the UK was quoted as 5,772 MW whereas the monitored capacity, i.e. that monitored by the National Grid, was 4,006 MW. The equivalent figures for the end of 2012 were installed 7,777 MW, monitored 5,705 MW.

This analysis uses the NETA data throughout – the capacity connected to and monitored by the grid. From the data on the NETA website, it is not possible to distinguish between onshore or offshore wind generation, or that from different parts of the UK. However, as this report covers the overall generation picture across the UK and does not break it down by region, this is of no consequence.

Data Source and Method of Analysis

The National Grid publishes electricity generation by fuel type data on its NETA website www.bmreports.com. This covers generation from all conventional industrial generators by fuel type, and from a large proportion of the industrial wind generation installations in UK.

This analysis given in this report takes the recorded data from www.bmreports.com at half hourly intervals and this data has been used to plot the monitored output from UK wind turbines over each month of 2013 and 2014 and to analyse the output in various ways.

Do more wind turbines improve average output?

The average monitored capacity in 2011 was 3,340MW and the average output was 1,109.5MW giving a 33.2% capacity factor. In 2012 the equivalent figures were 4,696MW monitored by the grid, with an average output of 1,439.5MW or a capacity factor of 30.7%.

As before(1), the data points for each 30-minute period as monitored by the grid are averaged over the full month and a figure for output as a percentage of monitored power is calculated.

(1) Intermittency of UK Wind Power Generation 2011 and 2012 – Derek Partington

2013	Monitored Capacity (averaged over the month) MW	Average Output (MW)	Average Capacity Factor (%)
January	5,894	2,321.3	39.4%
February	7,168	2,058.0	28.7%
March	7,139	2,146.7	30.1%
April	7,136	2,265.4	31.7%
May	7,136	1,998.8	28.0%
June	7,136	1,449.7	20.3%
July	7,136	975.5	13.7%
August	7,136	1,337.5	18.7%
September	7,136	1,778.4	24.9%
October	7,508	2,629.6	35.0%
November	8,185	2,708.9	33.1%
December	8,185	3,821.0	46.7%
Average 2013	**7,257**	**2,130.4**	**29.4%**

The figures show a significant variation in the average monthly capacity factor. The July average was 13.7% and that of December 46.7%. So even monthly averages vary by a factor of more than 3, a similar figure to that noted for 2011 and 2012.

2014	Monitored Capacity (MW)	Average Output (MW)	Average Capacity Factor (%)
January	8,185	3,444.6	42.1%
February	8,387	4,090.2	48.8%
March	8,403	2,722.0	32.4%
April	8,403	2,045.8	24.3%
May	8,403	1,618.9	19.3%
June	8,403	933.6	11.1%
July	8,403	1,338.2	15.9%
August	8,403	2,311.5	27.5%
September	8,403	1,022.6	12.2%
October	8,403	3,153.9	37.5%
November	8,403	2,514.8	29.9%
December	8,403	3,833.7	45.6%
Average 2014	**8,402**	**2,419.4**	**28.8%**

Again the figures show a significant variation from month to month, the June figure being the lowest at 11.1% and February the highest at 48.8% - an increase in variation from month to month of almost 4.4 to1.

Therefore from the data analysed the answer is “No, more wind turbines do not, on average, improve the average output.” This despite there being 2.5 times increase in the installed (average) capacity from 2011 to 2014.

In fact, month to month variation, even in output averaged over the month, has increased significantly in 2014 compared with the previous three years. If this is to be expected, simply because the installed capacity has increased, then the variation in output may be expected to increase still further as more turbines are added to the Grid, although at this stage we could equally well assume that this is primarily an artifact of the inherent variability of the wind resource.

Do more wind turbines reduce periods of low or very low output?

I have taken low output as being less than 10% of installed capacity and very low output as being less than 5% of installed capacity. Any percentage could have been chosen, but I believe that these are reasonable figures if one is to place any reliance on a sustainable source of supply.

In 2011 there were a total of 485.5 hours, or 20.2 days when output from the total UK wind turbine fleet fell to less than 5% of monitored capacity. The equivalent figures for 2012 were 714.5 hours or 29.8 days.

