BRITISH MANAGEMENT DATA FOUNDATION

GB Electricity Supply and Renewable Generation Targets: Questions and Matters of Concern

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Whereas energy policy should be formulated in relation to climate change, its feasibility is constrained by a combination of engineering realities and economic consequences. This paper discusses in a general way some of the known problems, in particular those connected with the wind generation levels implied by targets for renewable electricity supply in 2020. These are summarised as follows:

Plant Capacity Needs

- The currently scalable options for renewable generation, wind power, cannot by themselves provide a secure electricity supply.

- Irrespective of the level of wind capacity installed in the system the dispatchable (conventional) plant capacity available must exceed winter peak demand to guarantee security of supply.

- Most of the coal and nuclear capacity due to retire by 2020 must be replaced by plant with similar characteristics, probably new gas-fired generation (CCGT), with perhaps one new nuclear station. Since this new fossil-fired plant will only be part-loaded as it accommodates variations in wind generation it will face unprecedented physical and economic conditions.

System Operation

- For technical reasons the system must have conventional plants (coal, gas, nuclear or even oil) connected to the system and delivering power continuously in addition to any input supplied from renewable power generators (for reasons see below).
- To preserve system security as renewable generation capacity grows this conventional plant will necessarily be operated in ways that incur increasingly large constrained off payments charged to National Grid, and ultimately to consumers.
- In addition, unless subsidized by the taxpayer, the fixed capital costs of such underutilised generators would necessarily be passed through the competitive generation market to consumers. [2]

Gas Supply Flexibility

- It is not clear that the gas network can cope physically with the *rates of change* in demand from gas-fired electricity generation working to compensate for large wind power variations both unforecast and forecast.

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2 Sam Laidlaw, chief executive of Centrica, has observed that renewables, such as large-scale wind energy, were intermittent and required back-up generation, a role gas was uniquely qualified to fill. But as power stations that operate only intermittently would not be financially viable, Laidlaw said: 'The building of new gas-fired capacity must be incentivised so that gas can fulfil its role as a bridging fuel.'

http://www.thisismoney.co.uk/money/article-2008055/Energy-giants-want-billionswindfarms.html#ixzz1b3DBfIRi

The Unknown Scope for Renewable Power Capacity [3]

- The scope for renewable generation supply is limited by the total system power demand less that part of the demands that must, for technical reasons, be met by conventional generation. How much renewable generation capacity is either technically or economically feasible under this constraint is unknown, a deficit of knowledge that must be remedied if current policy goals are to be achieved.
- It is conceivable, perhaps probable, that the renewable capacity (MW) feasible under this constraint would be inadequate to generate the energy (MWhs) required by national targets, given historically achieved load factors.

Apart from raising questions as to the simple feasibility of the current policy, all of these matters have cost implications over and above the levy-funded subsidies required (which would themselves be of the order of £6bn annually in 2020). The scale of these additional system level costs is plausibly estimated by some industry sources as adding a further £5bn a year in 2020.

A more detailed explanation of these constraints and questions is as follows.

Ramping Services and System Reliability

Figure 1 shows the typical daily electricity load power demand for power during summer and winter in the GB electricity supply system. This demand is matched at all times by the power supplied by the system's generating stations, which is the key to a stable and secure electricity supply. Power (MW) measured by the height of the curves is the rate of delivery of energy (joules per second), whereas the energy (joules) supplied and consumed, which is the commodity traded in the market place, is represented by the respective areas under the curves (i.e. rate x time = MWh).

