Omnidirectional Radio Station Infrastructure.

Methodology for the Prediction of Wind Turbine Interference Impact.

Introduction

NATS has made a considerable investment over a period of years in funding and resourcing a program of field trials, independent academic study, and laboratory testing of radio equipment in order to understand and predict the technical impact of wind turbine development on Air Traffic Control radio communication systems. Aeronautical communications services are safety critical by their very nature and NATS is required under the terms of its operating licence and the Air Navigation Order to safeguard its infrastructure against inappropriate development. Our company policy is to support the development of renewable energy resources, whenever it can be demonstrated that the proposed development will not compromise the safe provision of services.

This document is intended to provide guidance to enable the prediction of wind turbine interference impact upon radio station infrastructure used for the provision of Aeronautical Communication Services.

Turbine interference prediction is a complex process which requires a detailed technical knowledge of radio propagation theory and the application of a defined prediction methodology.

Prediction of turbine interference impacts above a threshold value will not automatically result in the rejection of a given development proposal. Technical impact (interference levels) and operational impacts are assessed separately. The type of operational usage and the geographic location and volume of affected airspace (Volume of Interest) will affect the level of operational impact and hence sensitivity to a particular development proposal.

The level of technical impact in any given scenario will vary considerably dependant upon a number of variables including but not limited to:-

- Size of turbine
- Rotation rate
- Number of turbines
- Development layout
- Adjacent developments (accumulated impact)
- Physical separation from the radio station
- Terrain profile
- Signal levels
- Transmitted frequency

A wind turbine can produce two types of signal interference which are significant in the context of Aeronautical Communication Systems i.e. multipath reflection and amplitude modulation in the form of repetitive fast fading.

Multipath reflection is caused by reflection and re-radiation of a radio signal from the turbine tower structure – this is exactly the same phenomenon which would have caused image ghosting on an analogue television signal.

Amplitude modulation in the form of fast fading can be visualised as being a similar effect to that which would be observed when shining the light from a torch through the rotating blades of a desk fan.

Two assessment methodologies are discussed within this document, as follows:-

- Method 1 - Zonal assessment – Red, Amber, Green (RAG method)
- Method 2 - Carrier to Interference ratio prediction (C/I method)

The RAG method is used to enable a quick pass GO/NOGO assessment to be made for a proposed development and class of turbine, and to define the region of uncertainty where a more complex technical analysis will be required, supported by an operational airspace impact assessment.

Turbine Classes

This document defines five separate classes of wind turbines found in the UK as shown in table 1 below. These classifications have been defined to provide consistency in the safeguarding process. The reference turbine type is a design in common usage. Where a chosen turbine type is a borderline match for two classes and the appropriate classification may be ambiguous, then the larger turbine classification should be utilised for impact assessment.

Example - A turbine with hub height 20 metres, rotor diameter 18 metres, tip height 29 metres is classified as Medium Class due to the rotor diameter exceeding 15 metres.

Turbine Class	Hub Height Range	Rotor Diameter Range	Tip Height Range
Small	< 20 metres	< 15 metres	< 27.5 metres
Medium	20 – 40 metres	15 – 35 metres	27.5 – 57.5 metres
Large	40 – 60 metres	35 – 60 metres	57.5 – 90 metres
Reference	80 metres	90 metres	125 metres
Large Industrial	60 – 95 metres	60 – 126 metres	90 – 158 metres

Table 1 – Turbine Classes

NATS Radio Station Infrastructure

NATS operates a network of radio stations throughout the UK. These radio stations provide a range of operational services using the VHF and UHF aeronautical communications frequency bands. The relative level of operational sensitivity for a given development proposal will be principally be determined by terrain profile, the type of operational services being provided by the radio station and the volume of airspace affected. In general terms, VHF communications services tend to be less sensitive than UHF services to turbine related interference as can be determined from the relative RCS values for VHF and UHF bands in tables 4 and 5 below.

Carrier to Interference Ratio

For any proposed development, peak levels of turbine related interference (Carrier to Interference) must fall below a defined tolerance threshold (in dB) at the receiving equipment aerial input in order to guarantee the safe provision of services. This C/I value ensures that audio quality as perceived by either Air Traffic Controller or Pilot is not significantly impaired. The threshold value was determined from laboratory based susceptibility testing of a wide range of ground based and airborne radio receiver types. It has a modest safety margin included to allow for signal fading, effects of weather, multipath reflection etc., which will all potentially degrade the C/I ratio further.

Radar Cross Section

Radar Cross Section (RCS) is a critical radio frequency parameter which indicates the 'relative reflectivity' of a target and which is related to the physical dimensions of the target object and the illuminating radio frequency. In simple terms, the use of RCS allows the extent of turbine related interference to be determined for a specific type of turbine. The RCS value is a number defined on a logarithmic scale and it increases with turbine dimensions and frequency of radio signal. RCS values have been assigned to the classes of turbine as defined below and these values were used to define the extent of their associated RAG assessment zones.