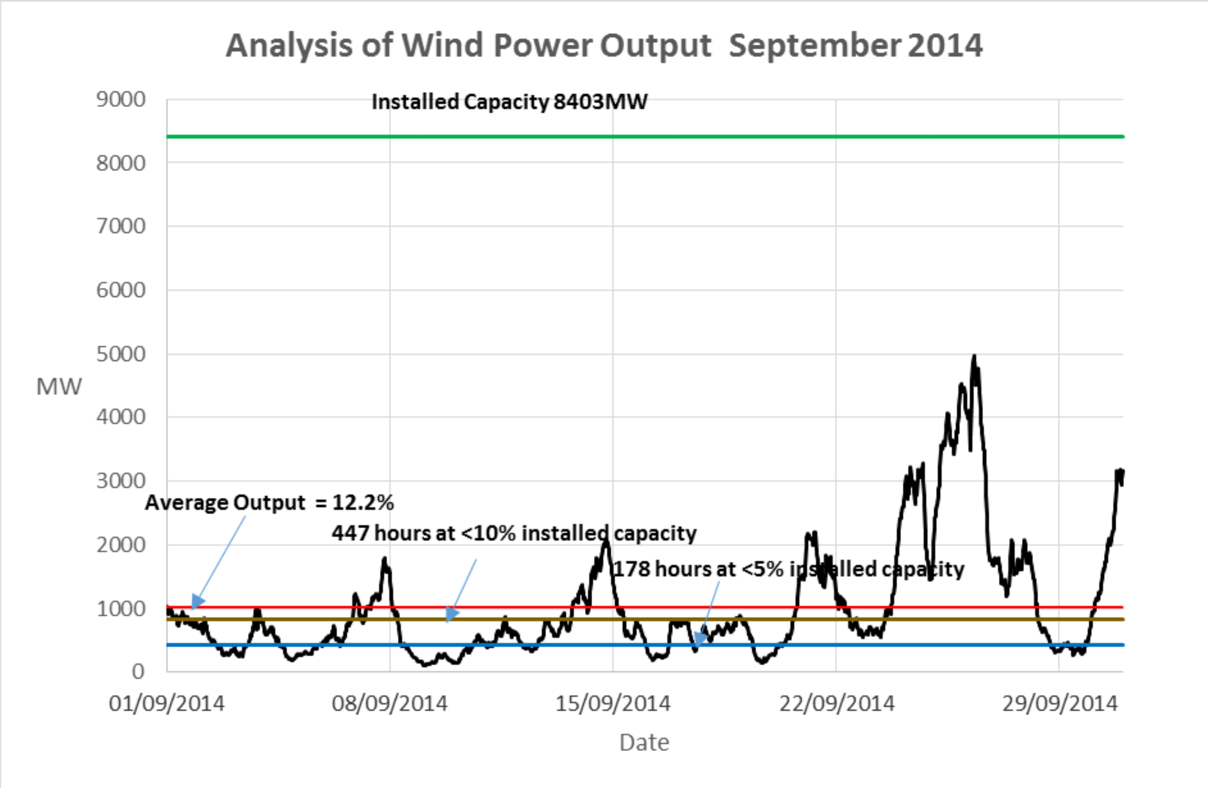
In 2011 there were a total of 1,370 hours, or 57.1 days when output from the total UK wind turbine fleet fell to less than 10% of monitored capacity. The equivalent figures for 2012 were 1795.5 hours or 74.8 days.

The table below gives the same data for 2013 and 2014, i.e. the total hours per month and per year where total output fell to less than 5% and less than 10% of installed capacity.

2013	**Hours Output <5% installed capacity**	**Hours Output <10% installed capacity**	**2014**	**Hours Output <5% installed capacity**	**Hours Output <10% installed capacity**
January	23.0	52.0	January	6.0	23.0
February	48.5	76.0	February	0.0	4.5
March	37.0	113.5	March	22.0	65.5
April	29.5	82.5	April	71.5	138.0
May	35.5	106.0	May	45.5	197.5
June	72.0	226.5	June	139.5	375.5
July	81.5	309.5	July	113.0	278.5
August	80.0	228.0	August	30.0	104.5
September	87.0	183.5	September	178.5	447.0
October	4.0	25.0	October	15.5	58.5
November	10.5	42.0	November	28.0	86.5
December	4.0	19.5	December	9.5	35.0
Total hours	**513**	**1,464**	**Total hours**	**659**	**1,814**
Total days	**21.4**	**61.0**	**Total days**	**27.5**	**75.6**

The data show no significant difference between the 2011 and 2013 periods and the 2012 and 2014 periods.

It can be seen that there are significant deviations from month to month. In the “worst” month, September 2014, the output from the total UK turbine fleet was less than 5% of their installed capacity for almost 25% of the time. In the same month the turbines failed to reach 10% of their capacity for over 62% of the time. The graph for September 2014 is given on the following page.



Over the 2-year period there was a total of 1,172 hours, or 48.8 days, when the output was less than 5% of nominal installed capacity. This compares with 50 days over 2011 and 2012. Looking at where output was less than 10% of installed capacity, for the two year period this was 3,278 hours, or 136.6 days compared with 131.9 days over 2011 and 2012. It should be noted that 136.6 days is well over 4 months in total over the 24 month period.

