COMMERCIAL SCALE ELECTRICITY GENERATION FROM WIND POWER IN GUERNSEY – A METEOROLOGICAL PERSPECTIVE

Introduction

This chapter will examine meteorological processes that relate to commercial scale renewable energy production in the form of generation of electricity from wind power. Solar energy is also discussed briefly.

The characteristics of wind flow in the Bailiwick of Guernsey

Wind Direction

Guernsey is said to have a prevailing south-westerly wind but this does not begin to describe the local peculiarities of wind flow across the island. The following wind rose diagram (Fig 1) shows wind direction averaged over 30 years at Guernsey Airport. The figures on the y-axis show the average percentage of time with light and stronger winds in each 30° sector.

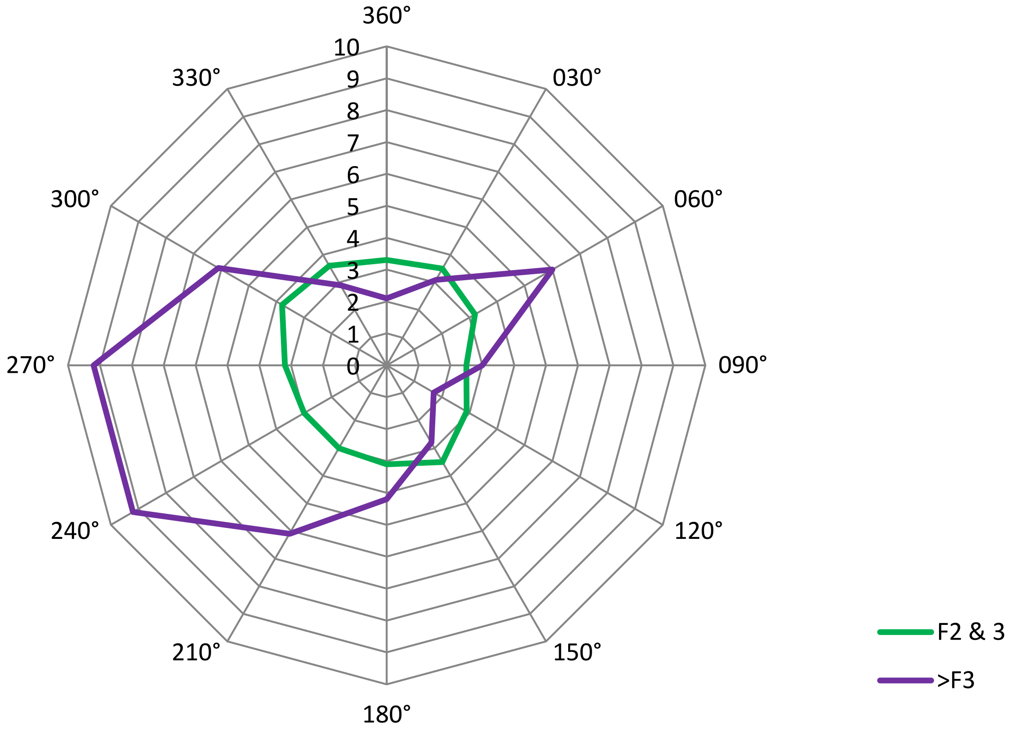

Fig. 1

The diagram shows that light winds of force 2 or 3 have no real prevailing direction whilst stronger winds of force 4 and above come mainly from a quadrant centred on a west-south-westerly direction. East-north-easterlies also provide many days with stronger wind speeds but strong winds from due north and from the east-south-east are relatively rare. The wind rose shows the 2 main influences on wind flows across the island, namely:

1. The established global circulation patterns which – in the North Atlantic Ocean – favour the development of semi-permanent "Icelandic Low" and "Azores High" pressure systems. The resulting atmospheric pressure differential forces a west or south-westerly airflow over the island which is generally stronger in winter than in summer.
2. The proximity of a large continental landmass which occasionally affects atmospheric pressure patterns and wind flow across the island. Strong solar heating of France combined with relatively cool sea temperatures over the English Channel can cause surface air pressure to fall over France with the formation of a "heat low". The effect is negligible in winter but reaches a maximum during spring and early summer (when land / sea temperature differences are at their highest) with east-north-easterlies being the most common local wind direction in the months of April and May.

