ECOTRICITY WIND TURBINE AT SWAFFHAM: A CONNECTION CASE STUDY

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FOREWORD

This case study is written with the aim of providing prospective embedded generation developers with information on an actual wind generation connection. The issues are addressed using the minimum of technical terms, as far as this is practicable and it is intended that specialist knowledge or experience should not be needed to gain an appreciation of the financial and technical constraints involved.

Some information is given on the background to embedded generation in the UK and this is necessary in order to understand some of the legal and regulatory issues involved in the connection of embedded generation.

Despite efforts by the electricity distribution companies to streamline their procedures, the process of obtaining an electrical connection to the public electricity network can seem complex and this work does not attempt to cover all of the issues involved. However, the story of the Swaffham wind turbine hopefully clarifies some aspects of the process by reference to the actual events.

There were no wayleave difficulties experienced in the Ecotricity (the project developers) turbine connection and relationships with Eastern Electricity (part of Texas Utilities) and the local authority were cordial throughout. Eastern have since changed their connection enquiry process in the interest of better customer service. In this regard a typical DNO network connection process for embedded generation is shown in the appendix.

As is frequently the case with embedded generator connections, a detailed technical study was needed in order to establish how best the local electricity company or Distribution Network Operator (DNO) was able to accommodate the generation capacity. This is a critical factor in the costing of a generation project and the DNO network connection. In the case of the Swaffham wind project, significant changes were made to the network arrangements as a result of the study. This affected the eventual connection costs.

The Ecotricity wind turbine at installation at Swaffham is one of the most technically advanced in the UK and remains an example of leading edge design. Despite the difficulties experienced by both developer and REC, each has reported that relations between the principles and with the site contractors have remained both constructive and cordial.

ECOTRICITY LTD WIND TURBINE, SWAFFHAM, NORFOLK

A RENEWABLE ENERGY CONNECTION CASE STUDY

1. PROJECT STATISTICS

Technology
Onshore wind energy.

Location
Swaffham near Kings Lynn, Norfolk.

Regional Electricity Company
Eastern Electricity (24seven are now the joint venture operating company who act as agents for Eastern Electricity)

Energy Purchase Arrangements
NFFO-4.

Declared Net Capacity
1.5 MW from a single 1.5 MW Enercon E66 wind turbine

Turbine details

Rotor diameter	66m
Rotor speed	variable, 10-20.3 rpm
Pitch	variable, by synchronised motor drives
Yaw	active control by adjustment motors and friction damping
Generator	direct-driven, ring-type rotor and stator.
Cut-in wind speed	2.5 m/s
Rated wind speed	13.0 m/s
Rotor speed	10-20.3 rpm.

Date of NFFO bid March 1994.

Date of Final Commissioning May 1996.

2. BACKGROUND TO PROJECT

The site at Swaffham in Norfolk was originally the subject of a NFFO-4 application and award in 1996 for the forebears of Ecotricity, Western Wind Power Ltd. Ecotricity have developed a strategy for a post-NFFO green electricity supply business supported by generation from landfill gas sewage gas and wind turbines.

In the long term, the turbine at Swaffham will form part of this strategy, although, in the meantime, the electricity generated there will be purchased by the host electricity company, under the terms of the NFFO-4 order.

Ecotricity selected an unusual design of wind turbine for their site in Norfolk. Apart from being the largest turbines in the U.K. the electrical characteristics of the Enercon units are easily accepted onto electricity networks and can generate at low wind speeds.

The site at Swaffham was designated by the local authority to be developed as an Ecotech centre - a local centre for demonstrating and publicizing environmental issues.

Electricity Privatisation

In 1983 the Energy Act made provision for generators to export electricity over the public electricity network, however, this first step did not provide full electricity market opportunities for embedded generators. This came with the Electricity Act of 1989, which set up a trading market for electricity in the UK by commercially separating the activities of generation, transmission, distribution and supply. This also involved the disbanding of the CEGB and the creation of the generators National Power plc and Powergen plc and the transmission infrastructure company National Grid Company. The nuclear power stations later formed the basis of a further generator - British Energy. Other companies, not previously a part of the industry were also able to apply for a licence to generate electricity.