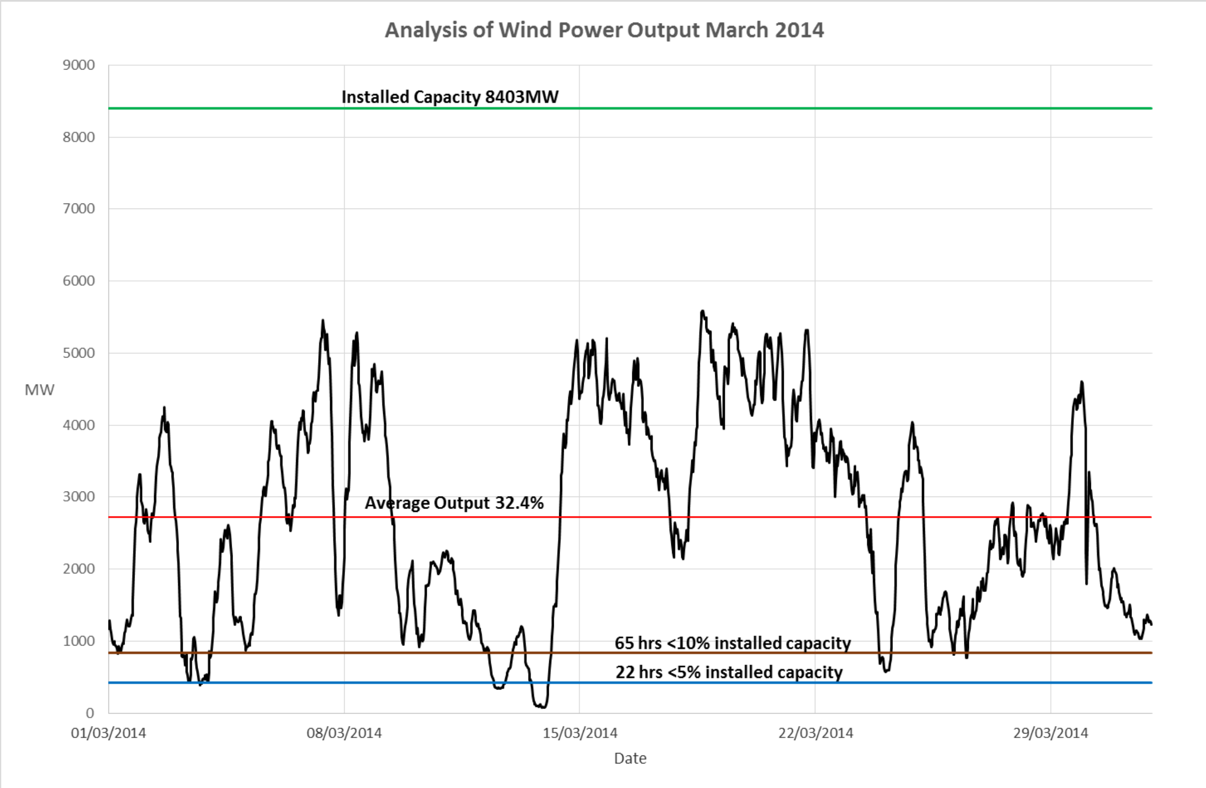
Therefore from the data analysed the answer is “No, more wind turbines do not reduce periods of low or very low output”. (Note: low output is a function of natural variation in the strength of the wind – which, of course, is not influenced by having more wind turbines).

Do more wind turbines reduce intermittency?

The Oxford English Dictionary defines intermittent as “occurring at irregular intervals; not continuous or steady”. It is obvious that wind in the UK intermittent. It is not steady – sometimes the wind blows strongly, sometimes weakly and sometimes not at all. But here we are not concerned with the strength of the wind but its effect on the output of the UK wind turbine fleet.

