A Claverton Paper

Wind and Nuclear and the Cycling of Fossil Fuel Plants

A View from 2018

Fred Starr PhD, FIMMM, MIMech, C.Eng

Abstract

The growth of wind energy in Europe and elsewhere is now giving us a clearer view of how it will impact on fossil fuel plants, which in most countries are needed as back up. But back up duties for steam and CCGT(Closed Cycle Gas Turbine) plants are not new. In recent times, fossil was back up to nuclear power, increasing the two shift requirement. This was becoming less of an issue as nuclear plants were taken out of service and not replaced. Now, the focus of back up is coping with wind.

Two shift operation can be scheduled, but wind power varies. It is worse than any other renewable resource**. Long distance networks relying on wind will not remove the back up requirement.** A hypothetical, but feasible situation involving 46GW of wind capacity spread between Spain, Britain and Ireland, suggests that even this very long distance network, wind power would need almost 100% back up for a significant portion of the time.

German experience shows that their nuclear has been operated in a load following mode. Hence, in principle, new-build nuclear could capture much of the two-shift load. This would have severe implications for fossil plant, which in extreme cases would then be solely restricted to wind back up. Some fossil plant would be off for days at a time.

British data indicates that the average rate of increase of wind power per hour is one tenth of the day time peak. Modern coal fired plants are claimed to be able to run at very low loads and would in principle be suitable for back up. The main questions would be thermal fatigue and economics. British experience with CCGTs suggest that they would be even better for back up, although they may not be so good at maintaining grid frequency.

1. Introduction and Preamble

The author has had a keen professional interest in the issue of the cycling and two shifting of power plants since 2001 when he helped organise one of the first conferences on this subject. But his concern originated in 1966, when working in British Gas on steam reforming plants. This were an oil refinery type process in which vaporised naphtha and steam, at pressure, were passed through spun cast stainless tubes containing a catalyst to produce gas. Tube wall temperatures were around 850°C, so that there was concern about thermal fatigue during start ups and load changes.

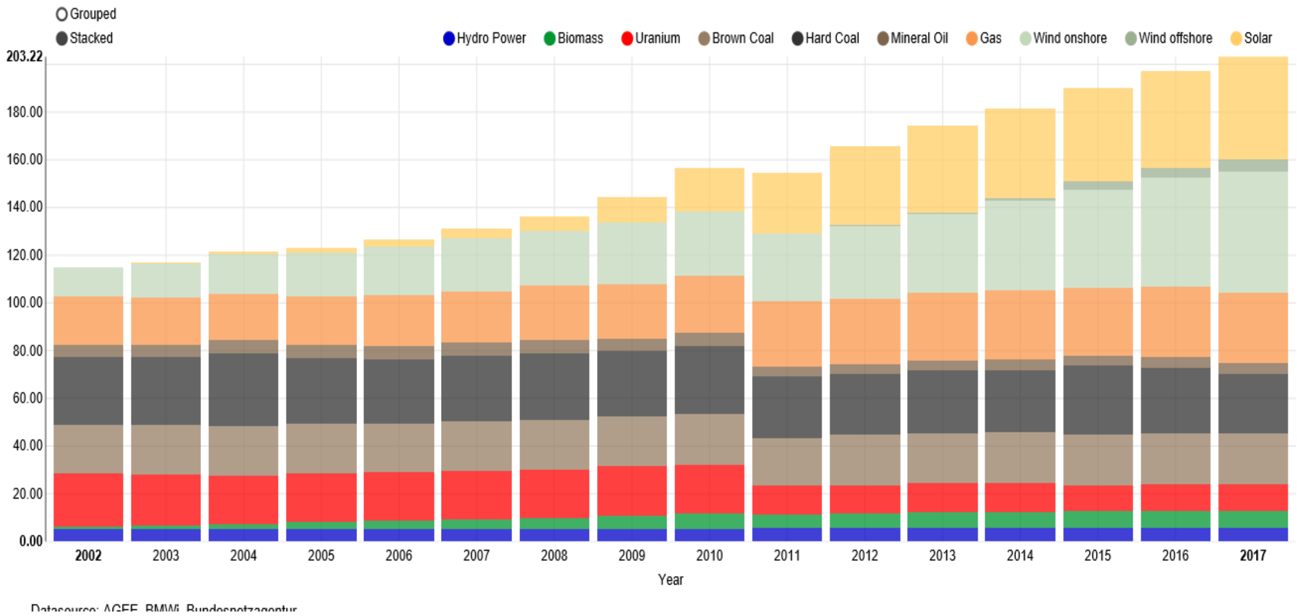
2. Changes in Fuel Use and Impact on Plant Cycling

Back in 2001 there was great interest in of plant cycling in many countries. In the USA the issue came to the fore because of the introduction of CCGTs. These began to compete with steam, where operators demanded at least as much flexibility from CCGTs as with the more standard form of power generation. In turn steam plants were compromised, since the perception, by accountants, was that CCGTs should be taking the base load, as they were more efficient. Accordingly even newer steam plants had to cycle.

In Britain a similar scenario was developing. The last coal fired plant built in this country was Drax, and since then, apart from Sizewell B, a PWR nuclear unit, every new plant has been a CCGT. Furthermore, in 1998, output from nuclear plants peaked at 91.2 TWh, almost 28% of the electricity generated. It is not surprising, given that nuclear provided base load power, that two shifting was becoming a serious issue for the then relatively inexperienced operators of CCGTs, as well as those running steam plants, who were more familiar with the problems. Because of this ETD Ltd were contracted to investigate the maintenance and costs issues associated with two shifting, and produced two major reports on this subject [1,2]. At the suggestion of EPRI, a conference was organised on this subject in 2001 [3,4].