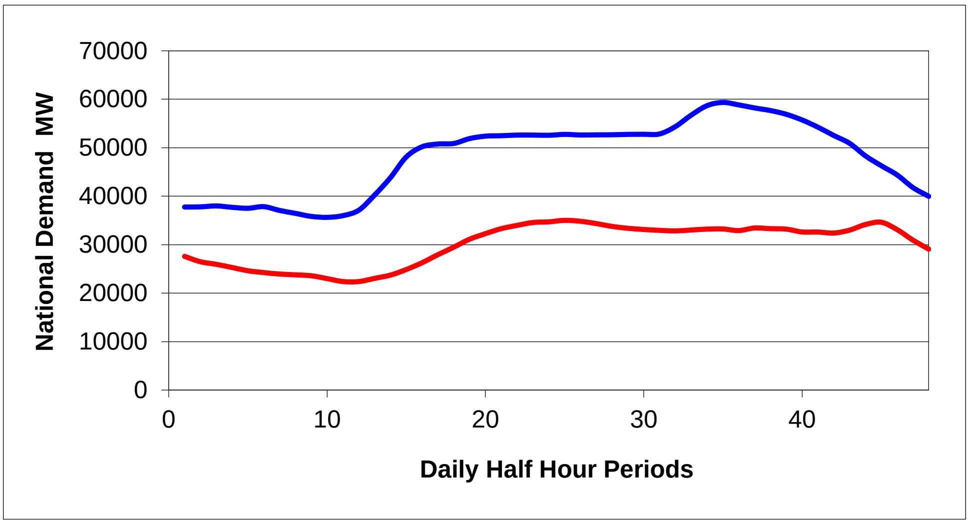

Figure 1. Typical GB Daily Winter and Summer Power Demands

Traditionally, the security of an electricity supply system has been measured by the availability of dispatchable plant over and above the peak winter power demand. The coincidence of low wind power with peak demand, however, is now well understood as being caused by large winter anticyclones that can cover most of GB. As various studies have shown, this means that no matter how much wind capacity is installed in the system the dispatchable (conventional) plant capacity available must exceed this peak demand level, although with somewhat less than the 20% target margin of recent years.

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3 Due to the specialised technical nature of the problems National Grid can best supply the extent of limitations based on their operational experience.

It follows that as existing coal and nuclear capacity in the system is retired up to 2020, security of supply will depend on the replacement of this lost capacity by other available and dispatchable capacity, usually but not entirely gas-fired plant.

Figure 2 shows the expected output from 25 GW of wind power capacity distributed throughout GB, modelled using Met Office wind records and matched with wind turbine operational characteristics, namely no output until wind speed is above 4m/s, full output around 15m/s, where it remains constant until 25m/s, above which the turbine shuts down. [4] The considerable variations in magnitude of total power output can be seen in this not untypical January winter month. Particular attention should be paid to the period following the 300th hour, where an 18 GW fall in 22 hours is closely followed by a 14 GW rise in 16 hours.

To balance this fluctuation, a large proportion of the nation's generating capacity would need to ramp down, disconnect from the grid and then within 38 hours be ramped back up and reconnected. This interaction with the despatch of other power plant on the system is an unavoidable consequence and is seen as having two negative effects: firstly, it would reduce the reliability of other plant, that was simply not designed for such cycling, and, secondly, reduce the economic utilisation of the most efficient thermal plant. Furthermore, studies show that the thermal efficiency penalty of part loading plant for 'ramping' duty is such as to erode, perhaps very significantly, the emissions savings expected from the introduction of renewables.

