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Assessing Backup Requirements for Wind Power

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So how much backup power capacity on the national transmission grid does grid-integrated wind power require? This analysis considers the meaning of 'back up' and the impact of wind power[1].

The transmission grid controllers have to arrange continuously an exact balance of the demand, C_{dem}, with the supply. This is done partly by the inertial reaction of the system itself and partly by the active initiatives of the controllers. The latter relates to the tariff arrangements for paying the generators. The dominant problem for the operators is to cater for the ever-changing demand of the load, which is outwith their control and may be rapid. They do this by:

(i) careful analysis of past variations and hence prediction of future hourly, daily, weekly, monthly and yearly loads,
(ii) having extra generating capacity waiting for increases in load and likewise generating capacity that can be reduced for load reductions.

The control stages are in order:

(i) allow the frequency and voltage to vary imperceptively within the statutory limits,

[1] For an in-depth review of wind variability and the grid, see 'Wind power myths debunked' by M. Milligan *et al*, *IEEE Power and Energy Magazine*, Nov/Dec 2009.

(ii) increasing power from part-loaded running plant,
(iii) if necessary, cut off large loads that have special low-price tariffs (load management),
(iv) order stationary or ‘spinning’ plant to come on line according to the tariff agreements with the plant owners and the time periods required by each type of plant e.g. ‘fast’ – hydro and pumped hydro ~3 minutes, gas ~15 minutes, ‘standing’ – coal ~4 hours.

The total of all such capacity available for control is the ‘short-term operational reserve capacity’, also less accurately called ‘spinning reserve’, labelled here C_{res}. In practice this is about 5% of real-time supply and must cover the risk of rapid disconnection from the largest thermal plant (e.g. large nuclear or coal plant ~2 GW). For the UK, C_{res} is about 2-4GW, dependent on the load by season and by time of day. In addition, there is the capability to reduce rapidly large loads by a further capacity of about 2GW. The total capacity of all types of plant connected to the grid is C_{total}. This includes plant not able to be used in control e.g. plant being repaired, maintained or refuelled; operating nuclear; most windfarms; microgeneration, and some partially mothballed plant held in ultimate reserve (e.g. old coal and oil plant). However, National Grid operators may not include all forms of renewable energy in their total, e.g. landfill gas, sewage gas, and microgeneration. In the UK, C_{total} is about 80GW. The difference between the peak demand in the year $C_{dem,\ max}$ and C_{total} is the ‘plant margin’ i.e. $C_{margin} = C_{total} – C_{dem,\ max}$. Sufficient plant margin is usually about 25% of annual peak demand. In the UK, $C_{margin} >> 20GW$. Only part of this plant margin is used to contract for the short-term operational reserve capacity C_{res}; however much of the remainder could be called for in the unlikely event that C_{res} become insufficient. Thus there is no explicit capacity that can be identified as the vague term ‘backup’, however, the totality of methods of utilising short-term operational reserve and plant margin may be called ‘backup’. The aim is to minimise, subject to costs, the statistical chance that supply cannot meet demand, including the chance that large plant may instantly fail in single or multiple events. Perfect security cannot be provided and is not expected.

For long-term planning of total capacity, a statistical method has to be used, since at any one time some plant will be unavailable due to maintenance, faults or, in the case of wind power, lack of wind. The statistical contribution from each plant is called the ‘firm power’, or ‘firm capacity’ C_{firm}, e.g. a 1000MW nuclear plant may be allocated a ‘firm-capacity’ of 850MW. Note that $C_{res} < C_{firm} < C_{margin}$, so, $C_{dem} < (C_{dem} + C_{res}) < (C_{dem} + C_{firm}) < (C_{dem} + C_{margin}) < C_{total}$.

The non-dimensional ratio of the firm-capacity to maximum capacity of a plant, or set of plants of the same type, is the 'capacity credit ratio' R. Hence $R = C_{firm} / C_{max}$. For the nuclear example, R=0.85.

Wind is obviously variable, but nevertheless windfarms have a statistical chance of operating. For each turbine, the ratio of the electrical energy actually generated in a year to the notional maximum from its generator operating continuously is the non-dimensional Capacity Factor, 'F'. A turbine in Scotland can be expected to have F~0.3, and in Midland or Southern England F~0.2. Note that the aggregated output of wind power across a region or country such as the UK can never trip out suddenly as thermal plant does quite commonly (perhaps about once per 18 months for a 1GW thermal plant, perhaps about once per week for all such plant nationally). Wind power variation is due to changes in wind speed, which is predictable meteorologically to a few days ahead. For shorter periods, aggregation of individual turbine and windfarm output greatly improves national reliance. Assuming constant demand, or indeed reduced demand due to improved efficiency of use, every unit of renewables electricity that enters the grid reduces the power needed from other plant. In practice it is fossil fuelled plant that reduces output, so fuel and carbon emissions etc are reduced accordingly. Thus the more wind power generation enters the grid, the greater is the capacity of fossil plant that becomes available as 'backup'. Thus, other factors being equal, the entry of windfarms onto the network <u>increases</u> and <u>improves</u> backup. Thus as more wind power is installed across the country and offshore, with total capacity, C_{wind}, so its statistical contribution increases as a positive contribution to C_{firm}.