The anemometers at Guernsey Airport are located so that they are not subject to any notable sheltering or funnelling effects and this means that the wind direction data from the airport can be used as a good guide for the open waters surrounding the island with the minor caveat that winds over the sea tend to slightly more "veered" than over land – hence a wind direction of 270° over open waters may be recorded as 250° or 260° at the airport. Only waters within a few hundred metres of the shore (especially where the shoreline consists of cliff) are likely to differ notably with respect to wind direction characteristics. On the island itself, various locations will however be subject to localised funnelling and sheltering and – in certain inland locations - this may alter the directional characteristics of the wind flow to a great extent.

Wind Speed

The mean wind speeds (in knots) at Guernsey Airport in 2010 and averaged over the past 30 years are shown in the table below together with some additional data on extremes:

WIND SPEED										
	MEAN SPEED (KNOTS)		NUMBER OF DAYS OF GALES				HIGHEST GUST (KNOTS)			
MONTH	2010	AVERAGE 1971-2000	2010	AVERAGE 1971-2000	RECORD HIGHEST	YEAR	2010	DATE	RECORD HIGHEST	DATE
JAN	10.8	14.7	0	2.6	11	1984	41	16th	77	25/1990
FEB	12.1	13.3	0	1.5	10	1990	41	28th	69	9/1988,11/1990
MAR	12.1	12.6	1	1.0	6	1980	53	31st	70	10/1982
APR	10.6	11.9	0	0.3	2	1964,72,83,94	37	2nd	60	9/1994
MAY	9.0	11.1	0	0.1	2	2007	30	10th	58	19/1996
JUN	8.1	10.6	0	0.0	0	–	34	10th	51	16/1965
JUL	8.7	10.3	0	0.0	1	1956,69	37	14th,15th	63	31/1983
AUG	10.6	9.7	0	0.0	1	1956,61,86	36	23rd	52	26/1986
SEP	9.8	11.1	0	0.2	2	1953,65,74,83	36	14th	60	29/1962
OCT	11.7	12.5	0	0.9	4	1967,76	41	23rd	81	16/1987
NOV	12.2	13.5	2	1.3	8	1977	52	11th	73	23/1984
DEC	11.1	14.5	0	2.2	9	1979	42	20th	83	15/1979
YEAR	10.5	12.1	3	10.1	20	1972	53	31-Mar	83	########

Fig. 2

The 30-year averaged wind speed at Guernsey Airport is therefore 12.1 knots ($6.2ms^{-1}$). The anemometers are located approximately 12 metres above the airfield. Whilst this figure would be very useful to a householder wishing to install a domestic wind turbine on the roof of a property that had good exposure to the wind, the figure does not give a good representation of the wind speed that would be experienced at the turbine height of a commercial wind farm for reasons that follow.

Whilst Guernsey Airport's wind direction data can be considered representative of unobstructed low level wind flow across the Bailiwick, its wind speed data needs careful interpretation. Several factors ensure that wind speeds across Guernsey and its surrounding waters can vary notably.

1. Altitude of different locations – wind speeds usually increase with altitude.
2. Sheltering – this may be induced by upwind obstructions such as trees and buildings
3. Funnelling – this effect produces localised increases in wind speed caused by airflow being channelled between obstructions or between larger topographical features such as hills.
4. Turbulence – although turbulence may not greatly affect the mean speed of the overall airflow, turbulent flow can cause problems for wind turbines and is therefore mentioned. It can also interfere with ability of instrumentation to accurately gauge wind strength.
5. Frictional effects – friction between the airflow and the surface of the earth has the effect of decreasing wind speeds in the lowest layer of the atmosphere.

The first four of these factors are easily comprehended and need not be discussed further although it should be noted that funnelling and sheltering effects often occur at the same location – all that is needed is a change in wind direction. Frictional effects, however, need further explanation as they vary widely across Guernsey and its surrounding waters and should therefore be fully understood before any decisions are made on the siting of commercial scale wind energy production.

