Can the grid cope with a large expansion of renewables – a Cornish perspective

With expansions of renewables such as wind and biomass in the pipeline for the UK, is the current electricity grid able to accommodate them? Dr Ian Billington *shares his research findings and assesses the case for the southwest.*

The UK needs to increase the proportion of electricity generated from renewable sources to 20% by 2020 in order to meet the Government's target as set out in the 2007 white paper. The same document states that, in 2005, renewable sources only supplied about 4.5% of electricity. To achieve such a significant increase, a range of renewable sources will need to be used which will inevitably impact on the electricity distribution and transmission system at various levels.

Here, the impact of large renewables integration at distribution network level (ll kV/33 kV/132 kV) is examined by looking specifically at one area – the electricity network in the far west of Cornwall. By reviewing the impact on the local distribution network of connecting locally available renewable sources of electricity generation on a wide scale, it was possible to establish the thermal capacity (rating of cabling and transformers to avoid overheating) and other limiting factors of the network.

Electricity generation from biomass and wind

For the scope of this particular study, biomass and wind as sources for electricity generation were felt best placed in this location to test the distribution network capacity and its ability to accommodate wide-scale embedded generation from renewable sources of energy.

In terms of biomass, wide-scale electricity generation from energy crops is anticipated to increase significantly in the future. Its estimated potential in 2025 is 33 TWh/year – about 9% of current electricity generation.

One energy crop candidate is wood in the form of short rotation coppice willow. Another is Miscanthus or 'elephant grass'. Of the two, Miscanthus is more suitable for the west of Cornwall and can be harvested annually. After planting, yields of the crop increase over the first 3–5 years to reach a peak of 12–16 tonnes per hectare per year. The crop has an energy content of 15–20 GJ/tonne.

There are many possibilities for using Miscanthus to generate electricity. Gasification is most likely to be developed in the longer term due to its potential increase in efficiency – there is a potential increase from 35% for a steam-cycle plant (at the scale of plant applicable in this case study) to over 40% for gasification.

There is currently over 2,400 km^2 of farmland in Cornwall. If half of this land was used for energy crop production the estimated electricity generated would be in the order of 2,700 GWh.

In terms of wind energy, Cornwall is blessed with high wind speeds – more than 620 km^2 of land records average annual wind speeds of 7 m/s or greater. Placing wind turbines on all the farmland in Cornwall would provide an estimated 7 TWh/year of electricity.

The Cornish electricity grid

In 2005 Cornwall used approximately 3,000 GWh of electricity – this represents a quarter of the county's total energy use. The bulk of Cornwall's electricity is supplied by the national grid at 400 kV from power stations such as Hinckley Point in Somerset. This 400 kV supply runs as far as Indian Queens in the centre of Cornwall, where a gas turbine generating plant (which is run at times of peak demand) is also situated. From there, links at 132 kV and 33 kV run to a large transformer station or Bulk Supply Point (BSP) at Hayle in West Cornwall.

From Hayle the local electricity grid radiates out with lines at 33 kV and 11 kV to smaller substations. It is then transformed down again to 400 V three-phase and 230 V single-phase supplies.

Results from biomass assessment

Seen from an electrical perspective, the sensible place for site generation plans, to minimise the amount of extra cabling, is as close as possible to existing substations or the Hayle BSP. In this particular case study three options for biomass generation expansion were examined:

- generating locally – that is at the farm level with one gasifier/generator per square kilometre;
- transporting the biomass to a gasifier/generator site at each local primary substation (33 kV/11 kV substation); and
- transporting the biomass to one large CCGT power plant at Hayle BSP.

Using half the farmland in the selected small area of Cornwall gives the results shown in **Table 1** and **Table 2**. In **Table 1** the generation efficiency is the assumed overall efficiency of the gasifier, prime mover and the generator. The capital cost is that of the gasifier, prime mover and generator, and the cabling costs are those of the cables, step-up transformers and connection to substation.

The calculations in this study suggest 300 GWh/year of electricity could be provided from just 50% of the farmland in the selected small area of Cornwall. This is about 10% of the total county's 2005 electricity demand and represents a saving of about 150,000 tonnes of carbon dioxide per annum.

The figures show the benefits of increased efficiency of generation and reduced capital and maintenance costs with an increase in plant size. Cabling and connection costs make up a significant proportion of the total cost of electricity from small plant but an almost insignificant amount for larger plant, resulting in smaller cabling costs but higher transportation costs.

Most importantly, large-scale generation plant will generate more electricity in total from the same amount of biomass than a collection of smaller plant. Therefore the wide-scale use of energy crops used as a fuel for electricity generation is likely to centre on larger regional gasification/generations plants rather than very localised smaller plants.