A reference turbine class has been defined (see below). RCS values for this turbine type have been established and refined over a period of time in line with the practical application of safeguarding high availability critical infrastructure systems. RCS Values have been assigned to four further classes of wind turbine – these values have been scaled from the reference turbine RCS at 461 MHz in terms of swept blade area and radio frequency.

RCS values have been calculated assuming an illuminating frequency of 127 MHz for VHF, and 368 MHz for UHF frequency bands.

Method 1 - Zonal Assessment

This method has been developed to enable rapid and non technical GO/NOGO assessments to be made for simple development proposals only – i.e. between 1 and 10 turbines. Where the development proposal is complex in terms of scale, local environment, cumulative impact or terrain profile then this method is not appropriate but it can be used to obtain an initial indication of potential impact.

Zonal assessment is made on the basis of two parameters:-

- Minimum separation between turbine and infrastructure site assuming a flat earth
- Angular displacement of turbine hub with respect to infrastructure site base level

Reference to Figure 1 and Table 1 will allow a Zonal assessment to be conducted.

Assessment zones are defined as follows:-

- RED – The minimum separation distance from an infrastructure site at which a single turbine of a given class can be sited and which will ensure a minimum acceptable C/I ratio at the receiver equipment. Violation of this parameter will result in automatic rejection of the development proposal.

- GREEN – The separation distance from an infrastructure site at which a multiple turbine development (up to 10 turbines) of a given class can be sited and which will almost certainly exceed the required C/I criteria at the receiver equipment irrespective of terrain, geometry and operational considerations.

- AMBER – The separation range situated between RED and GREEN zones. In this region it is anticipated that the proposed development will produce a level of comms interference and could potentially impact safe service provision. An amber zone assessment will not necessarily imply rejection of the proposal. The development will require a more detailed technical assessment using the C/I method as defined below with any degradation in communications performance deemed acceptable following an operational impact assessment conducted by NATS air traffic operations personnel.

  NOTE – It is apparent that the probability of acceptance for a development falling within the amber zone definition increases as physical separation and elevation angle tend towards the green zone.

RAG Safeguarding Criteria – nearest turbine

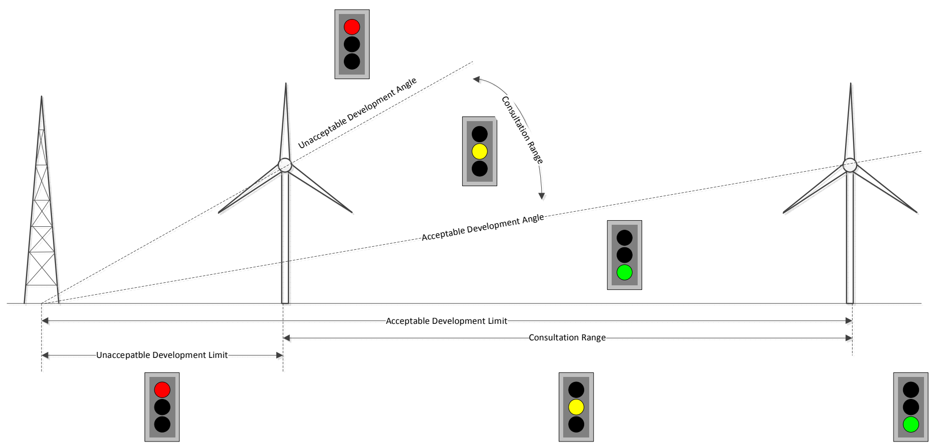

Figure 1 – RAG Assessment Methodology (for illustration purposes only)

	Distance		Angle	
	Red (km)	**Green (km)**	**Degrees Red**	**Degrees Green**
Large Industrial	2.1	17.2	2.6°	0.4°
Reference	1.3	10.5	3.5°	0.5°
Large	0.8	5.8	3.6°	0.6°
Medium	0.5	3.5	4.6°	0.7°
Small	0.25	1.8	4.6°	0.7°