The Firm Capacity Margin ($C_{firm} – C_{dem}$) is already present to cater for possibilities of plant outages at times of peak demand; this margin is about 25% of total generating capacity. The margin is therefore available to cover also for the predicted, yet relatively rare, times when there is no wind power across the whole country. If national wind capacity is less than about 5% of C_{firm}, then such total loss of wind does not affect the margin significantly. Should national wind capacity become greater than about 50% of the margin, then extra firm capacity would be needed, e.g. from biomass thermal plant. This condition would correspond to about 10GW of wind capacity in the UK. So considerable wind capacity can be installed randomly across the whole network before the firm capacity margin is affected by wind.

For short-term operating reserve capacity, C_{res}, changes in wind power generation result from changes in wind, which are predictable in national terms several days ahead. The shorter the time ahead, the greater the accuracy of aggregated prediction. The UK National Grid has calculated the extra reserve capacity needed as a function of wind capacity[2]. If wind is 10% C_{total}, then C_{res} should increase by 3 to 6%; if 20% C_{total}, then C_{res} should increase by 4 to 8%. The increase in costs is proportionately much less, just 1% for 20% C_{total} of wind. UK wind power capacity at February 2010 is about 4GW, so in practice no extra short-term reserve capacity is needed. Only when the wind capacity reaches about 8GW in the future will special reserve alterations be needed. Then extra fuel will be needed for the extra spinning reserve, in which case the worst scenario is an extra 4% of energy above the wind energy supplied[3]. The net wind contribution to annual abated fuel nationally would then have been reduced by only 4%. As more turbines and windfarms are connected throughout the country, so it becomes more likely that wind power will be operating; consequently wind power is included statistically as a contribution to C_{firm} and so less other plant margin capacity is needed. The reduction in capacity of conventional marginal capacity due to the wind turbines is defined as the capacity credit of wind power $C_{R,\,wind}$. The capacity credit ratio of windpower is:

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\begin{aligned}
R_{wind} &= C_{R,wind} \,/\, \text{capacity factor} \\
&= C_{R,wind} \,/\, F.
\end{aligned}
$$

The grid operators and other agencies have studied the integration of wind power into the grid with considerable detail. Also available for study is the successful integration of wind power into the Danish network to a capacity of more than 20% of their total capacity. Such studies and analytical techniques are published in professional academic literature, including studies for the UK grid[4]. The conclusion of such studies is that the maximum capacity credit for UK wind capacity of ~30% of C_{total}, will be about 7GW. Thus in calculating firm capacity C_{firm} for, say, 22GW of installed wind power, the grid operators will add 7GW to the firm capacity of all other generators because of the wind power. Note that this is not zero as often implied by those opposed to windpower.

What does all this mean in practice? The present grid control methods and operational reserve of ~10GW is more than adequate for present UK wind power capacity of 4GW. As the wind capacity increases

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[2] 'Managing variability', D. Milborrow, report to WWF-UK, Greenpeace UK and Friends of the Earth EWNI, 2 June 2009.

[3] Ibid M. Milligan *et al*.

[4] See for example D. Milborrow, 'Quantifying the impacts of wind variability', *Energy*, **162**, issue EN3, pp105-111, Institute of Civil Engineers, UK.

in the future the short-term operational reserve capacity, C_{res} has to increase slightly, with a small increase in costs. However, C_{firm} and C_{margin} will tend to increase due to the capacity credit of wind power, but since the small increase in C_{res} is obtained from C_{margin}, the net effect on the system is small. As time progresses, plant becomes old and is removed. Thus the plant margin capacity C_{margin} reduces and new plant is built to restore C_{total}. This progression has always happened and will continue to do so. However, in the future the system will include significant wind power. Obviously, for these conditions replacement capacity for short-term operational reserve C_{res} has to be other than wind e.g. thermal plant, perhaps powered by biofuels. However, because of its capacity credit, the wind power will contribute positively to the plant margin, C_{margin}. Overall, by taking the opportunities presented by the replacement of retired plant, the overall system can be expected to accommodate the changes.

These conclusions are supported in the UK National Grid[5]:

> "The persistence effect of wind (i.e. its output is naturally subject to fluctuation and unpredictability relative to the more traditional generation technologies) coupled with the expected significant diversity between regional variations in wind output means that, while the balancing task will become more onerous, the task should remain manageable. Provided that the necessary flexible generation and other balancing service providers remain available, there is no immediate technical reason why a large portfolio of wind generation cannot be managed in balancing timescales. It is anticipated that balancing volumes and costs will increase as the wind portfolio increases. National Grid estimation of these volumes and costs will be highlighted via a separate consultation report on future system operations, which is due to be published in May 2009. In the longer term, we do not think it likely that there will be a technical limit on the amount of wind that may be accommodated as a result of short term balancing issues but economic and market factors will become increasingly important".

[5] GB Seven Year Statement, 2009, National Grid, Chapter 4: Embedded Generation.

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