Several years later, at the HIDA Conference in 2008, I reported that nuclear output in Britain had fallen to just 13% and concern about two shifting was not what it once was [5]. This proportion was unusually low, as nuclear was going through one of its periodic bouts of unreliability. It has since recovered, and last year supplied about 18% of British demand. This figure should stabilise until about 2020, which is just two years away. However, although at the present moment, nuclear capacity is claimed to be in the 10-11 GW range, at the time of writing it is down to around 7 GW.

Figure 1: Changes in Generating Capacity in Germany 2002-2017



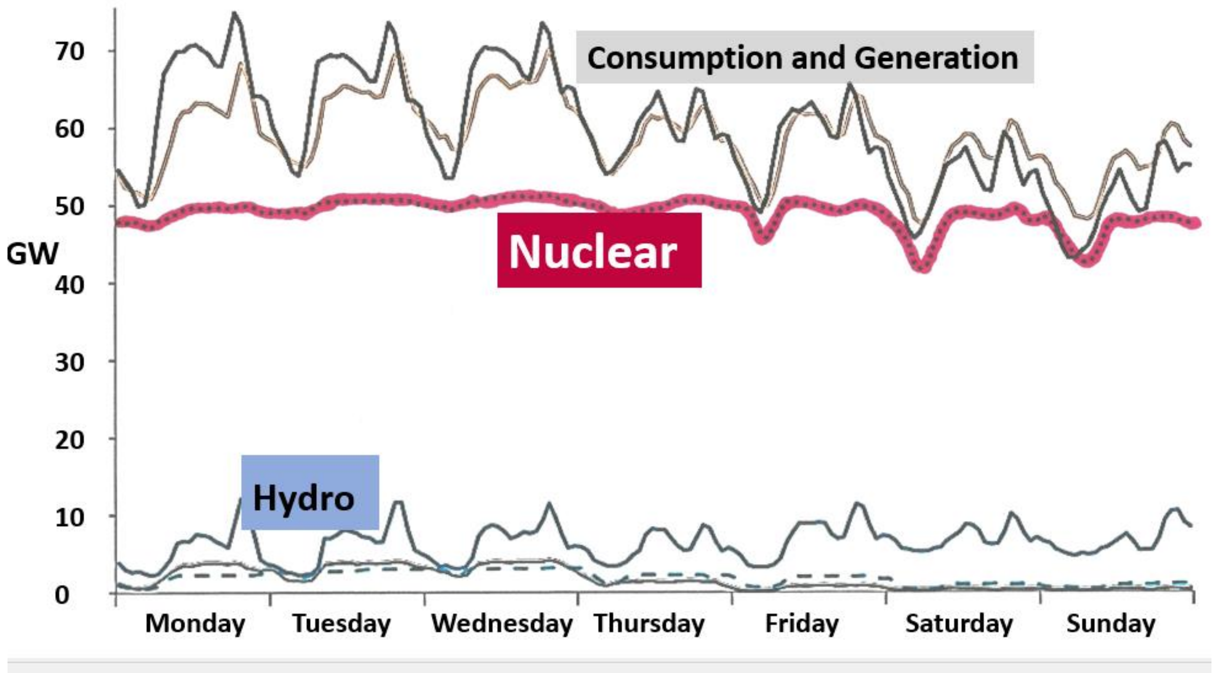
The nuclear situation in Germany is not dissimilar. In 2011 a number of nuclear plants had to be retired, capacity falling from 21.5 GW to 12.1 GW [6]. Figure 1 shows the change in plant mix since 2002. Nevertheless, although nuclear only represents about 7% of installed capacity. It does appear to be a highly reliable form of generation, with a load factor of 86%. It punches far above its weight in comparison to some other sources. Lignite and biomass fired steam plant come close, at respectively, 76% and 74%. Coal fired units only run at 41% of capacity, suggesting that they are being used for two shifting and winter time use. The load factor of CCGTs is quite poor at under 13%, and are even worse than wind, which averages 15%. PV is lowest at about 11%.

3. Feasibility of Nuclear Plant Cycling

Although it is not something which is welcomed by the nuclear sector, designers and operators are also having to consider the need for cycling, although the emphasis seems to be to meet the changes in demand rather than to cope with the vagaries of wind or solar energy

In 2011, the OECD issued an excellent report on nuclear plant cycling, although, as will be seen, some German authors would regard its conclusions as being over-conservative [7]. At the time the report was being written, a limited number of PWRs in France were being turned down to about 25% of design load, although the 50-70% range was more common. However, this was a pre-planned schedule. Plant turndowns fitted in with what was the forecast daily and weekly French demand. Turn downs also depended on how much power was being exported at night to other countries, or being used for pumped storage. The situation in Germany seems to have been somewhat similar.

Figure 2: French Electricity Generation and Consumption Over a Typical Week



Accordingly, as Figure 2 shows although there is some variation in output from the French nuclear fleet, it is only really noticeable at the weekends. The night to day variation in demand is met largely from hydro and also by import and export of power. Note that there is a distinct difference between what the French electricity industry generates and what is actually used in France. The lowest lines in the graph refer to fossil plants which play a very minor part in generating electricity.

Reactor output is modified by actuation of the control rods. Additions of boric acid are also used to control reactivity, as this element absorb neutrons, with high concentrations being used when a new set of fuel rods are installed. Up to the mid-life of the reactor bundle it is possible to change the output on a daily basis, by altering the boric acid levels. But both techniques, control rods, and boric acid, need to be used judiciously. Although withdrawal or insertion of control rods can be done instantaneously, this can distort the thermal output of the core, leading to local overheating and fuel can problems. Diurnal changes in boric acid will add to level of radioactive waste. One estimate puts this extra load at about 12 tons a year from a 300 MW reactor.

