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THE FUNDAMENTAL PROBLEM WITH INTERMITTENT ENERGY SUPPLIES

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Abstract. The result of introducing intermittent, non-flexible electrical energy, e.g. from wind, into an electrical system in which the energy source is almost entirely natural gas, is to *increase* the use of gas. It is fairly easy to see that to be the case in *theoretical principle*, but theoretical principles are not always readily accepted by those who are struck by the fact that in order to make the theoretical analysis, substantial departures from actual practice have to be assumed. So in this paper, after a brief look at the theoretical picture, we show that the theoretical analysis remains valid when it is applied to the actual operation of electrical supply. An entirely gas-fired system is one end of a spectrum. To the extent that a system is coal-fired, there is likely to be some alleviation, because the output of coal-fired plant can be varied, to some extent, without loss of efficiency.

The importance of that 'space' which is the energy equivalent of 'prime land'

The fundamental problem with introducing into an electrical system something as erratic as wind turbines is that their infeed uses up a valuable 'piece', or 'block', of electrical demand. What I mean by a 'piece' is best explained by asking you to imagine a graph, ideally about ten metres wide, which shows total electrical demand on the vertical axis, and the time period of one year on the horizontal axis. Although this is only an imaginary graph, let us label it **Graph G** (G for gross) for easy reference (Figure 1 is *somewhat* similar).

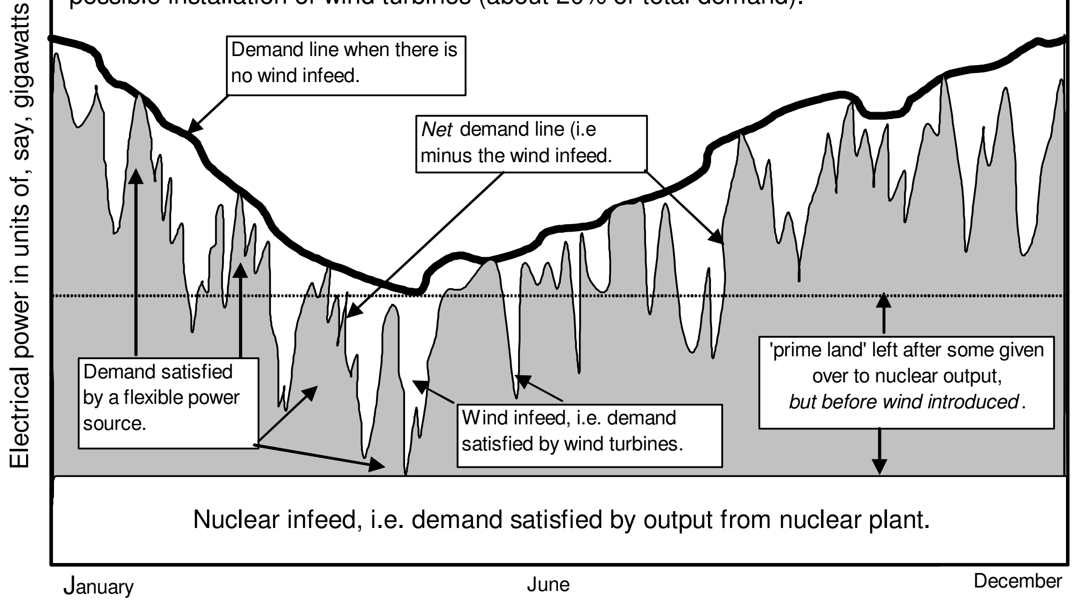
The demand line will, of course, be fluctuating, both because of daily variation and seasonal variation. But demand never gets close to zero. There will always be a substantial space between the horizontal axis and the annual 'valley' demand (the opposite to the annual *peak* demand). That space on the graph represents an energy equivalent of prime land, for it allows constant input to the grid throughout the year. It is this 'piece' of reliable demand which allows nuclear plants to be run in South Korea at 95% capacity factor, Finland at just over 90%, and Switzerland at 90%. These high *capacity factors* that are achieved by nuclear plants improves their *efficienc*y (the UK's nuclear capacity factor was only 85% at the same period, but that may be because of inappropriate regulations which failed to prioritize nuclear output). The *efficiency* of CCGTs (Combined Cycle Gas Turbines) is even more dependent than nuclear plant upon being allowed to operate at full capacity, so use of this area of constant demand would allow CCGTs to operate at 60% efficiency. Moreover, *in these same favourable circumstances*, engineers say there is potential for them to improve to 70% efficiency by 2020. Yet introducing wind energy up to the point at which the *peak* infeed from the wind was equal to the 'valley' demand (which incidentally would mean that wind would fill about 20% of total electrical demand) would completely destroy this energy equivalent of 'prime land'. That destruction would produce problems for nuclear input as well as for highly efficient Combined Cycle Gas Turbines, and probably also for highly sophisticated, low emission, coal-fired plant.