The Area Electricity Boards, hitherto responsible for the sole distribution and supply of electricity in their authorised areas, became Regional Electricity Companies (now known as Distribution Network Operators), with licences to distribute and supply electricity in their own area, but with the opportunity to acquire further licences to supply electricity to users in other DNO areas - the basis for competition in electricity supply. At the same time other energy companies also entered the market to supply electricity. A means of charging for the use of the local electricity distribution network was developed to enable the ‘distribution business’ to finance the planning, construction and maintenance of the network and this then provided the mechanism for a ‘carrier’ tariff to enable a fair charge to be made where the contract for electricity supply is with an organisation other than the host DNO.

Non-Fossil Fuel Obligation Order

In order to encourage the generation of electricity from new or renewable energy sources, at privatisation, the Government placed an obligation on the Regional Electricity Companies. This required them to purchase a certain amount of electricity from new and renewable sources and encouraged prospective generators to bid for electricity contracts under a mechanism known as the Non Fossil Fuel Obligation (NFFO).

The production of electricity from wind turbines was one of the technologies eligible for a 'NFFO' contract. The NFFO-4 order provided Ecotricity with an assured index linked price for the electricity generated for a fixed term of 15 years.

Electricity Supply Connection Arrangements - 'Competition in Connections'

RECs are bound by a licence obligation to facilitate connections to the public electricity distribution network equally to demand and generation customers.

In April 1995, the Office of Electricity Regulation (OFFER) introduced commercial competition into the process of obtaining connection to the public electricity distribution system. Once the electrical connection configuration has been determined by the host DNO, the developer can elect to appoint a contractor (as an alternative to the local DNO) to carry out certain aspects of new connection work (to include, for example, project management, procurement, trenching, civil works, electrical works and in some circumstances, electrical design). The local DNO will now provide a short list of 'preferred' contractors who meet their required standards for such work.

3. WIND TURBINE TECHNICAL BACKGROUND

Most wind generators are asynchronous 3 phase electrical machines driven by the turbine blades via a gearbox. Asynchronous machines are not able to generate below a pre-determined speed – according to the number of poles wound into the machine electrical field and the gearbox ratio. Furthermore, in order to generate power, the device must draw reactive power from the network or local capacitors. Reactive power drawn from the network can cause some connection complications for electricity companies, because local voltages on the network can be affected by this reactive power flow.

The particular turbine employed at Swaffham is unusual in several respects, apart from currently having the tallest turbine tower and the highest power output in the UK, it is connected to the local network via a power electronics converter. This device enables a synchronous generator to be used with the turbine. In this case, the generator forms an integral part of the turbine nacelle and employs no separate gearbox. Synchronous machines are fixed speed devices but with its a.c/d.c/a.c. power electronics link, this unit is able to generate at variable speed and without causing flicker on the network. A filter is also incorporated into the output circuit to avoid harmonics being injected into the local network.

Unlike asynchronous machines, which only generate at fixed speed, the power electronics link enables the Swaffham turbine to cut in at a very low wind speed of 2.5 m/s with rated power output available from wind speeds of 13.0 m/s upwards. Above 13.0 m/s, the variable pitch turbine blades progressively feather, allowing the rotor speed to rise to a maximum of 20.3 rpm, while maintaining rated output at 1.5 MW. The lack of electrical pulsing associated with the cutting in and out of conventional asynchronous devices is thus avoided and the ability to generate at low wind speeds increases the yield of the turbine.

4. GENERAL NETWORK CONNECTION LIMITATIONS

Owing to the physical scale of wind turbines, most sites proposed for this technology tend to be rural locations. Rural electricity networks are generally of lighter electrical capacity than urban networks. The effect of this is to restrict the potential installed capacity of embedded generation. Weak rural networks exhibit measurably higher point-of-use voltages at periods of low demand than at periods of high demand and the connection of a wind turbine will tend to increase voltages at periods of low demand. It is a primary responsibility of the DNO to operate a safe, reliable network which does not allow voltage swings beyond regulated limits. Despite the use of network automatic voltage regulators at higher voltages, voltage rise at periods of low demand remain the most common limiting factor in the rural connection of embedded generation. Since directly connected asymmetric wind turbines tend to absorb more reactive power as they generate more real power, then this effect may be less severe than initially expected. In practice, although the power factor of generators may be altered, as with the Swaffham generator, the operating regime will remain the responsibility of the REC who may insist that the device operates close to unity power factor – or within a range of values determined by network limitations.