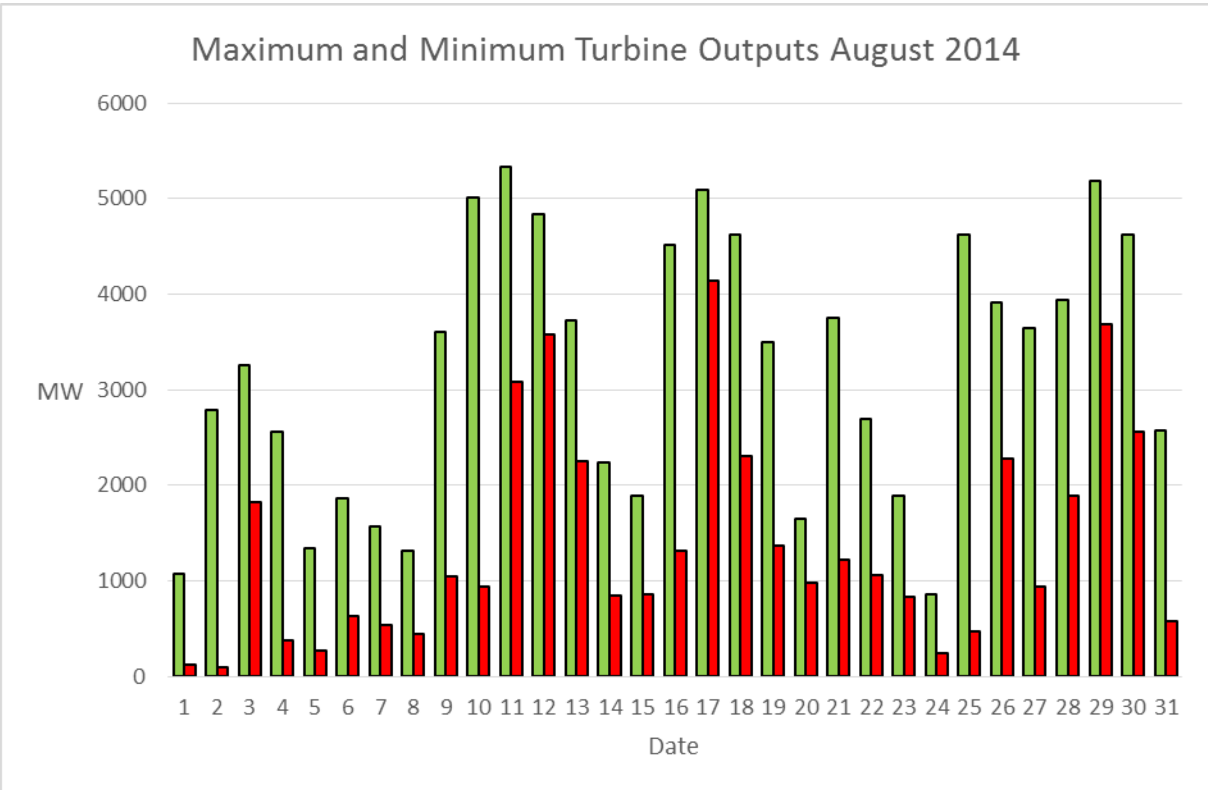
To demonstrate the intermittency I have plotted the total UK wind turbine output for every month over the 24 months studied. The graph on the following page shows data from a typical month, from March 2014.

It can be seen that during March 2014, the wind was always blowing somewhere in the UK as the output from all the wind turbines feeding the National Grid never fell to zero. However, the output varied dramatically from day to day, with a minimum output of 75MW and a maximum of 5,582MW – a variation of almost 75-fold.



This graph is quite typical and detailed graphs, with additional data, are given for each of the 24 months analysed in the appendix.

Intermittency can also be presented as daily minima and maxima in any month as shown in the bar chart below for August 2014. This is again a typical month where the average capacity factor was 27.5%.



On a single day, 2nd August, the variation from minimum to maximum is almost 30-fold.

The following table gives the minimum output during each month over the 2 years for which the data was analysed.

2013	Minimum Output MW	As % of capacity	2014	Minimum Output MW	As % of capacity
January	188	3.2%	January	221	2.7%
February	26	0.4%	February	706	8.4%
March	32	0.4%	March	75	0.9%
April	81	1.1%	April	63	0.7%
May	113	1.6%	May	52	0.6%
June	22	0.3%	June	84	1.0%
July	123	1.7%	July	46	0.5%
August	31	0.4%	August	96	1.1%
September	69	1.0%	September	109	1.3%
October	309	4.1%	October	223	2.7%
November	296	3.6%	November	240	2.9%
December	294	3.6%	December	178	2.1%
Average	**132**	**1.8%**	**Average**	**174**	**2.1%**