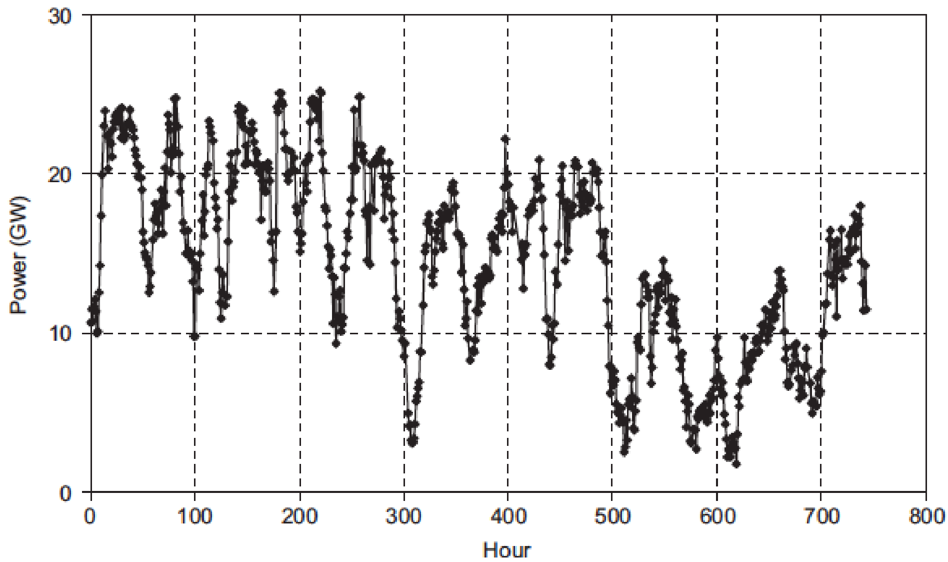

Figure 2 Modelled power output from 25 GW of GB wind generation capacity for January 2005

With a substantial proportion of central generation powered by natural gas it is envisaged that these power swings from wind will be compensated by gas-fired plants, which in turn will induce comparable power swings on the gas grid as plants ramp up and down. The international power system consultants PB Power have made an analysis of such behaviour in the context of the GB electricity supply system. [5] They concluded that *if the wind fleet exceeded 10 GWs the current mix of generating plant would be unable to ensure reliable electricity supply, and that consequently for the larger wind capacity planned for 2020 to be managed successfully, up to 10 GW of fast-response generating plant or controllable load will be needed to balance the electricity system.*

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4 James Oswald, Mike Raine, Hezlin Ashraf-Ball, 'Will British weather provide reliable electricity?, *Energy Policy* 36 (2008), 3202–3215.

5 Parsons Brinkerhoff *Powering the Future* (Newcastle: December, 2009).

Electricity interconnection with mainland Europe would offer some fast-response capability, but would be unlikely to offer predictable support. Without additional fast-response balancing facilities, significant numbers of UK electricity consumers could experience regular interruptions or drops in voltage.

PB Power report that the most economic and effective power plant will be those types with the lowest capital cost, favouring technologies with higher carbon emissions, such as Open Cycle Gas Turbines (OCGT). But when operating with limited, irregular and less-predictable hours, **such plant types are incompatible with the limitations of the gas network, and would therefore need to use liquid fuel, probably diesel or kerosene, further increasing CO_2 emissions.** Indeed, there is some evidence to suggest that investors are further seeking to reduce their exposure by seeking to construct cheap marine diesel sets to run on a variety of fuels.

The views summarised in PB Power's study are based on expertise arising from many years of practical power systems engineering experience, and their judgement that existing levels of system reliability can only be maintained provided that not more than about 10 GW of wind is added to the present mix of conventional plant types is a useful horizon for policy makers and investors. Beyond this level, the higher wind capacity targets presently envisaged would require the market to add considerable quantities of inefficient standby generation plant.

PB Power also confirms the importance of the hitherto little-discussed question as to how much rapid variation in demand the GB gas network can tolerate at times of maximum winter load. The rapid 70% fall in wind output evident in Figure 2, corresponding to about 18 GWs, is a load that would have to be transferred immediately to other synchronous generation plant, mainly gas-fired, and thus to the gas supply network. *Whether this would be feasible with or without due warning is a question for the National Grid and gas suppliers.*

System Frequency Response – another need for fast-response generating plant

Variations in electricity demand or generator output result in fluctuations in system frequency. Control of these fluctuations is effected firstly by the inertial response of the synchronous generating plant connected to the system and, secondly, by the operating reserve that provides the rapid, active, control of power output. Inertia determines the rate of change of frequency; reserve arrests the falling frequency and then restores it towards its nominal value.

For the large interconnected GB system, with its high inertia levels, slower-acting primary reserve is at present adequate to cope with generation loss. However, with increasing wind generation, the on-line synchronous inertia will, on average, fall by 2020. The maximum rate of system frequency change is directly proportional to the system inertia; thus the lower the system inertia, the faster the frequency will fall following the loss of a generator, and hence the faster the primary reserve response required.