If it is in the DNO's interest to use the characteristics of the generator for network support purposes, then the operating characteristics (as distinct from the energy generated) will form part of a separate contract for services with the REC. In this regard it would be conceivable that the energy, network support elements and Triad support could be traded individually, giving rise in principle to separate contracts with three parties.

Conventional wind turbines without 'soft start' thyristor equipment can create short term voltage fluctuations as they cut in and out. This is experienced locally by electricity users as 'flicker' and is a further limiting factor on weak rural networks where the fault level is low. Conversely, variable speed turbines using power electronics couplings should have less effect on network flicker, although DNO's will need to satisfy themselves that levels do not cause a local deterioration in quality of supply.

Power electronics devices can nevertheless create harmonics – higher frequency currents which can distort the sinusoidal quality of the local public electricity supply. The DNOs work to national maximum limits of harmonics on their networks and may therefore require a harmonic analysis of proposed power electronics controllers in order to satisfy their licence obligations in respect of power quality. Since power electronics controllers use a similar technology to variable speed motor drives, which are now commonplace, this technical issue is unlikely to be a major limitation in practice.

Developers should note that DNO's will usually require the connection of wind turbines to the network to be made at 11kV and to a three phase line of adequate capacity.

5. SITE SPECIFIC CONNECTION ISSUES.

The choice of the site at Swaffham in 1996 was influenced by the planned establishment locally of the Ecotech Centre. Application was subsequently made to Eastern Electricity for a budget connection cost, on the basis of the availability of a suitable and sufficient adjacent 11kV overhead line.

- The developers were quoted a budget estimate of £40,000 by Eastern Electricity and this itself was subject to an administration fee of £500. A network connection to an embedded generator is normally subject to a whole cost contribution from the generator developer. The charging philosophy is different from that employed in calculating the capital cost contributions required for demand customers (consumers) since the latter results in income to the DNO distribution business via 'use of system' or transportation charges. In the case of embedded generation, 'use of system' charges are not normally applied and so a whole cost contribution is required.

  Note Electricity companies' infrastructure and staffing is conventionally funded from electricity demand customers and therefore all costs associated with individual embedded generators must necessarily be borne by those generator developers. While most electricity companies will usually meet developers to discuss broad principles of connection at nil cost, or for a notional fee, when network details need to be examined and calculations made, all companies will seek to recover the full costs involved. This work cannot be a final design, since that implies the need for network details and generator machine characteristics, which are not normally available at that early stage. However these outline proposals should be sufficient to enable application to be put forward for project finance, or, as with the Swaffham turbine to enable a NFFO bid to be constructed.

- Following the budget proposal by Eastern Electricity, a planning application was made to the local authority, which was readily accepted. In parts of the U.K. local authorities have placed planning limits on the extent of wind turbine development.

- In 1998 the developers returned to Eastern Electricity to request confirmation of the point of connection. At this time the electricity company needed to carry out the detailed network study referred to above. The network study costs amounted to £2,500. In the intervening period, local changes had taken place to the distribution network, arising from increased network loads. This, together with the detailed study, resulted in a different network connection arrangement from that envisaged at the initial budget stage.

  The detailed study could not however be carried out before the full generator characteristics were available to the REC. In the event, a cautious approach to the

risk of flicker from the turbine, combined with the recent local network changes, resulted in a closer point of connection.

- Following the detailed network study, a connection offer price of £41,000 was made to the developers in October 1998, and was revised to take separate account of the contestable element of the work in February 1999.

- The developers elected to use a 3rd party utility services contractor to carry out contestable elements of the connection, including civil works, excavations and cable laying. Supply was finally energised in August 1999.