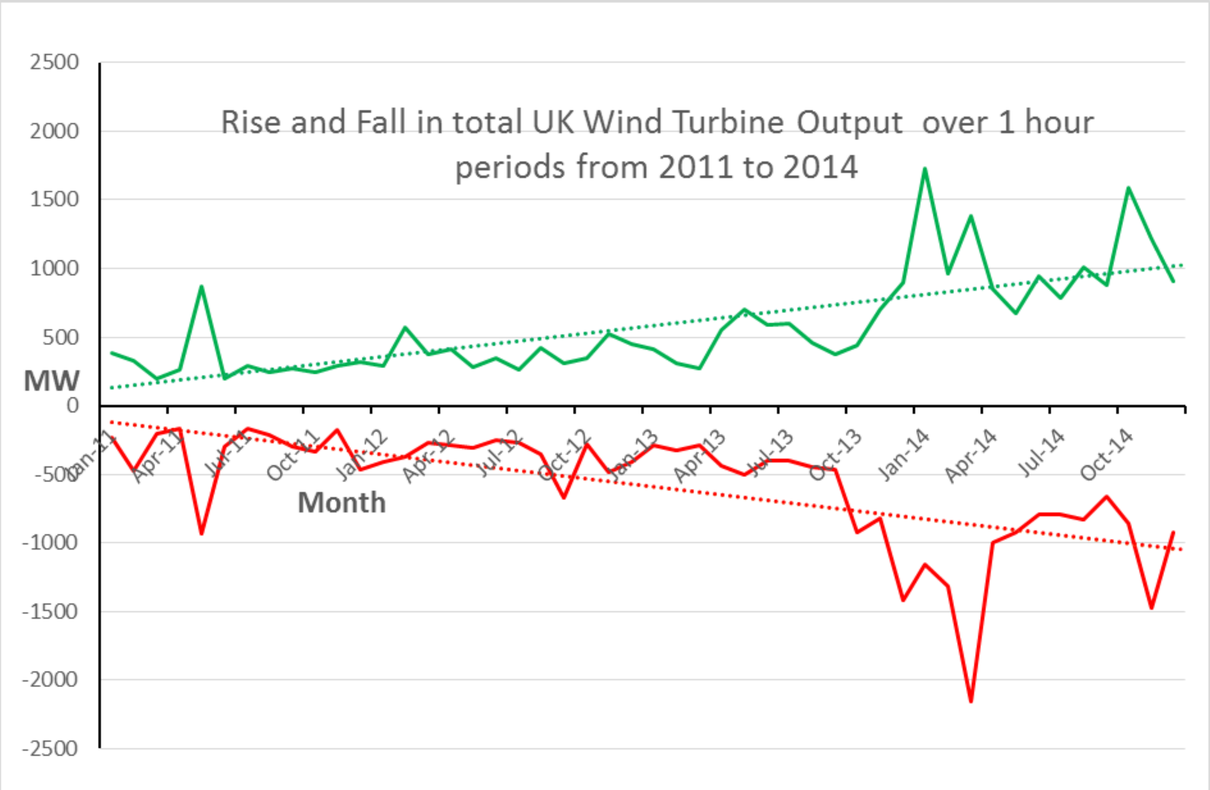
Therefore the assumption that the wind is always blowing somewhere in the UK may be true, but at times it is barely blowing enough to generate any significant energy. In 10 out of the 24 months monitored, the minimum output dropped to 1% of capacity or less at some time. It should also be noted that the minimum output levels have not significantly changed since 2011, even with more wind turbines being installed. The equivalent average minima for 2011 and 2012 were 2.1% and 1.5% respectively.

An alternative method of measuring intermittency is to look at how much output rises or falls over a given period, for example taking the maximum rise and fall over one hour in any given month.

Maximum change in output (MW) in any one hour								
	Rise (MW/hr)				**Fall (MW/hr)**			
Year	**2011**	**2012**	**2013**	**2014**	**2011**	**2012**	**2013**	**2014**
January	385	287	410	1,727	-236	-413	-288	-1,156
February	330	568	306	966	-475	-369	-323	-1,315
March	195	374	276	1,384	-207	-270	-286	-2,153
April	266	412	556	850	-169	-286	-434	-998
May	873	279	703	673	-937	-304	-501	-919
June	198	350	586	940	-300	-248	-403	-793
July	289	260	601	786	-168	-274	-396	-795
August	246	419	462	1,005	-213	-353	-447	-828
September	272	310	377	880	-302	-674	-468	-665
October	242	343	442	1,590	-333	-275	-925	-859
November	288	523	701	1,212	-179	-480	-821	-1,478
December	314	445	900	909	-463	-412	-1415	-926
Average MW/hr	**325**	**381**	**527**	**1,077**	**-332**	**-363**	**-559**	**-1,074**

As can be seen the maximum rise and fall has increased significantly as operational capacity has increased. This is the variation which the grid has to cope with, bringing in conventional fossil fuelled stations when output falls and taking them off line when it rises.

The above data can be plotted to give a trend showing the year on year increase.