Xenon-135 poisoning, which is a feature of nuclear plant operation, is generally assumed to preclude reactors operating in a genuine two shift mode, that is, being shut down at night and restarted in the morning. The isotope is short lived and is continually generated during normal operation of the reactor, absorbing neutrons. When running at baseload, a high but equilibrium level builds up. When the power is reduced, and the neutron flux falls, there comes a point, when the xenon will be capturing so many neutrons, that the chain reaction ceases, and the reactor shuts down. If this were to happen, it would takes some days before the reactor could be re-started.

The OECD report also examined the impact of running at lower loads on electricity costs. Not surprisingly there was an impact. At a 5% discount rate, when the average power output falls to 60% of design, the cost per kWh would increase by a half. The figures are broadly in line with USA estimates, given in the same report. The increased was from 50 to 74 USD/MWh over the same range of outputs.

In contrast to the OECD report, Ludwig et al take a much more robust view of what nuclear plant cycling has been and could be, basing their claims on experience in Germany [8}. It appears that when the German plants were designed the power companies insisted on an ability to load follow, thereby enabling nuclear to meet the day-to-night swings in demand. Pressure vessel components, etc were to have an adequate fatigue life. Accordingly, a number of nuclear plants have operated in a load following mode, in contrast to what goes on in other countries.

In Germany load changes on the PWR are made by actuation of a special set of control rods, although there are some indications that boric acid may also be utilised. With BWRs the ability to change output comes from an inherent characteristic of the boiling water reactor whereby the fission rate depends on the density of the cooling water. Accordingly, the power output can be regulated by speeding up the flow rate, something which is easily done by increasing pump speed.

Various assertions are made by Ludwig et al about what, in principle, might be achievable. For example it is claimed that ramp rates of 5% per minute are possible. It is also stated that if no electricity is required from a nuclear plant, it might run indefinitely in this state by using its power to keep plant ancillaries operating. Hence when power is needed by the grid, the plant would be able to respond immediately. Frankly, I would doubt whether the Regulatory Authorities would permit a nuclear plant to operate in this fashion

So, in summarising the position, a more conservative approach is taken by the authors, largely based on the original specification. If this practice was adopted, I too agree that it will be adequate in compensating for wind. Minimum output would be about 50%, with a ramp rate of 2% per minute.

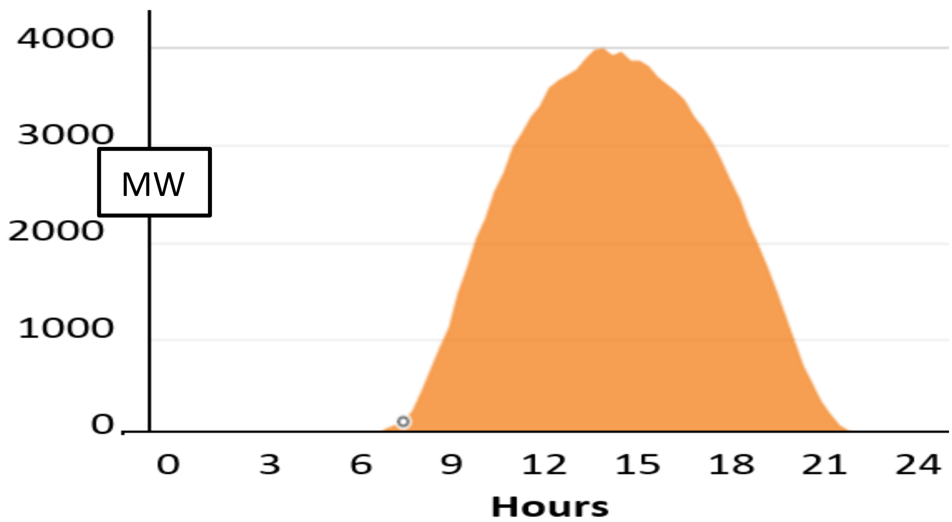
Despite these encouraging views by the Germans, it is conceded that some modifications and changes to operating practices would be required. A vital feature would be the provision of new instrumentation to allow operating staff to keep the heat flux in reactor core within limits. The ability to alter flow rates would probably require new valves and pumps. Some concern is expressed about differential expansion between fuel pellets and the Zircaloy cladding, leading to what might be best described as thermal/corrosion fatigue. The authors suggest a preliminary conditioning treatment at an elevated power loading may be advisable, when a new change of fissile material is installed. However, despite more frequent cycling, pressure vessel life would still, it is claimed, be more than adequate, although more NDT would be required.

In my view, despite these optimistic claims, nuclear would never be used to compensate for the vagaries of wind. What nuclear could do is to “capture” much of the normal day-to-night load following market. If this were to happen, steam and CCGT plants would be left to coping with wind. This would be a duty that would not be suitable for advanced coal fired plants, which are burdened with high capital costs and long start up times.

4. Photovoltaic Solar

PV solar is having a real impact, but it is much more forecastable than wind. Solar is never generated during the middle of the night, when power demands are at their lowest. Wind power, at these times, can be an embarrassment. In Northern Europe, as well as the days becoming shorter, at any time between November and March, solar power can disappear owing to heavy cloud, fog, frost or snow. Even when the weather is sunny, in the winter months, solar will be useless at meeting the evening peak. But for many countries solar will be present to some extent, in day time, all the year round. Furthermore, irregularities in output from individual PV arrays caused by clouds passing over the sun, are evened out on a national scale. As Figure 3 shows the curve of solar output is remarkably smooth. What can happen as a weather system moves in, solar production will be better during one half of the day than the other.

Figure 3: Typical French Solar Output for an Average September Day in 2015



It follows that the impact of solar power will be to modify the demand curve, removing the need for power from other sources, during the middle of the day. In some cases, and at certain times of the year, this might result in an apparent increase in the morning and evening peaks, compared to the demand over a 24 hour period. In a sense solar PV power is schedulable, and is far easier to deal with than wind.