Final supply arrangements

The point of connection to the local network is an 11kV SF_6 (Sulphur hexafluoride) metalclad ring main switchgear unit, which, unusually shares a common enclosure with the developer's resin insulated generator transformer, adjacent to the turbine tower.

The generator electrical protection equipment, 400V switchgear and turbine electrical controls are mounted within the same building as the high voltage equipment, but in a separate room, accessed via its own external door.

2, 200m lengths of 150mm^2 ethylene propylene rubber (EPR) 11kV underground cable link the connection into the local 11kV ring circuit from Swaffham Grid substation.

Wayleave arrangements

An important aspect of obtaining an electricity supply connection is the negotiation by the REC of wayleaves – seeking permission to lay cables or erect overhead lines on private property. While a selected route or means of distribution may seem the cheapest due to short lengths of underground cable or overhead construction, the landowner can object to the use of his land and refuse a 'wayleave', forcing the use of alternative arrangements. In this case, the local authority was the landowner and pledged support for the overall turbine scheme, which was at the heart of the intended Ecotech Centre.

<u>Note</u> While an REC is obliged to negotiate wayleaves on behalf of generation and demand customers alike, some landowners have, in the past taken the view that future demand use is a more acceptable reason for allowing a wayleave for conductors under or over their land than generation - which will enable the generator/developer to profit expressly from the connection by virtue of the sale of energy and possibly other network benefits over the conductors.

6. CONCLUSIONS

Inevitably, in a project which is novel in concept and execution, there are lessons to be learned for all concerned. However, relationships remained cordial and Ecotricity have since commissioned and built a second wind turbine at a site at Bloodhill, near Great Yarmouth, also in Eastern Electricity's area. This was a technically different development and substantial changes were eventually needed to the planned connection route in order to secure wayleaves for the underground cable to the site. Such major changes call for close liaison between the DNO, the developer and any site contractor. 24Seven (for Eastern Electricity) and Ecotricity have commented in relation to the two developments as follows.

- Eastern Electricity has made amendments to its connection enquiry process to assist developers, but they continue to underscore the need for a detailed understanding by developers of the 'Competition in Connections' process.

- The sequence of events in the commissioning of the electrical protection equipment is critical and close co-ordination between DNO, developer and turbine commissioning staff and any site electrical plant contractor is essential.

- The physical scale of large wind turbines calls for heavy lifting plant. This should be used in conjunction with a detailed method statement, prepared with input from all site professionals, to ensure the integrity of cable routes and other local buried services.

- Ecotricity considers Eastern Electricity to be a helpful, pro-active DNO in relation to embedded generation. The final connection costs can differ substantially from the budget indication however and Ecotricity would like to see clear explanations of such changes.

Finally, as further endorsement of the working relationship, it is understood that a second turbine is now planned for the Bloodhill site.

FURTHER INFORMATION

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APPENDIX

Typical outline procedure for achieving the connection of an embedded generator. Note particular policies will vary between DNOs.

Customer/developer Action	Distribution Network Operator Action
Make initial enquiry to DNO (verbal)	Inform customer of: • charges for feasibility study • information required from customer • effect of inflation on construction works
Formalise enquiry: • accept feasibility charge • provide outline information	Commence feasibility process • check completeness of information provided • verify/call off payment • raise internal documentation • estimate cost of detailed network design study. • notify customer of feasibility study
Receive feasibility, accepts detailed design charges + agreement to provide further technical information as required.	Commence detailed design process: • check completeness of information provided • verify/calls off payment • raise internal documentation • carry out design • compile quotation for network construction • plan and programme for construction. • obtain wayleaves/easements • prepare design/quote response to customer as connection offer
Accept connection charges and provides any further technical information	Commence construction process • verify customer's acceptance • verify wayleave acceptance • call off payment (less design fee) • construct network alterations
Liase with DNO re. competition in connection options and construction programme	liaise with customer/agent re. competition in connection options and construction programme
Liase with DNO re. commissioning tests and electrical protection tests	Liaise with customer re. commissioning and electrical protection tests.