Frictional Effects on wind speed

Frictional effects vary depending on the type of surface over which the wind is flowing. The open, largely unobstructed grassland and concrete surfaces which cover the airfield at Guernsey provide a relatively low friction surface in comparison to a built up area such as the Town Centre or a wooded area such as that which partly surrounds St Saviours Reservoir. Winds speeds at the airport therefore are almost always higher than in these other two locations.

Land surfaces of any nature apart from smooth ice and snow, however, tend to exert a greater frictional drag on airflow than water surfaces. As a result, wind speeds at sea tend to be higher than those experienced under the same weather conditions on land unless the land observer is standing in a location where relatively high altitude and funnelling of the wind overcomes the increased friction of the land surface. An example of such a location is La Coupée in Sark where funnelling can occur if winds are strong and from the WSW or ENE, but such locations are relatively rare.

As has been mentioned, the Guernsey Airport anemometers are generally free from the effects of sheltering, funnelling and turbulence, but they are not at the same height as the hub of a commercial wind turbine, which may be anything from 20m to 70m higher. As the altitude increases, the frictional effects that characterise the surface layer become less pronounced and the wind becomes stronger. The resulting wind profile is known as the **wind gradient**. Over open water, the frictional effects of the water surface are relatively small anyway, and it is for this reason that offshore wind speeds in the lowest layer of the atmosphere tend to be higher than those experienced over land.

Wind Farms

Before considering the viability of commercial scale electricity generation from wind power, it is necessary to understand how it is utilised in the United Kingdom and continental Europe. Groups of wind turbines – collectively known as wind farms – have been installed in increasing numbers in recent years. Wind farms can be divided broadly into onshore and offshore sites with onshore sites being less expensive to develop, but offshore sites being less visually intrusive and more productive in terms of electricity generation.

Fig. 3 (copyright free)

The amount of electricity generated by a wind farm depends on a number of factors including:

1. Installed Capacity
2. Load Factor

The installed capacity refers to the total number of megawatts (MW) which can be generated if each turbine is working at its highest efficiency.

The load factor is the ratio of the net amount of electricity generated by the wind farm divided by the net amount of electricity that the wind farm would have generated had it been operating at its net output capacity. The load factor for wind energy in the British Isles falls within the range of 25% to 40% in a year when wind speeds are average. The prevailing west to south-westerly wind that blows across the British Isles is, on average, strongest in the north and weakest in the south. A wind farm located in Guernsey or its surrounding waters, therefore, would experience a load factor at the lower end of this range.

Thus, to give an example, if a small wind farm was established in the Bailiwick with an installed capacity of 2MW and a load factor of 28% is assumed, the wind farm would produce a theoretical 4,906 MWhours per year[1]. In practice, this would be reduced somewhat by turbines failing or being taken offline for maintenance and also by power transmission losses which will depend on the distance of the wind farm from the customer. To state the obvious, generation of power is limited to periods when the wind is blowing with sufficient strength. Commercial wind turbines are generally allowed to turn slowly in low wind speeds but do not generate viable amounts of electricity until a certain threshold wind speed is attained. Similarly, in very high wind speeds, electricity generation may be suspended to avoid damage to the turbine and surrounding infrastructure.

Siting of Wind Farms

As may be appreciated, the correct siting of a wind farm is critical with regard to its efficiency. A wind farm with a high load factor is considerably more efficient than one with a low load factor. For this reason, we must now consider which areas of Guernsey and its surrounding waters would be most suited to the installation of wind turbines. To sum up, these areas should:

- Be as free as possible from the effects of wind sheltering, funnelling and turbulence.
- Be where frictional effects (as discussed above) are as low as possible.

It is not within the scope of this chapter to comment further, but other considerations affecting the siting of onshore wind farms would obviously include the planning process, proximity to housing and how any installations of commercial wind turbines could impact negatively on existing systems such as the Guernsey Airport radar. Other considerations – such as the latter – could also affect siting of offshore wind farms.

It is therefore important that studies are undertaken to measure or accurately estimate wind speeds at turbine hub height in the areas that are seen to be most favourable for the generation of wind power. The areas which may be practicably used for an onshore wind farm are small. Residential development covers much of the island leaving only cliff lands, some coastal promontories and offshore islets as possible sites.