5. The Increasing Impact of Wind Energy

In most of Europe, nuclear capacity is being wound down as plants are reaching the end of their lives. Even in France the plan is to switch over to 50% renewables, the country already having about 9GW of wind and 5GW of solar. The reduction in nuclear capacity, within Europe, should make it easier for fossil plants, as there will be less need for two shifting. But any benefit will be far outweighed by the impact of wind energy, it give a cycling problem of an entirely different magnitude. The critical issue is the unpredictability of wind, a feature which tends to be downplayed by its protagonists.

6. Backing up Wind Energy : An Objective View

Back in 2010, I suggested that when wind farm capacity reached about 15% of the total, special measures would be needed to cope with the fluctuations of wind power. Figure 4 taken from my HIDA conference presentation of that date, summarises the situation. On the Continent the European wide grid had been created to even out differences in supply and demand between one country and another. The most visible outcome is that Continental grid frequency stays remarkably close to 50Hz. As a by-product the hope was that this could be used to smooth out wind power variations. In practice weather systems are often Continent -wide, and wind power has proved an issue.

Fig 4: Wind Power in Some European Countries in 2009

Country	Wind Capacity (Proportion)	Other Generation	Comments
Denmark	**3.5GW (25%)**	**Centralised CHP**	**Import / Export essential to wind**
Spain	**20GW (20%)**	**Hydro, Coal, CCGT, Nuclear**	**Hydro used as backup**
Germany	**25GW (20%)**	**Coal, Nuclear, Hydro, CCGT, CHP**	**Export / Import is feature of German power supply**
Ireland	**1.5 GW (20%)**	**Coal, CCGT, Oil**	**Island network, poor external connections**
Britain	**4GW (5%)**	**CCGTs, Coal, Nuclear**	**Island, network, very poor external connections**

Nothing too serious has occurred so far, although there have been fluctuations in grid frequency. But a pessimistic view is that we have “not seen, nothing yet” and a wind power grows the Continent as a whole will experience the kind of issues now being faced by Ireland

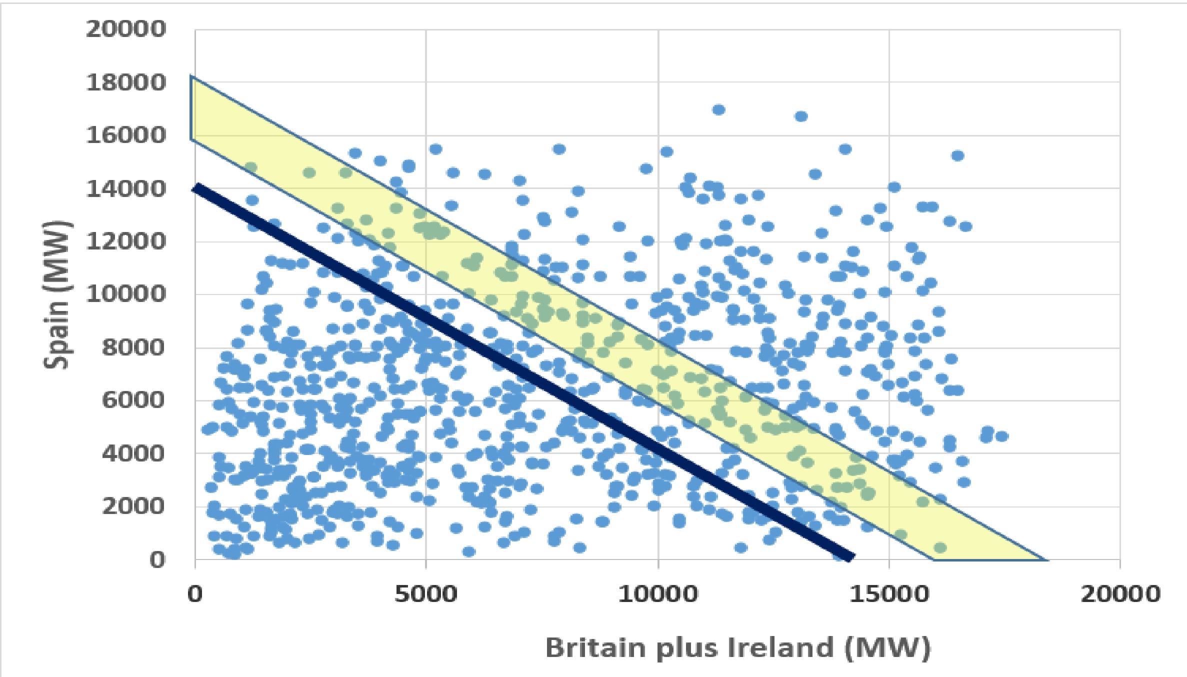
This country given its size and isolation, has had special problems, putting some strain on fossil plants. As such the Regulator has sought advice on the costs of coping with wind from, inter alia, European Technology Development. Britain is in a similar situation, with the problem growing. In 2010 wind capacity was in the region of 4GW. At the time of writing this paper, September 2015, it has reached about 13 GW, and will be starting to have an impact.

The actual drop in wind power during anticyclones is quite startling, with falls to just a few percent of capacity. On 5th April 2015, In Britain, grid connected wind fell to 92 MW from a capacity of 8403 MW. In Spain it dropped to 149 MW out of 23000 MW on 5th Sept 2014. And in Denmark, whose wind farms are concentrated into a relatively small area, the 24th March 2015 was a very bad day, resulting in just 22 MW coming from 4000 MW of capacity. In short, wind power can drop to around 1% of capacity very rapidly.

It has been asserted that longer distance connections would even out the supply of wind power. But this only seems possible over enormous distances, taking the grid network well outside the confines of the European Union to places where population densities are low.