Table 2 – RAG Assessment Parameters

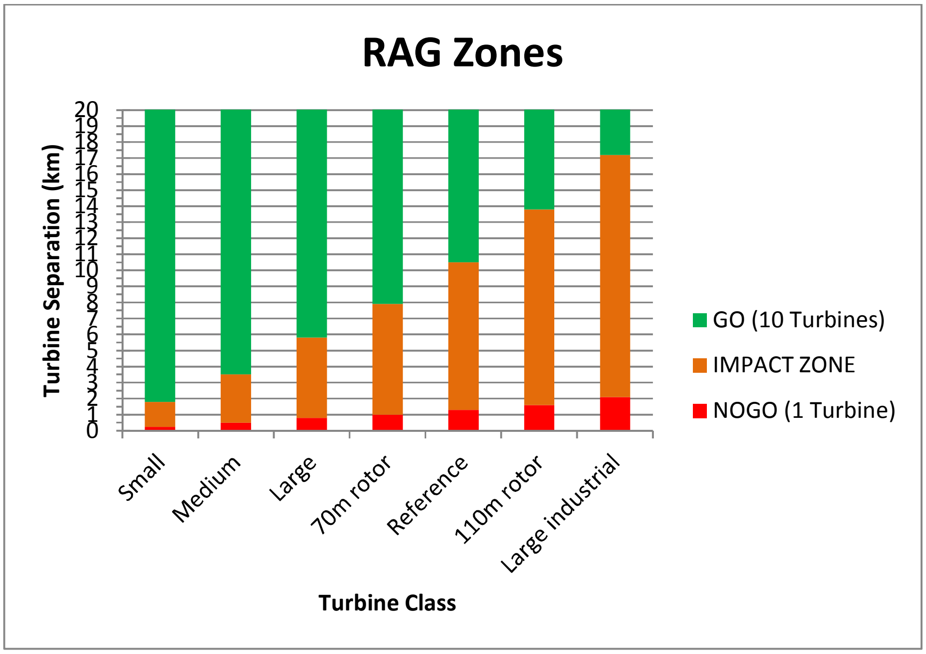

Figure 2 – RAG Zones

Out of Scope Proposals

a) If no part of a turbine installation is visible to the radio site, then regardless of physical separation or size / quantity of turbine(s), that development proposal will be acceptable.
b) For single turbine developments, if the hub height falls below radio station base height (AMSL) then the red zone physical separation criteria can be used without any further analysis. i.e. any turbine which would otherwise be classified as marginal (Amber) development is deemed to be acceptable by default provided that minimum physical separation is maintained as defined by the red zone criteria for that turbine class.
c) Developments proposals that either fall into the Amber "Impact Zone" or are deemed inappropriate for Zonal Assessment may be acceptable if supported by technical impact assessment using the C/I prediction method as described below and subject to a favourable operational impact assessment undertaken by NATS air traffic operations personnel.
d) Large developments i.e. turbine tip height greater than 110 metres AGL , and / or more than 10 turbines will require detailed assessment using the C/I prediction method as outlined below.

Interpretation of Assessment

Separate assessments are made for both hub elevation angle and physical separation to allow terrain effect to be factored – see table 3 below.

Where terrain slopes downwards and away from the radio site towards the proposed wind farm then turbine related interference is reduced allowing physical separation to be reduced. Upward sloping terrain will tend to increase the interference effect and physical separation must be increased to compensate.

ASSESSMENT			
DISTANCE	ANGLE	OVERALL	RATIONALE
RED	RED	RED	Excessive impact
RED	AMBER	AMBER	Terrain sloping downwards
RED	GREEN	GREEN	Terrain sloping downwards
AMBER	RED	RED	Excessive impact
AMBER	AMBER	AMBER	Indeterminate impact
AMBER	GREEN	GREEN	Terrain sloping downwards
GREEN	RED	AMBER	Terrain sloping upwards
GREEN	AMBER	GREEN	Marginal impact
GREEN	GREEN	GREEN	Acceptable impact

Table 3 – Combined Assessment

Method 2 – Carrier to Interference Prediction

C/I prediction is a complex process which requires a detailed technical knowledge of radio propagation theory and the application of a defined prediction methodology using professional radio planning software tools. This type of assessment must be performed by following the defined methodology and undertaken by a suitably qualified consultancy practice or organisation.

NOTE – NATS reserves the right to independently verify any C/I prediction produced by a third party by utilising the prescribed methodology and supplied development data.

NOTE – Receiver Sites will be assessed as Transmitter Sites using the methodology defined below.

Radiation Pattern Envelope (RPE)

A generic RPE should be produced for the specific class of turbine as outlined below.

Turbine RCS values in tables 4 and 5 should be selected for the most appropriate class of turbine as previously defined in table 1.