Areas adjacent to the cliffs in the southern half of the island are generally unsuitable as the cliffs can force an airflow to rise almost vertically in places which, in turn, produces wind shear and turbulence over the cliff lands and renders them largely unsuitable for the placement of wind turbines. Other lower-level coastal promontories may be partly sheltered by nearby high ground.

Two areas that appear to have potential for onshore wind generation are Lihou Island and certain exposed sites in the far north of the island such as Chouet. Lihou has a small amount of shelter from high ground to the east and south-east, but as can be seen from figure 1, strong winds from these directions are relatively infrequent. Chouet, apart from one or two small stands of trees, has little natural shelter from any direction.

Although Guernsey Airport has a long record of wind data, it is unfortunate that the island has no corresponding data set for offshore winds. Data sets such as that for the Channel Light Vessel exist, but that site is too distant from the island to be wholly reliable as an indicator of local marine winds. Enquiries to Trinity House elicited the response that wind data for Les Hanois and the Casquets lighthouses were not kept. Other calibrated anemometers – such as the one at St Peter Port harbour – can give an indication of marine wind speeds but only when the wind is blowing from a direction that is not subject to sheltering or funnelling effects from the adjacent land.

Measurement of coastal wind speeds

Before the suitability of any site for any onshore or offshore site can be assessed, there is a need for at least one full calendar year of wind data from a site that is well exposed to marine winds.

This can be done by several methods:

- Direct measurement at hub height (best if wind farm site is known and approved)
- Remote sensing – e.g. SODAR
- Measurement and extrapolation

Fig. 4 - Source: Garrad Hassan and Partners Ltd

Direct measurement

Direct measurement involves erecting a tower and installing an anemometer at turbine hub height together with a data logger. Onshore, the tower may have a height of 50m to 80m and will need a substantial concrete base. Offshore, the installation of a tower fixed to the seabed as in Fig. 4 is occasionally undertaken in the investigatory / planning stage for wind farm developments.

Direct measurement provides an accurate measurement of turbine height wind velocities. The cost of the mast installations is however high. An offshore installation that is anchored to the sea floor as in Fig.4 can be as expensive as £1m^2. The development of an adequate database of wind conditions using this method usually takes about 2 years.

Remote Sensing – e.g. SODAR

SODAR stands for Sonic Detection and Ranging and is similar in many ways to RADAR with the exception that sound waves rather than radio waves are used for detection purposes. The system operates by issuing an acoustic pulse and then analysing the intensity and Doppler shift of the return signals. With recent technological advances, even a low range SODAR can now be used to accurately profile wind direction and velocity up to heights of several hundred metres which is considerably higher than is needed for a local study relating to wind energy. Unlike many other measurement systems, SODAR is also able to detect and measure levels of turbulence in the atmosphere.

Fig. 5 (copyright free)

SODAR units are, however, generally large, expensive and vulnerable to vandalism. Their use offshore tends to be limited to fixed platforms such as those already installed and utilised by the oil industry. The best suitable local sites for such a unit would be areas from which the public are barred and where there is a 24 hour security presence, but such suitable locations – such as Guernsey Airport – do not coincide with plausible wind energy generation sites. SODAR at Guernsey Airport could prove useful for detecting any potential turbulence and wind shear dangers for aircraft on approach, however SODAR is not generally considered to be essential at the world's airports. Proposing a SODAR installation at Guernsey Airport for the dual use of wind profile data gathering and aviation safety would therefore raise questions of cost effectiveness that would not be easily answered.

Doppler LIDAR (Light Detection and Ranging) can also be used to accurately profile wind direction and velocity in an atmospheric "cone" several hundred metres high.

Measurement and Extrapolation

Although direct measurement of wind speed at turbine height by means of a high mast or using SODAR ensures data that accurately represent winds at this level, as has been mentioned, the costs of purchasing and installing either high masts or SODAR would be considerable. As a less expensive option, monitoring could take place from a relatively low mast (e.g. 10 metres) similar to the one shown in Fig. 6 provided that it is sited in an exposed coastal area – preferably in a location that is seen as promising such as the Chouet peninsula. Ten metre wind data could then be extrapolated to provide an estimate of wind strength at the turbine height of an onshore installation.