In support of this contention, the author has been logging the instantaneous wind outputs from a number of EU countries on a twice daily basis for the past seven years. Hence it is possible to see whether sharing wind power between distant parts of the EU is a solution to the vagaries of wind. To make the argument more realistic, we need to suppose that we had two separate sets of wind farms of a similar capacity in parts of Europe which are a long way from each other. Given what some Governments are saying this is not an unrealistic supposition.

Figure 3 : Instantaneous Power Output from Spanish Wind Farms and that from a British/Irish Combination



For example Spain presently has over 22700 MW of wind capacity. Eire has about 2200 MW, and, in Britain, there is about 8400 MW connected to the National Grid network. Furthermore, there have been some blue-sky plans about building extra capacity in Eire by Britain, for supply to Britain. This could help Britain reach its target of 20 GW of wind by 2020.

Let us suppose that enough capacity were constructed in Britain and Eire to equal the 23000 MW Spain has already. Then let us suppose that direct current links are built between Spain and the UK/Eire Combination. Such interconnections are not cheap. The recent link between the Netherlands and East Coast of England is reputed to have cost about 600 million Euros and only delvers 1GW. This corresponds to a cost of about 600 €/kW. One might expect a link between Spain and Britain to cost at least twice as much, given that the link will have to take a somewhat indirect route to keep to the Continental shelf and avoid France. One can envisage an interconnection cost in excess of 20 billion euros.

Discounting the cost, do we have evidence that, on average, when the wind blows strongly in Spain, this north western area of Europe is becalmed, and vice versa? The Back Up Interconnection Graph shown Figure 3 suggests not. Each dot, of which there are over 900, represents the wind power being generated by British/Eire combination at the same time as that being generated in Spain. Ideally each dot should all lie within the downwards sloping band, which is about 2GW wide with the total power of the combination (i.e x+y axis) being between 16 to 18 GW. Clearly this is not the case.

Also note that there is a concentration of points in the left hand corner of the graph. This implies that despite the separation of wind farms there will be many times when wind power in both areas of Europe is at a low level. At these times significant back up from other sources is needed. In Spain, the back up is met, to some extent, using hydropower, but in Britain and Ireland the only realistic supply is from fossil fuel plants.

Fig 4: Pareto Plot of Instantaneous Output from a Spain plus British/Ireland Combination of 46MW Capacity

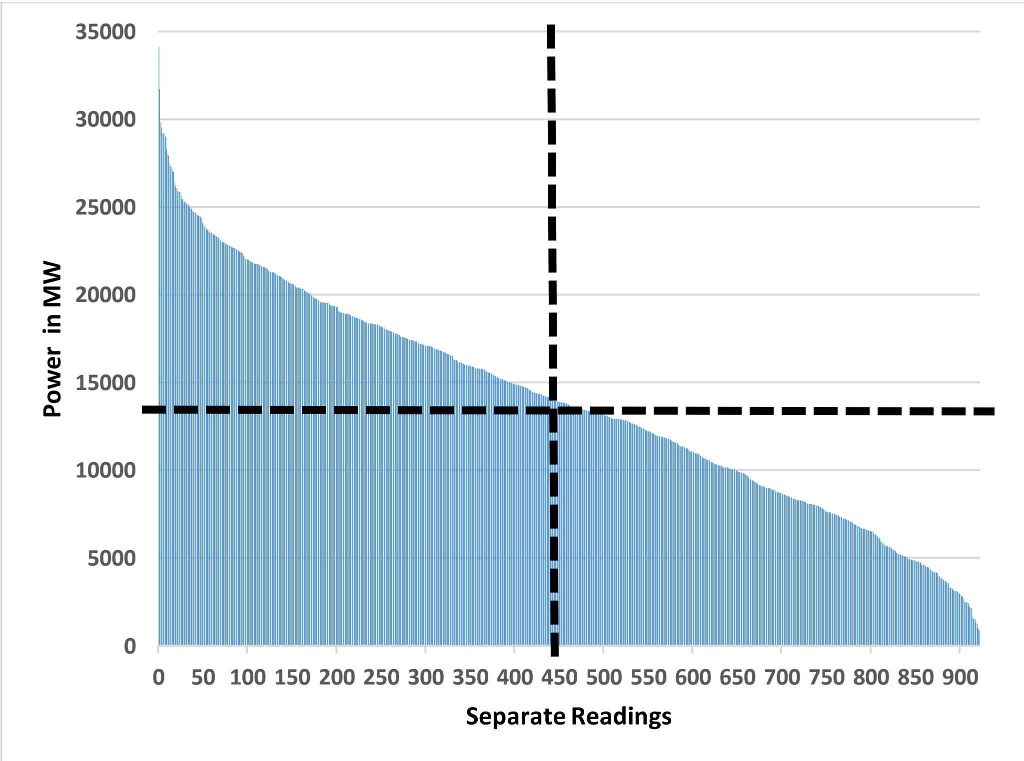


Figure 4 plots the combined wind output for each data point. The maximum power that was reached during the survey was 34107 MW, with the minimum being a mere 859 MW, less than 2% of the capacity over a very widespread system. Inspection of the graph indicates that for more than half the time, wind power did not reach the average. Accordingly, this tri-nation grid would need at least 13 GW of back up, and possibly somewhat more, given that power plants which are not used very frequently tend to be the most unreliable. Conversely just under half the time back up would not be needed and a varying proportion of it would be have to be shut down. The question then is how frequently would the back up be used?

7. How Often Would Back Up Needed?

Table 1 shows how often back up plant might be brought into use. Some plant would be brought into action as soon as the power from wind dropped below 14GW, and would be operating for almost 100% of time. On the other hand plant that was really only intended for near-windless days would be running for less than 3% of the year. At this level standby diesels would be a better way of meeting this shortfall than with steam or CCGT plant.