VHF	**Bistatic**		**Monostatic**	
	dBsm	**RCS m^2**	**dBsm**	**RCS m^2**
Large Industrial	51.0	125707	41.0	12571
Reference	48.1	64136	38.1	6414
Large	43.8	23952	33.8	2395
Medium	39.9	9700	29.9	970
Small	32.5	1782	22.5	178

Table 4 – RCS Values – VHF

UHF	Bistatic		Monostatic	
	dBsm	**RCS m^2**	**dBsm**	**RCS m^2**
Large Industrial	55.6	364254	45.6	36425
Reference	52.7	185844	42.7	18584
Large	48.4	69405	38.4	6940
Medium	44.5	28106	34.5	2811
Small	37.1	5162	27.1	516

Table 5 – RCS Values - UHF

Alternatively, where Frequency = 127 for VHF, 368 for UHF, RCS values can be derived by scaling from the reference turbine as follows:-

- Monostatic RCS value = 10 Log (23281 * (Rotor Diameter / 90)^2 * Frequency / 461) in dBm^2
- Peak Bistatic RCS value is 10dB higher

Radiation Pattern Envelope (RPE) is derived as follows:-

- General Scatter Region (GSR) – use Monostatic RCS value
- Forward Scatter Region (FSR) – use Bistatic RCS value
- Roll off characteristic between FSR and GSR is generated using the relative amplitude (RA) equation as defined by ITU-R BT805 (the reference turbine uses a mean blade width of 2.5m, other turbines are scaled proportionately).

RPE’s are aligned individually for each turbine with FSR peak values coincident with the bearing from radio site to turbine.

<u>Turbine Transmit Power</u>

Transmit power values shall be calculated for each individual turbine as follows:-

- Calculate free space path loss between transmitting aerial at the radio station and the turbine hub.
- Determine any path losses above free space.
    - NOTE – Path loss above free space can be derived using ITU-R 525/526/Delta Bullington propagation model and a k factor of 4/3
- Calculate the equivalent isotropic signal received at the hub at 127MHz and 368MHz.
- Using conventional radar theory and the appropriate RCS value, calculate the isotropic power re-radiated by the turbine at 127MHz **(Power A)** and 368MHz **(Power B).**

Radio Station

Baseline (default) data for a typical radio station shall be used, as follows:-

- Tower coordinates to < 10 metres accuracy
- Antenna height – 10 metres
- Operating Frequency
  - VHF : 127 MHz
  - UHF : 368 MHz
- Aerial Polar Pattern : Omnidirectional
- Aerial Gain : 2.1 dBi
- Aerial system losses : 3dB
- Transmitter Power
  - VHF : 50 Watts
  - UHF : 100 Watts

Turbine(s)

Baseline data for each turbine shall be used as follows:-

- Tower coordinates to < 10 metres accuracy.
- Aerial height – Use hub height AGL
- Operating Frequency
  - VHF – 127 MHz
  - UHF – 368 MHz
- Aerial Gain : 0 dBi
- Aerial system losses : 0dB

- Transmitter Power
  - VHF : as calculated **(Power A)**
  - UHF : as calculated **(Power B)**
- RPE forward lobe for each turbine to be aligned in a direction pointing away from the transmitter on the bearing (True) from radio site to turbine

Propagation Model

The following radio propagation model shall be used for coverage plot prediction:-

- ITU-R 525/526/Delta Bullington

Coverage Plots

VHF – Produce coverage plots from radio site using field strength limit of 26 dBuV/m

UHF - Produce coverage plots from radio site using field strength limit of 35 dBuV/m

Produce VHF and UHF coverage plots from the radio site at the following altitudes:-

- 1000ft AGL
- 2000ft AGL
- 5000ft ASL
- 10000ft ASL
- 20000ft ASL

At the same altitudes as above, produce turbine coverage plots to cover the same area as the radio station. Where Wanted signal (**W**) is the carrier (**C**) and Unwanted signal (**U**) is the turbine related interference (**I**) -

For a single turbine:-

- At each altitude, produce a C/I ratio map with the turbine interferer
    - **Acceptance criteria = > 20dB C/I ratio in the volume of interest**

For multiple turbines:-

- 1) At each altitude, produce a C/I ratio map for the worst single turbine interferer
    - **Acceptance criteria = > 23dB C/I ratio in the volume of interest**

NOTE – Equates to two worst case turbines with in-phase interference

- 2) At each altitude, produce a C/I ratio map with all turbine interferers added
    - **Acceptance criteria = > 14dB C/I ratio in the volume of interest**

NOTE – Assumes all turbines producing in-phase interference

Notes

1) Volume of Interest is defined as a volume of airspace in which there is a predicted degradation of signal quality due to turbine related interference and there is an operational requirement for aeronautical communications.

2) The Volume of Interest will be determined following an operational impact assessment performed by air traffic control personnel as part of the mandated safeguarding process.

3) Dependant upon the Volume of Interest as determined for any specific case, predicted C/I ratios which fall below the relevant acceptance criteria will not automatically exclude a development.

4) When performing an interference prediction, a useful check is to determine the degree of confidence inherent within the prediction. This can be achieved by repeating the prediction process using progressively higher values of monostatic and bistatic RCS until the appropriate C/I threshold is breached. A significant variation in RCS between the published value for the turbine class and the RCS value required to breach the C/I threshold is indicative of a reasonable safety margin and provides some level of confidence that the development proposal will not compromise ATC service provision.

Wind Turbine Communications Impact Assessment - Process Flow