Therefore, given the demand levels shown Figure 1, there is a minimum system inertia level determined by the availability of adequate quantities of sufficiently fast-acting reserve to arrest the frequency fall before load shedding (blackouts) are unavoidable. As noted, the system's synchronous inertia will tend to fall as the level of non-synchronous penetration of renewable generation rises. Since a minimum inertia level must be maintained, it is possible that increased and potentially costly curtailment of non-synchronous renewable generation will be required if current performance levels are to be maintained. [6]

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6 Eirgrid and SONI calculate for Ireland that 'instantaneously' no more than 50% of capacity should be non-synchronous.

Voltage Control

In order to gauge the scope of renewable generation, National Grid guidance is needed as to the levels of synchronous generation capacity required to maintain minimum inertia limits, and as to what percentage of power demand would be met by this connected synchronous generation.

The balance and pattern of voltages across an electricity network is critical for consumer load supply at any point and, in a more complex sense, for transmission of power from generating stations to load centres. Energy policies based on economic theory alone do not and cannot take account of constraints to electricity supply arising from this scientific reality.

The key to voltage control is the supply of reactive power, a commodity *considered but not resolved in the original privatisation of the industry, and one that has no spot market value.* Without going into technical issues, generators simultaneously supply both active power and reactive power in various ratios determined by physics. [7] While reactive power can be provided by a number of different sources not all sources are of equal utility, synchronous generators being the most reliable for purposes of security of system operation.

With the 25 GW of wind power envisaged by 2020 there would be a substantial decrease in the average on-line synchronous reactive capability, and control of the reactive output of the wind fleet during voltage disturbances could be critical for secure system operation.

Unfortunately, reactive power cannot be transmitted far and so has to be generated locally with respect to the load centres; but conventional synchronous generators that are connected for the purpose of maintaining local voltage levels around the country *are also constrained to produce active power,* which could further limit the output of active power (MW) from renewable generation.

To summarise, the minimum generation levels needed from the portfolio of conventional synchronous generation plant connected to the system has a significant impact not only on its ability to deliver the services necessary for the secure operation of the power system, but also on the maximum generation levels that are available for renewable generation. Such minimum generation levels may be, for example, 50% for CCGT stations or individual generators, and 35% otherwise, as in Eire. [8]

Costs

Aside from the physical aspects of the engineering problems described above, these concerns all have cost implications over and above the £6bn a year levy-funded subsidy required to meet the electricity industry's contribution to meeting the 2020 Renewables Directive for a 15% renewable share of Final Energy Consumption.

Specifically, grid expansion, system balancing, and the operation of a shadow generation fleet at low load factor and in demanding physical circumstances, would all be required to maintain system security and to minimize constraints. Though these integration and management costs are difficult to gauge, their order of magnitude can be estimated with reasonable confidence, and one authoritative calculation suggests that this could add as much as another £5bn annually in 2020 to consumer costs, resulting in a total policy premium over alternative systems of upwards of £10bn a year.

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7 A bathroom shower provides a helpful analogy: power, which is the rate of delivery of energy, is equivalent to the rate of delivery of water; energy is equivalent to the amount of water used. The rate of water supplied, i.e. power, not the quantity paid for, i.e. energy, is the only useful measure of effectiveness. Voltage is equivalent to the pressure governing the rate of water delivery. Reactive power supply determines the voltage level.

8 "Ensuring a Secure, Reliable and Efficient Power System in a Changing Environment", Joint Report by EIRGrid and SONI (Systems Operator for Northern Ireland), June 2011.

Such costs will seem very high if fossil fuel prices remained low, and even in the case where fossil fuel prices rise significantly, it is unclear that the renewables targets, ambitious though they are, would offer a satisfactory buffer. In the event, it seems probable that the consumer would face high fossil prices *and* very high renewables costs. This is a combination with potent political consequences.

Conclusions

To address the technical and economic questions in the 2020 scenario requires detailed power system engineering expertise with considerable input from the National Grid, which alone is in possession of much of the relevant data. Even without such input, however, it should be appreciated that physics and system security constraints can, from time to time, limit the capacity of all forms of generation that can be connected to the electrical power system and thus contribute to the market for electrical energy. Renewable generation is no different in this respect. More connections both within and between systems, together with a growth in the use of electric vehicles, may help ease these constraints, but the limitations imposed by the necessary use of conventional plant will remain.

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