Table 1 : Back Up Requirements from a Spain plus Britain/Ireland Combination of 46 GW Capacity

Wind Power Generated	Proportion of Time	Back Up Required
Below 2 GW	Less than 3%	0 -14 GW
2-4 GW	3-11%	10 -12 GW
4-6 GW	11-24%	8-12 GW
6-8 GW	24 - 39%	6-8 GW
8-10 GW	39 – 58%	4-6 GW
10-12 GW	58 -77%	2-4 GW
12 -14 GW	77 -99%	0-2 GW

To what degree would wind power cut into the output of fossil fuel plant that might have been expected to have been running in the absence of wind energy? Obviously, since the hypothetical system produces an average power of 14GW, the fossil plant sector would lose that level demand for a significant proportion of the time. But Table 2 shows that up to 26 GW is also at significant risk. This level of generating capacity would be off line for 13% of the time.

Table 2 : Shutdown of Fossil Plant in a Spain plus Britain/Ireland Combination of 46 GW Capacity

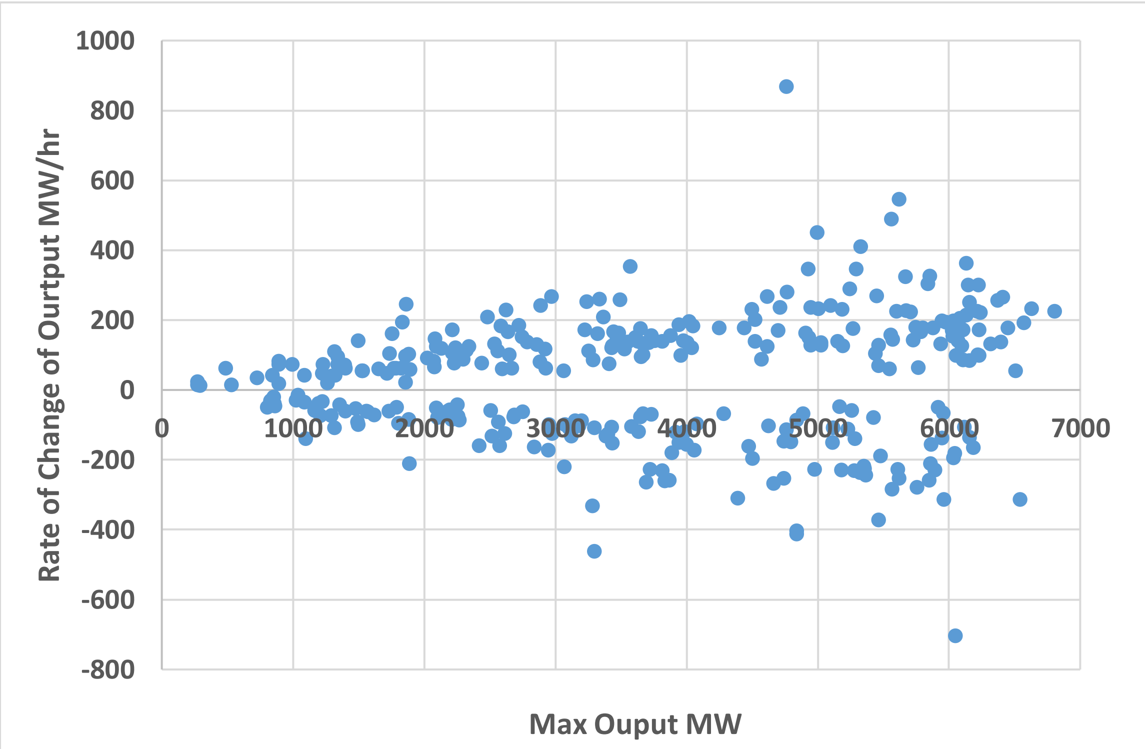
Shutdown of Fossil Plant	Proportion of Time
14-16 GW	61%
16-18 GW	42%
18-20 GW	31%
20-22 GW	22%
22-24 GW	13%
24-26 GW	8%
26-28 GW	4%
28-30 GW	c.1%
30-32 GW	<0.2
32-34 GW	<0.1
34-36 GW	Negligible

In reality, because very high levels of wind energy are fairly rare, it is unlikely that the top "slice" of wind power would be used. There is some evidence from Britain that although the National Grid gives a daily forecast for the wind power peak, the forecast levels are hardly ever reached

8. Rates of Change of Wind Power

An equally important issue is the rate at which fossil plant is able to respond to the daily or even hourly changes in electricity from wind. Here we need to reliable figures on the rates of change of wind power. It doesn't vanish, as some people seem to think, in a matter of minutes. The rates of change shown in Figure 5 are based the wind farms currently connected to the British National Grid. Capacity, at the time of writing, is 8403 MW. It excludes Northern Ireland, but it also excludes 3-4 GW of locally based wind energy, some of which is connected to the 33kV network and would have some impact on demand. The "X" axis in Figure 5 shows the maximum power output reached on the day in question and the "Y" axis the rate of change during that day between the minimum and maximum power outputs.

Fig 5: Rate of Change of Wind Power versus Maximum Output



There are two distinct bands of a roughly triangular shape. The upper band was where the power output was rising. The lower one, showing a negative rate of change, was where the wind output was falling. As one might expect, at the times when wind output was high, power output tends to change most rapidly. It would corresponds to a widespread storm passing over Britain. Note that even during stormy conditions, the rate of change of wind output can be quite low.

The trend of the rate of change, in terms of MW/h suggests that this is about one tenth of the peak wind power on the day in question. Hence, if peak wind power hits 6000 MW, the average rate of change will be 600 MW/hr. It is a figure that needs to be treated with some caution as the very short term increase might be 3-4 times the average rate. That is, given the example of a 6000 MW peak, the rate might increase to over 2000MW/h over a half hour period, and then fall back. Given the wind capacity we have in Britain at the present time this kind of change seem to be quite tolerable. Obviously as wind capacity goes up faster rates will be experienced, but even twice as much wind, bringing total British capacity to about 25 GW should not cause serious difficulties.