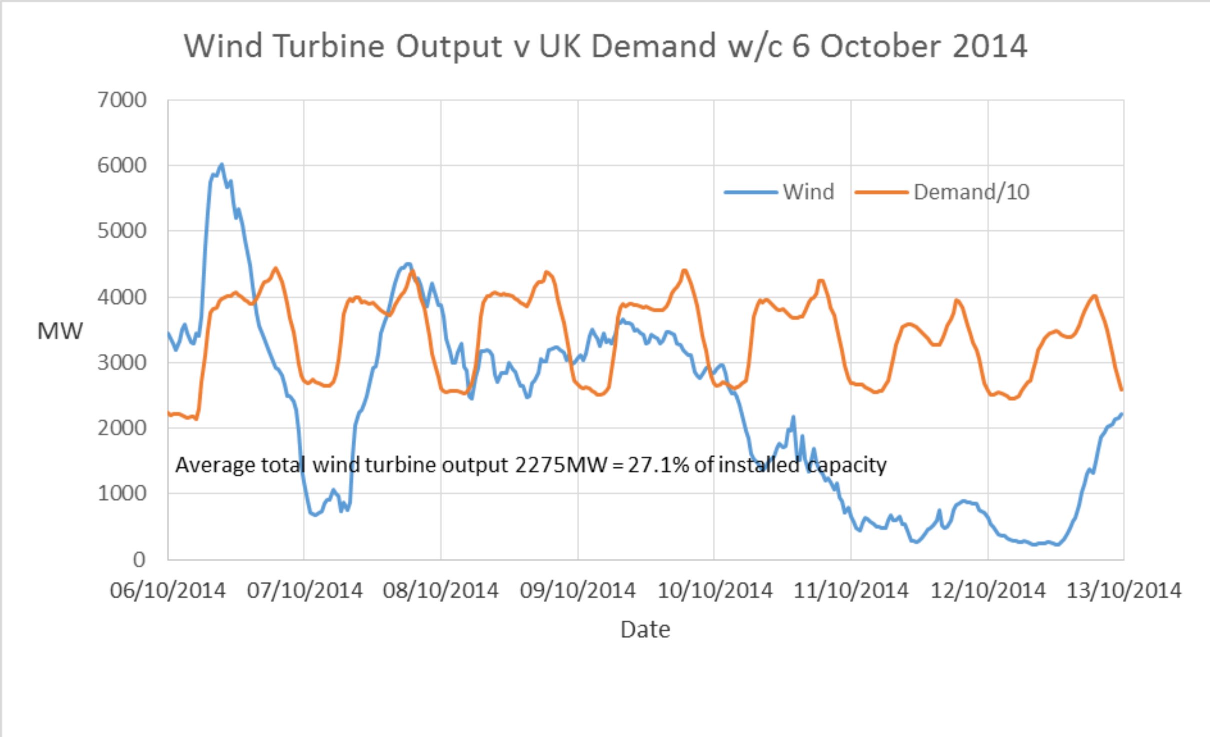
It can be seen that The National Grid is now having to cope with variations in output (intermittency) of over 1,100MW over one hour periods. It can also be seen that this variation is increasing by about 250MW per year. It should also be noted that 1,100MW is 13% of the installed capacity and is over 40% of the average monthly output in 2014. The peak fall over one hour was 2,153MW in March 2014, a figure which is likely to be exceeded as more turbines are connected to the grid.

Therefore, from the data analysed the answer is “No, more wind turbines do not reduce intermittency. In fact using two alternative measures, minimum output during the month and variation in output over 1 hour, then more turbines increase the impact of intermittency”.