Is the reason for that clear? Perhaps not, so let us look at it another way, by thinking of a slightly different graph. This graph, which we will call **Graph N** (N for *net*), is essentially the same graph, but this time the line we draw shows, the electrical demand *minus the demand satisfied by infeed from the wind turbines*. In other words, it shows consumer electrical demand *net* of the demand satisfied by infeed from the wind turbines. The remaining demand has to be satisfied from other sources than wind turbines.

If we install sufficient wind turbines so that their *peak* infeed amounts to the same as the 'valley' demand of consumers, then what would happen to the graph? Obviously when the *peak* infeed from the wind turbines happened to coincide with the 'valley' consumer demand, the *net* demand line on the graph would come down to the bottom of the graph: that is there would be zero 'other' demand once the wind infeed had been subtracted.

Thus, at that particular time, any input from nuclear or CCGTs would be surplus to requirements. Let us reiterate that: after the wind had provided its infeed, there would be *no 'other' demand at all.* Either the wind power could be allowed to go to waste, or the nuclear stations and CCGTs would have to adopt the undesirable measure of closing off their production. Obviously this is a worse case scenario, but the line on the graph would often be making incursions into the area where one would either have to let some wind infeed go to waste or rein back the output of the nuclear power and the CCGTs.

Fig. 1. Demand, minus specifed inputs from wind turbines, & how it is satisfied. Thick line shows daily electrical demand with *no* infeed from wind turbines. The outline of the 'stalactites' shows daily *net* electrical demand, with approximately the maximum possible installation of wind turbines (about 20% of total demand).



Shaded area is the *net* demand which has to be satisfied by flexible power sources, which would be hydro to the extent available, variations in coal-fired output to the extent available, OCGTs, and CCGTs when possible.

A theoretical analysis of introducing wind turbines into the 'prime land'

We have seen that there is a problem, but we have not quantified it. Let us return mentally to Graph G, but now, bringing it slightly closer to the real situation in the UK and USA, imagine that down at the bottom of the graph there is a horizontal strip which represents the fairly constant input from nuclear plant. That would still leave a gap between the top of the nuclear input and the 'valley' demand. We would not want to add more wind power than an amount such that at *peak* infeed the wind turbines would close the gap to the valley demand. Were we to exceed that, then, on occasions, the wind turbines plus the nuclear plant would produce an output above demand, and electricity would go to waste.

There is no way that we can order wind turbines to follow demand. The best we can do with them is to 'flatten out' their variable infeed by using a flexible input to top up the infeed of the wind turbines when it falls below their peak infeed. The important point is the share of the work that will be done by the wind turbines, and the share that will be done by the flexible input, which I will call the DIB (dominant in-harness backup), for reasons that will soon become apparent. The rule, derived in another paper,[1] is this:

Share of wind input = (1 / *peak* infeed factor from wind turbines) x infeed factor.

For both the UK and USA, this works out as (1 / 0.80) x 0.24 = 30%. Thus wind can supply 30% of the 'block' of electricity determined by the *peak* demand, while the flexible supply operates <u>in harness</u> to <u>backup</u> the wind, providing 70% of that 'block' of electricity, and thereby deserves the name <u>dominant</u> (hence DIB).

Rehearsing the arithmetic that has been presented in the other paper just referred to, we can say that the 70% is likely to be supplied inefficiently (35%) due to operating 'in harness', so the gas needed will be 0.70 / 0.35 = 2 units, whereas were there to be no wind turbines, the 100% of electricity would be supplied by CCGTs operating efficiently (60%), and the gas needed would be 1 / 0.60 = 1.67 units. Thus using wind turbines *increases* gas consumption by (2 / 1.67) -1 = 20%.