These data only apply to Britain where the wind farms are becoming quite widespread. In a country like Denmark, where the wind farms tend to run north-south, or in Eire, where there are just a small number of farms, rates of change will be higher.

9. Steam and CCGTs as Back Up

Even before wind energy began to have an impact, the ability of power plant to two shift was a vital requirement. Day to night changes in demand could be forecast and were easily handled with steam plants being held in the hot hold condition overnight. But increasing penetration by wind gives the prospect of fossil fuel units having to be shut down for days at a time, then suddenly having to go to full output from a cold or warm start. Blum and Brugg state that modern steam plants can run down to 10% of full load, but pressures would then be less than supercritical. It then appears that a steam-water mixture will be exiting from the boiler, with the water having to be recirculated via a steam separator, suggesting a drop in efficiency in this condition. At above 50% load output can be increased by 5% a minute. That is, on an 800 MW plant, 40 MW/min [9}.

Figure 6 : Variation in the Output of British CCGTs During a Winters Day in 2013

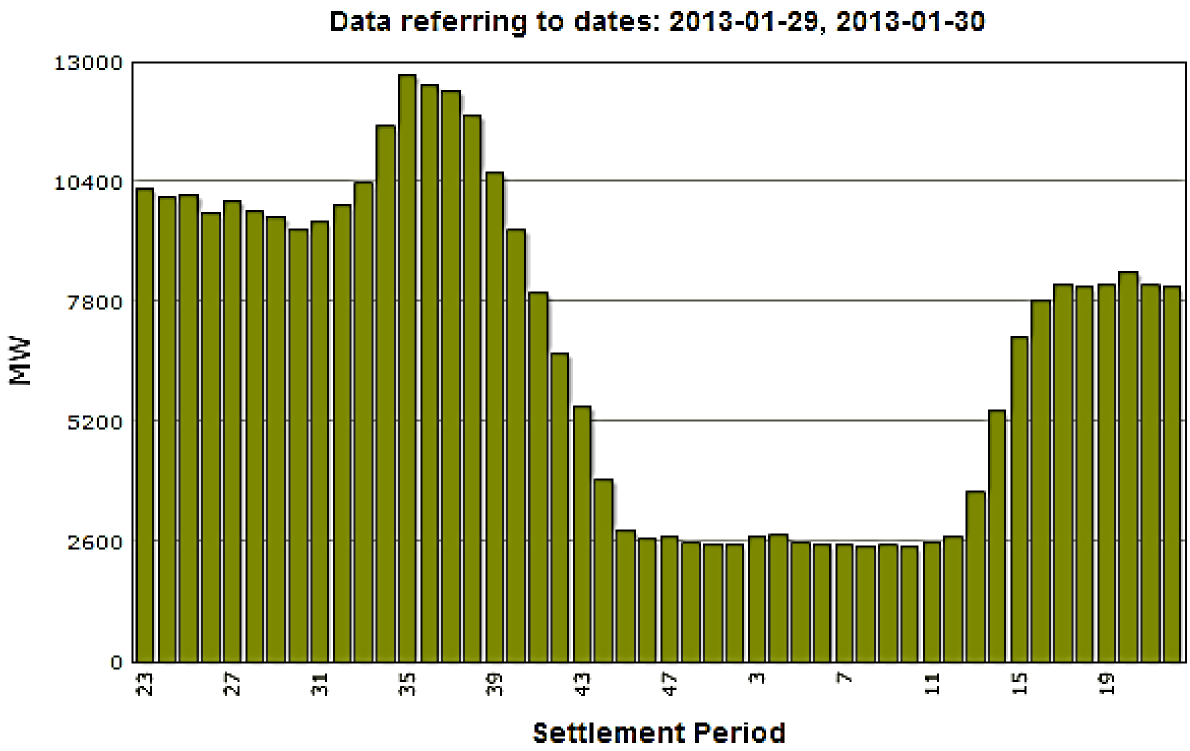


Figure 6 shows how the current British fleet of how about 20 GW of CCGTs can respond to a change in demand. The figures on the “x” axis correspond to half hour periods. As the right hand portion of the graph shows, the rate of increase was over 2000 MW/hr. On this basis, it would seem that for operational staff there would be little difficulty in compensating for changes in wind output.

It would therefore seem that CCGTs are well adopted to coping with wind, as even older models of CCGTs can respond very quickly to changes in demand. More recently Siemens have introduced improvements with their F class machines to get output up to full load in less than an hour [10]. Some of these improvements are similar to the recommendations made in the ETD report on plant cycling previously mentioned. These include improved water treatment and condensate polishing, maintenance of the vacuum in the condenser and reducing thermal stress levels in the HRSG. This is accomplished by maintaining the HRSG at a good temperature during hot standby, using stack dampers to conserve heat and utilising an ancillary steam supply to keep equipment hot. A more radical change has been the use of a Benson boiler configuration on the hotter section of the HRSG. This eliminates the boiler header and, with it a major thermal stress issue.

Part load efficiency is a consideration, but there is not much hard information available from the CCGT manufacturers or operators. Fortunately, Wartsila have published a comparison of CCGTs versus their own diesels, which is probably a reasonable guide, although it seems to be based on computer simulations [11]. As can be seen from Table 3, the CCGT plants will maintain an acceptable efficiency down to 40% of design output. Specific fuel consumption will then increase by about 15%. The simple cycle machines fare much worse with sfc increasing by 40%.