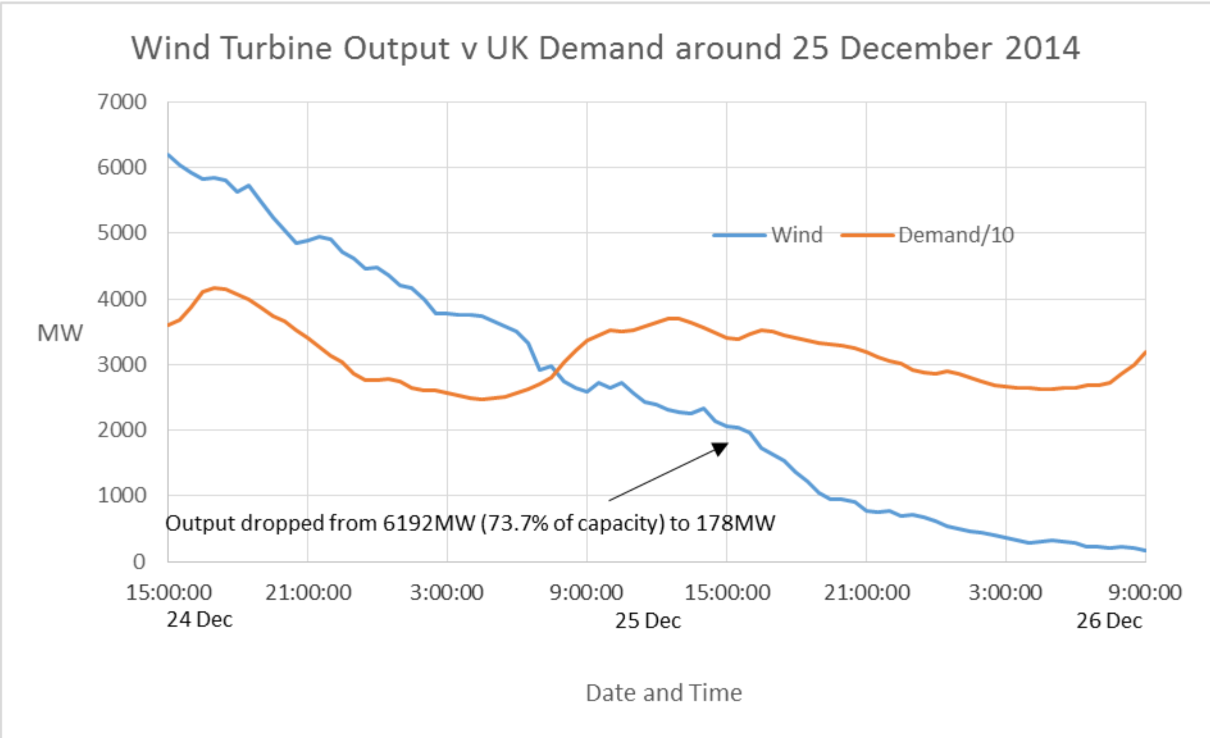
Do more wind turbines make it possible to close any conventional, fossil-fuel power stations by making up for additional demand on the grid on peak times?

If the variation in output matched the increase or decrease in demand on the grid, then there would be no need for back-up in the form of conventional, fossil-fuel power stations. In order to see if output from wind turbines in any way matches demand, the total output has been plotted against demand on the grid over the last seven months of 2014. In order to fit the graphs on the same scale, UK wind turbine output has been plotted alongside grid demand divided by ten.

A typical week, from October 2014, is shown below. As expected, there is no correlation between output and demand. The output varied over the week from a high of 6,000MW on 6 October to a low of 200MW on 12 October with no form of repetitive pattern in between.



The graph above does shows a pattern on some days where output from wind turbines falls as demand rises and vice versa, which is not atypical. In fact over Christmas Day 2014, if wind were relied on to cook the turkey, then there would have been a public outcry as output dropped steadily from over 6,000MW on Christmas Eve to under 200MW on Boxing Day.



Therefore, from the data analysed the answer is “No, more wind turbines do not make it possible to close any conventional fossil fuel power stations”.

Discussion

In this report I have carried out a more detailed analysis of the data for 2013 and 2014 available from the NETA website compared with my previous report covering 2011 and 2012.

I had expected that as more turbines were connected to the grid that this might have some smoothing effect on the overall output, even if that effect were not greatly significant. However, this has not been the case.

Taking my four criteria for the justification, or otherwise, for a continued increase in the number of wind turbines connected to the Grid:

1 Do more wind turbines improve average output? No.

Average capacity factor fell over the period studied compared with the previous two years, whilst the variation in average capacity factor from month to month, as measured by highest average to lowest average, increased. This is shown in the table below.

Year	2011	2012	2013	2014
Average Monthly CF %	33.2	30.7	29.4	28.8
Variation in average monthly output (highest to lowest)	3.1x	2.7x	3.4x	4.4x

2 Do more wind turbines reduce the periods of low or very low output? No.

There is no trend in periods of low (less than 10% of installed capacity) or very low (less than 5% of installed capacity) output over the periods 2011-2012 and 2013-2014.

Year	2011	2012	2013	2014
Number of hours/year when output is <10% of installed capacity	1370	1795	1464	1814
Number of hours/year when output is <5% of installed capacity	485	714	513	659

3 Do more wind turbines reduce intermittency? No.

Using the data analysed in this report and comparing it to that in my previous report shows no significant change in the average monthly minimum expressed as a percentage of installed capacity.

Year	2011	2012	2013	2014
Average yearly minimum as percentage of installed capacity	2.1	1.5	1.8	2.1

Retrospective analysis of the data for 2011 and 2012 has allowed the maximum rise and fall in output over one hour period to be assessed for each month. These are plotted in the report and smoothing out peaks and troughs gives a trend increasing by about 250MW per year to a figure of over 1,000MW/hour on trend by the end of 2014. A fall of over

2,000MW/hour was observed in March 2014. These figures are very significant as they represent the changes in output which the Grid has to cope with and which has to be compensated by conventional fossil fuelled power stations.

4 Do more wind turbines make it possible to close any conventional, fossil-fuel power stations by making up for additional demand on the grid on peak times? No.