That is a very brief rehearsal of the calculation, as the primary reason for this paper is not to present the theoretical picture. Those of an academic inclination may readily accept that although the idea of running a DIB to flatten out the infeed (i.e. fill in when wind infeed is less than *peak* infeed) is not realistic, it nevertheless gets at the underlying truth. However, I have discovered that those who are CEOs of electrical companies say that the analysis is too far from what goes on in practice to be able to say that it reflects reality, and hence is dubious. Thus the rest of this paper is designed to show that if one looks at reality, it is apparent that the outcome is the same as the above theoretical simplification suggests.

Refining the demand and supply picture to reflect reality more closely

I will not ask the reader to conjure up further mental pictures, but rather to look at Figure 1, which is a simplifed amalgam of Graphs G & N. For practical reasons, instead of trying to show the variations in *net* demand that occur during the course of each day, the *net* demand line there shows the mean *net* demand for each *day* (*net* because it is minus the demand satisfied by infeed from the wind turbines). So because of the lack of detail within each day, we must bear in mind that what is said of the figure will not be absolutely true, because it only shows an approximation to the *net* demand, but I think that it will prove fairly obvious that that particular departure from reality does not undermine the argument.

The broad line on Figure 1 shows what demand would be with *no* infeed from wind turbines. In such a case, the gross demand and the *net* demand are obviously the same.

Visualised in that way — no wind infeed — Figure 1 is very simple, and we can see that there is a substantial gap between the top of the nuclear infeed and the horizontal line that passes through the 'valley' demand. That 'prime land' is available for CCGTs to use without a worry in the world!

For the most efficient operation, we need not limit the CCGTs to that 'prime land' area. During the winter, we can safely bring some more CCGTs into operation, knowing that they will be able to run efficiently, either by running continuously, or perhaps by two-shifting, that is operating at one output during the day and another during the night. That is they can 'occupy' the triangular areas on the left and the right, above the 'prime land' and below the bold line.

So, omitting the refinement of managing the diurnal variation (to follow that precisely really needs hydro power, to the extent that it is available, coal-fired plant, and Open Cycle Gas Turbine, OCGTs) we can see that without wind turbines virtually the whole of the area under the thick line, extending down to the top of the infeed from the nuclear plant, is a sensible area to be operating CCGTs.

Now let us bring on the wind turbines, and with them all those 'stalactites' descending from the thick line, which have the effect of producing craggy peaks of *net* demand. You will note that because we intentionally installed sufficient wind turbines so that their *peak* infeed is equal to the distance between the top of the nuclear infeed and the valley demand, there are inevitably times when the *net* demand (the outline of the 'stalactites') drops down to the top of the nuclear infeed. So the 'stalactite' outline *net* demand is not arbitrary, but rather represents, reasonably accurately, the effect of introducing the wind turbines.

We can also see, from Figure 1, that with the wind turbines in the system, all the 'prime land' that was available to the CCGTs has been eliminated (i.e. there are no clear runs throughout the year any more). Moreover, the previously somewhat useful triangular areas, to the left and right of the graph, have been fatally invaded by 'stalactites', which serve to produce further craggy peaks of *net* demand.

It is now, I think, apparent that the theoretical analysis — which suggested a much reduced role for CCGTs — will still be true when we take full account of the more complicated picture of what actually happens in the real world of satisfying electrical demand. So, with luck, the theoreticians and the practical men will now be able to agree! At the very least, I would expect the heart of a CEO of any electrical transmission company to sink at the prospect of having to fill in, with a flexible power source, the space between the top of the nuclear infeed and the jagged outline of *net* demand, shown as the craggy peaks of Figure 1, not forgetting that, on a larger scale, the line would be barbed with 365 diurnal oscillations, which would look like hedgehog quills hanging from the 'stalactites'. The effect of photovoltaics is more complicated, in that the infeed will often occur predictably (in some places), and when daily demand is high. All that will be said here is that their intermittent infeed might sometimes cause the same problems as wind.

Conclusion

It takes a bit longer to understand exactly what is happening in the real world when we introduce wind turbines into an electrical supply system, than it does to do a theoretical analysis in which the 'block' of supply that can be serviced by "wind plus DIB" is treated as a separate entity. However, we have seen that the simple theoretical picture looks likely to arrive at results which will hold true in the real world of operating a gas-fired electrical supply system. But it must be noted that this is a theoretical study to the extent that is assumes an almost entirely gas-fired system. Coal-fired plant may allow some variation of its output without significant loss of efficiency. That is the subject of another paper.

1. See *Wind Power and Natural Gas*, page 9, paragraph starting, "The E.ON area extends…" The file is temporarily available at www.members.aol.com/optjournal4/eon5.doc