There are of course, considerable uncertainties in the cost breakdown, but the overall electricity cost found here for a large plant

Option	Plant	Generation efficiency (%)	Capital cost (£/kW)	Cabling and connection (£/kW)
One generator per km^2	230 kW gas engine	29	2,500	900
One generator per substation	Gas engines, 1.7–4.6 MW	35	2,100	165
One generator at Hayle BSP	39 MW CCGT	43	1,600	80

Table 1: Biomass plant size, efficiency and costs

Option	Fuel contribution (p/kWh)	Amortised plant capital costs (p/kWh)	Amortised cabling and connection costs (p/kWh)	Transport and handling costs (p/kWh)	Operation and maintenance costs (p/kWh)	Overall cost of electricity (p/kWh)	Total electricity generated (GWh/year)
One generator per km^2	2.7	3.2	1.2	0.4	3.2	10.7	207
One generator per substation	2.3	2.7	0.2	0.4	2.7	8.3	250
CCGT at Hayle	1.8	2.1	0.1	0.6	1.9	6.5	307

Table 2: Breakdown of final electricity cost

using gasified Miscanthus (6.5 pence/kWh) is consistent with estimates for the UK by E4tech.

The study also finds that even using 50% of the farmland the low spatial energy density of energy crops could be accommodated in the existing capacity of the local electricity distribution network without the need for any network reinforcement.

Wind energy assessment

The spatial density of the wind resource (in areas of high annual average wind speeds such as Cornwall) in terms of GJ/hectare of land is much higher than that of energy crops. This could result in installed generating plants exceeding the capacity of the local electricity network. As part of the Cornish study, three separate connection scenarios were assessed to test this possibility.

The first scenario explored wind energy deployment up to the existing thermal capacity limits of the local electricity network. The second and third scenarios explored reinforcement of the local network in order to allow the bulk of the available wind resource to be connected.

In the second scenario, the grid is reinforced by increasing the 33 kV/11 kV transformer capacity at primary substations and the 33 kV cabling links to these substations. In the third scenario, reinforcement is carried out at 132 kV with two additional 132 kV BSPs established in the study area.

Results for each of the three scenarios are shown in **Table 3**.

Although the second and third scenarios had the same installed capacity, the points of network connection were more widely distributed in the second scenario – hence the higher average annual electricity generated. Despite this advantage, the cost-per-unit of electricity generated in the second scenario was higher than in the third due to a considerably higher reinforcement cost in the second scenario.

In addition to this, the third scenario was felt to be a more practical solution than the second due to the fact that up to ten additional 33 kV overhead cabling links, routed in parallel, are required for some primary substations in the second scenario.

In addition to the limitation of thermal capacity of the local network the study also considered other potential technical limitations such as fault current, voltage control and protection operation.

The fault current limits of the existing local electricity network (the rating of the protection equipment, in terms of maximum fault current which can be safely cleared) limited the generating capacity for induction machines to 531 MW and synchronous machines to 234 MW. Both of these exceed the thermal capacity limit for the Hayle BSP local area network.

In the scenarios, all wind farms were connected directly to primary substations to overcome the majority of voltage control problems by having control by automatic voltage transformer tap changing located at the same location as the point of connection.

Distribution network connection

The requirements of the host local licensed Distribution Network Operator (Western Power Distribution for the South West of England, which includes Cornwall), for protection equipment to protect the local network are set out in the Electricity Association document G59 (up to 5 MW) and G74 (above 5 MW or above 20 kV).

The grid code updated in 2005 by National Grid Electricity Transmission (which oversees the operation of the national electricity transmission system) places new requirements on wind farms – two major new requirements being fault ride-through and voltage control. Both requirements introduced the need for wind farms with induction machines (without a power electronic grid interface) to have fast switched capacitances and reactances such as SVCs (static var compensators) and STATcoms (static compensators). These allow the control of reactive power flow and so provide voltage control, enable the holding up of voltage levels during a fault and reduce the extent of over-speeding of the machine.

Scenario	Capacity installed (MW)	Electricity output (GWh/year)	Cost of electricity p/KWh
One	88.2	59	2.35
Two	214.2	581	2.85
Three	214.2	562	2.72

Table 3: Comparison of economic assessments for the three wind scenarios

Key findings

After consideration of the thermal capacity of the local distribution network and other potential technical constraints such as fault current limits, this investigation shows that the distribution network in the southwest does have capacity to accommodate significant amounts of embedded generation. This capacity was also found to extend beyond the local distribution network level to the 132 kV and 400 kV grid levels.

The capacity limits can also be significantly increased with network reinforcement. If planned effectively at suitable voltage levels, this can be achieved at a reasonable price.

With the need for voltage control and fault ride-through, the technical requirements of grid connection have increased for embedded generators. However technical solutions are available to enable these onerous requirements to be achieved.

A number of assessments have also been carried out (by a number of different contractors appointed by the then Department of Trade and Industry) on parts of the electricity network in North Wales and the East Midlands. These indicate significant capacity for the connection of embedded generation (potentially from renewable sources of electricity generation as reviewed in this study), which could be further enhanced with network reinforcement at reasonably economic levels.

To meet the UK Government's target of 20% of electricity generation from renewable sources by 2020, a significant amount will need to be connected at local distribution network level. There is a sizable amount of capacity at this level to connect the wide-scale use of renewable sources of electricity generation such as energy crops and wind energy. Increasing this capacity will prove much more economic and have less overall visual impact if implemented in a planned manner.

The case study also shows that there is considerable capacity available in terms of the basic resource from wind energy and biomass for electricity generation. The renewable energy is there to more than meet the UK targets and the distribution network could accommodate much of this. But in order to achieve 20% of electricity generation from renewable energy by 2020, a significant increase in the rate of new renewable sources of generation being built will be required. ●

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