A minimum of 12 months of data gathering would be needed, after which the data from the 10 metre mast would then need to be analysed and converted to an estimate of the turbine height wind. One equation that is sometimes used to estimate wind gradient by wind energy engineers is expressed as follows:

where:

v_w is the wind velocity in ms^{-1} at turbine hub height
v_{10} is the wind velocity in ms^{-1} as recorded by the anemometer on the 10m mast
h is the height of the wind turbine hub in metres
h_{10} is the height of the mast (=10 metres in our case scenario)
α is the Hellman exponent

However, a more widely recognised equation based on meteorological processes is the following logarithmic relation:

where:

u(z) = wind velocity at height (z) in metres
u* is the shear velocity

κ is Karman's constant
z_0 is the roughness height

Before an average turbine height wind could be calculated however, Guernsey Airport wind data would then need to be analysed for the period in question to ascertain the windiness of the 12 month period against Guernsey Airport's 30 year average winds. The raw data would then need to be adjusted accordingly to give a statistical interpretation of the 10 metre wind for a year with average windiness. This averaged figure could latterly be extrapolated to show average wind speeds at turbine hub height and then used to calculate potential electricity generation figures for the site and as a minimum indication for an averaged wind velocity figure for an offshore wind farm.

Fig.6 – Measuring wind direction & speed at 10 metres. Source: Campbell Scientific

Before leaving these equations behind, it is worth noting that they also illustrates the fact that wind turbines with the highest hub heights are able to take advantage of stronger wind velocities not to mention the fact that these larger structures allow for the installation of larger turbines with greater generating capacities. In this vein, therefore, bigger installations are more efficient installations and in the event that an onshore wind farm is contemplated it must be said that the efficiency of the installation will be in proportion to its visual intrusiveness.

Other ways of measuring and estimating average wind speeds offshore Guernsey

Accurate measurement and/or estimation of offshore winds is more difficult and expensive than measurement and estimation of onshore winds, but remains possible through a variety of methods. In general though, these methods may be worthy of investigation and financial investment only after a definite decision has been made to undertake detailed professional investigations of offshore wind power generation at a specific offshore site.

The measurement and extrapolation technique described in previous paragraphs can be used in a more complex form known as **MCP (Measure Correlate Predict) Analysis**. MCP could be used in conjunction with data from a 10 metre mast and datasets from nearby locations such as Guernsey Airport and the Channel Light Vessel. Further data is also available from the NCEP/NCAR[3] Wind Reanalysis database which contains data that runs from 1948 to the present.

Computer models may also be used to obtain predicted average turbine height winds. Such models may utilise data from the NCEP/NCAR Reanalysis database, but are designed to be more user friendly to the wind energy industry and offer better resolution of wind speeds than the NCEP/NCAR's rather coarse 2.5° grid.

Existing records from nearby French wind farms may also be of use although none are sufficiently close to Guernsey to be relied upon completely. As an example, Les Grunes Wind farm, which is located between Jersey and the coast of Normandy, quotes a 10 year mean wind speed of 9.28ms^{-1} at a height of 100m a.m.s.l.[4] Whilst it would be tempting to use this figure for planning purposes, it should be noted that the wind farm may benefit from a continental sea breeze effect during the summer months. Conversely, winds from winter depressions passing over or to the north of the UK should be slightly stronger on average over the waters to the NW of Guernsey than over Les Grunes.

It should also be noted that if offshore wind turbines with a relatively low hub height are constructed in Bailiwick waters, a large tidal range means that the effective hub height above water level may be variable enough to affect hub height wind speed in rough weather when high seas exert a greater frictional effect on the lowest layers of the airflow.

Annual and short period variations in local wind speeds

In considering commercial scale generation of electricity from wind power, some comment must be made about the inter-annual and short-period variability of local wind speeds. Figure 2 shows the averaged wind speed in 2010 to be 1.6 ms^{-1} lower than the 30 year average speed. Such a deviation from average is not uncommon. There are also windier years when Guernsey's weather patterns are dominated by a mobile westerly regime with long series of depressions moving over or to the north of Scotland. These variations are not, however, necessarily random and one of the lessons of the local weather record is that calmer years and windier years often group together and these periods of calmer or windier conditions can persist for as long as a decade or two.