Table 3 : Part Load Efficiency of Simple Cycle GTs and CCGTs

Power Package	**40% Load**	**60% Load**	**80% Load**	**100% Load**
Siemens SGT6- 500F Simple Cycle	26.0	30.8	34.0	37.0
GE 7FA-0.5 Simple Cycle	26.0	30.9	34.6	38.0
Siemens SGT6- 500F CCGT	45.8	47.9	50.2	53.0
GE 7FA-0.5 CCGT	47.3	49.5	51.8	54.5

The Siemens and GE gas turbines being modelled in this exercise are industrial types, with modest pressure ratios, high exhaust temperatures and, in consequence rather mediocre efficiencies compared to aero-derived machines. These would be in the 42-45% range. On this basis CCGTs would appear to have an efficiency advantage over the aero-derived down to quite low loads. This assessment, does leave out, of course, the extra fuel which is required to bring a CCGT on line, where the fuel used to heat up the HRSG needs to be taken into accout.

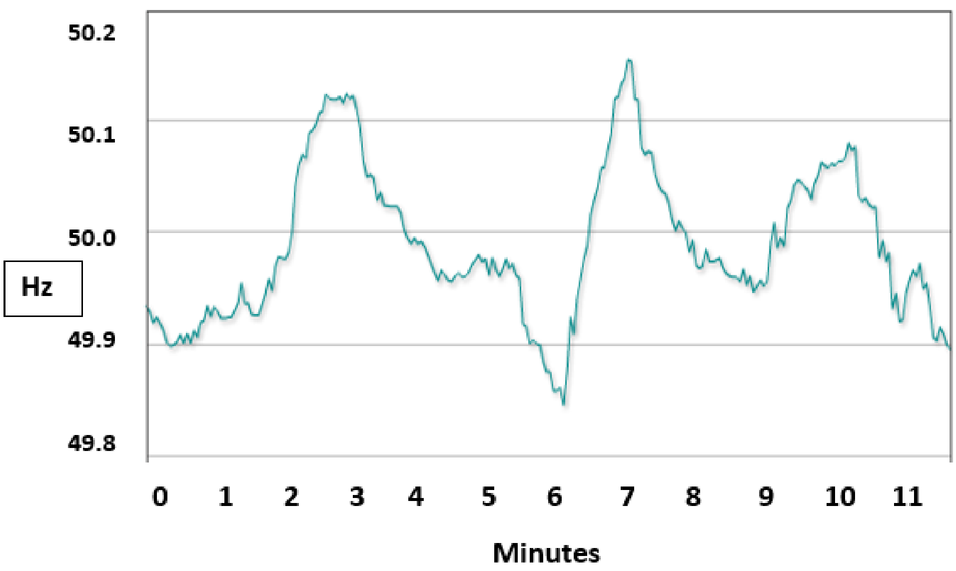
10. Potential Maintenance Issues and Frequency Control

Even when CCGTs are well handled, it is impossible to avoid rapid changes in temperature for the hot sections of the gas turbine and the HRSG. Not too much can be done with the hot section of the gas turbine; temperature changes when burners are turned on or turned off are rapid. In the case of the

HRSG good detailed design to minimise the impact of differential expansion will greatly help. A vital feature is adequate drainage of condensate.

It is worth commenting that some concern has been expressed about the impact of wind on grid frequency. In the opinion of the author, this is not really an issue. In fact the quite marked variations in frequency, which can occur at the beginning and end of the day seem to be caused by the difficulty in matching the supply to the demand. Figure 7 shows the sort of variation which can occur over a twelve minute period.

Fig 7 : Variation in British Grid Frequency in the Late Evening



There are reasons for thinking that, rather than wind, it is the increasing use of CCGTs that is exacerbating the situation. One obvious issue is the taking off the grid of a CCGT when its output drops below 50% of design, which, for example, might have caused the precipitate drop after the first peak in Figure 7.

There is another characteristic of CCGTs, which will probably exacerbate these quite wide fluctuations in grid frequency. The power of a CCGT is determined by the rate of air being drawn in by the speed of the compressor, and this speed (or rpm) is determined by the grid frequency. Hence if the frequency falls, which is indicative of insufficient power being generated throughout the grid network, even less power will be coming from individual CCGTs, making the situation even worse. To restore frequency will require a drop in voltage somewhere along the system, so that less energy is being consumed. It will be difficult to get an exact balance, the result then being that an excess of power is being generated, with the grid frequency exceeding 50 Hz, the result being the sort of overshoot shown by the second peak. Before the widespread use of CCGTs, when the grid was being powered by steam plant, a shortfall in power could be rectified by putting more steam onto a turbine.

11. Discussion and Conclusions

The progressive closing down of nuclear in a number of countries temporarily reduced the need for fossil fuel plants to two shift, that is, to shut down at night and start up during the morning. However, as wind energy increases in importance, there will be an increased need for fossil plants to come on-line and go off line at short notice. If nuclear power does make a resurgence, and are rationally designed and operated, as seems possible given German experience, with an ability to load follow the daily changes in consumer demand, this will make the operating practice of fossil plant event more arduous. The effect of solar and solar and tidal power, and CHP will be broadly similar. They too will be grabbing a slice of the power market and leaving a very irregular residue for fossil.

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2 IA. Shibli and F. Starr **"Damage to Combined Cycle Gas Turbines Due to Cyclic Operation"** ETD Report 1012-iip-09 c/o European Technology Development Ltd 2002 www.etd1.co.uk

3 Proc of Seminar on **"Cyclic Operation of Power Plant- Technical Operation and Cost Issues"** ed Shibli, Starr, Viswanathan and Gray (2001) London, England

4 RP. Skelton and F. Starr, **"Introduction and Report of Discussion to Seminar on Cyclic Operation of Power Plant 2001"** Materials at High Temperature 4, 18 (2001)

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