As expected, analysis shows that there is no correlation between variations in output from wind turbines and demand on the Grid. Often the opposite is true - when demand rises, output from wind turbines falls and vice versa. This has a significant negative effect as back-up has to be provided from conventional, fossil-fuel power stations not only to cater for increase in demand on the Grid at peak times but also to cover for any possible fall in output from the UK wind turbine fleet at the same time. (It is understood that fossil-fuel generators being run in stop-start mode to provide this back up are very inefficient and may be producing significant additional carbon dioxide than when operating in their designed steady state.)

So, taking some of the renewableUK statements:

- "Electricity needs of more than a quarter of UK homes powered by wind in 2014" – should this be "Electricity needs of more than a quarter of UK homes powered by wind in 2014 some of the time"?
- "Wind farms feeding into the grid…provided 9.3% of the UK's total electricity supply in 2014" – should this read "Wind farms feeding into the grid…provided 9.3% of the UK's total electricity supply in 2014 when averaged over the year"
- "Other records were broken in December, with a new monthly high of 14% of all UK electricity generated by wind" – should this be counterbalanced by "but in June 2014 electricity generated by wind was only one quarter of this figure".
- "Onshore wind farms reduce CO_2 emissions, provide energy security….". Taking the analysis in this report, and the previous one, there is no basis for this statement. There is patently a need to provide back-up for wind turbines which are feeding into the Grid and therefore CO_2 emissions may possibly be increased rather than decreased as conventional, fossil-fuel power stations have to be operated inefficiently in order to provide this back up. Similarly there is no energy security if output can fall from over 6,000MW to under 200MW over a 42 hour period as it did over Christmas 2014.

Based on the above, I would like to see evidence that any conventional power station has been able to be closed down as a result of the introduction of over 8,000MW of wind turbine capacity feeding into the National Grid. Similarly I would like to see evidence of reductions in CO_2 emissions through the introduction of wind turbines where a holistic approach to meeting the demand on the Grid is taken into consideration.

Conclusions

Over the period studied, January 2013 to December 2014 inclusive, wind turbine operational capacity connected to the UK Grid has increased from 5,894MW to 8,403MW. The operational capacity in January 2011 was 2,490MW; therefore there has been an increase of almost 3.4x over the four year period.

The conclusions to be drawn from the data analysis are:

- An increase in the operational capacity does not improve average output. In fact the average monthly capacity factor has fallen over the periods studied, dropping from 33.2% in 2011 to 28.8% in 2014.

- An increase in the operational capacity does not reduce the periods of low or very low output as measured by the number of hours per year when output was low (less than 10% of installed capacity) or very low (less than 5% of installed capacity). There is a variation from year to year but no pattern emerges. The mean low output over the four years was 1,617 hours/year with a standard deviation of 197 hours/year and the mean very low output was 599 hours with a standard deviation of 96 hours.

- An increase in the operational capacity does not reduce intermittency. If taken as a measure of intermittency, the average monthly minimum expressed as a percentage of installed capacity was 1.9% with no significant variation from year to year.

- Taking maximum rise and fall in output over one hour period as a further measure of intermittency, the National Grid is now having to cope with variations in output of over 1,100MW over one hour periods, with this variation increasing by about 250MW per year. This is very significant as it represents the changes in output which the Grid has to cope with and which has to be compensated by conventional fossil fuelled power stations.

- An increase in the operational capacity does not indicate any possibility of closing any conventional, fossil-fuel power stations as there is no correlation between variations in output from wind turbines and demand on the Grid. Often the opposite is true - when demand rises, output from wind turbines falls and vice versa. This has a significant negative effect as back-up has to be provided from conventional, fossil-fuel power stations not only to cater for increase in demand on the Grid at peak times but also to cover for any possible fall in output from the UK wind turbine fleet at the same time.

Therefore, taking the four criteria above, there is no case for a continued increase in the number of wind turbines connected to the Grid.

As stated in my previous report, it is incumbent upon the Government to ensure that the British consumer is getting value for money from industrial wind turbine installations and that they are not just paying subsidies to developers and operators (through ROCs) whilst getting nothing back in return in terms of CO_2 emission reductions through the supplanting of fossil-fuelled power generation.

Based on the results of this and my previous analysis I cannot see why any policy for the continued increase in the number of wind turbines connected to the Grid can be justified.

About the Author

Derek Partington has a degree in Physics. He was formerly a Chartered Engineer and a member of both the Institute of Physics and the Institute of Measurement and Control.
He worked for British Steel for 30 years and Local Government for 10 years, in both cases as a Project Manager and Business Analyst.
He has been undertaking research into wind turbines for over 6 years.