The reason for the annual variation has much to do with a climatic phenomenon known as the NAO (North Atlantic Oscillation) which is strongly linked to the strength and direction of travel of depressions in the North Atlantic. As a broad generalisation, high NAO values are associated with windy years, mild winters and an above average number of gales, whilst low NAO values bring calmer conditions, an increased risk of severe cold in winter and few gales. A graph of NAO values shows occasionally quite marked decadal variations. The most recent variation has been towards lower annually averaged NAO values.

The NAO also varies markedly on a shorter timescale that can be measured in terms of days and weeks and this shorter term variation also affects local wind speeds especially in winter.

Unfortunately, the dynamics of the NAO are not completely understood and prediction of NAO values becomes unreliable after 7 to 10 days. This therefore raises the prospect that monthly and annual averaged wind speeds across the island are – for the foreseeable future – unpredictable and notably variable.

Trends in local wind speeds

The variability of annually averaged wind speeds and the tendency of calmer and stormier years to group together can easily lead to a misinterpreted trend via the selection of inopportune start and end dates so there is a need for care to be taken in the interpretation of local wind data.

Some older members of the public have commented to Guernsey Met Office on a perceived fall in average wind speeds in recent decades. If this could be proven, it can probably be attributed to new building developments and a gradual restoration of tree cover following the tree-felling and fuel shortages that occurred during the latter part of the German occupation. These local observations do not, however, indicate that turbine level wind speeds have fallen across the island but rather that the frictional effects of new buildings and trees have reduced wind speeds in areas where people notice.

Climate models have generally forecast increased storminess and higher averaged wind speeds over the north Atlantic and north-west Europe in response to human induced climate change[5]. As a result of this, Professor Edward Hanna from the University of Sheffield undertook a wide ranging and comprehensive study of surface pressure variability (a proxy for changes in wind velocity) across Northern Europe and the North Atlantic[6] which included the use of data from Guernsey. The study concluded that wind strengths and storminess had not increased in recent decades. This accords with Guernsey Met Office statistics from Guernsey Airport which show no statistically significant change in wind speed over long periods of time.

The Radar Issue

The chief problem with wind turbines and radar is with primary radar, where a ping is sent out and the scatter is received to identify moving objects. With a wind farm on a hill there would be a shadow effect, although that is not an issue here. Most radar now work on the Doppler principle where the radar looks for moving targets and turbines are moving targets. While this is not a problem in itself as most computers now have the processing power to deal with the constant movement, the problem arises in tracking a target through wind farms. Most radar manufacturers now accept that this is an issue that needs to be overcome and have working technology that allows tracking of targets over turbines. This means that the wind farm itself would not provide any insurmountable obstacle. The main issue would be the **additional costs** associated with each additional wind farm, it takes 2 to 3 months to optimise radar to its environment and every new wind farm would need re-optimisation, which would require someone from the company to come to Guernsey.

There can also be some problems with secondary radar through scattering the signal, but this is not usually an issue.

More information on wind farms and aviation is available from the Civil Aviation Authority - http://www.caa.co.uk/application.aspx?catid=33&pagetype=65&appid=11&mode=detail&id=2358

Notes and References

[1] Calculated as 2 x 0.28 x 24 x 365

[2] Intelligent Energy Europe - http://www.wind-energy-the-facts.org/en/part-i-technology/chapter-5-offshore/wind-resource-assessment-offshore/measurement-offshore.html

[3] National Center for Environmental Prediction / National Center for Atmospheric Research

[4] Data from Global Offshore Wind Speed Database - http://www.4coffshore.com/windfarms/request.aspx?id=owsdb&version=2&windfarmid=FR10

[5] Singarayer, J.S., J.L. Bamber, JL & P.J. Valdes (2006) Twenty-first-century climate impacts from a declining Arctic sea ice cover, *Journal of Climate* 19, 1109-1125.

[6] Hanna et al (2007) New insights into North European and North Atlantic surface pressure variability, storminess and related climatic change since 1830 (Journal of Climate).

Hanna commented in his conclusion as follows: "….in general, global climate model (GCM) projections of changes in North Atlantic storminess (as a main example) vary widely and remain unreliable. The models are in urgent need of further refinement and need to be checked against an improved observational record (IPCC 2007**)**."