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Tappaghan Wind Farm
County Fermanagh, Northern Ireland

28 June 2006

(Revision 1.1 – January 2007)

Analysis of the interaction between Wind Turbines and Radio Telemetry Systems

based on tests conducted on 29 March 2006

Figure 1 - General view of Tappaghan wind farm control room/sub station and the four closest turbines.

Summary

(1) This report details an investigation into the interference to a UHF radio telemetry link caused by wind turbines. The link involved operates between the wind farm at Tappaghan, County Fermanagh, Northern Ireland and a Northern Ireland Electricity radio scanner site at Pollnalaght.

(2) The radio path is 8.7 km in length, but there is no line of sight between the transmitter and receiver as the path is obstructed by rising ground at the Tappaghan (outstation) end of the link.

(3) Although the radio path is non-line of sight, it is typical of the terrain over which many utility radio telemetry links operate. The predicted path loss is 127 dB, well within the maximum path loss of 143 dB permitted under the planning specification for this type of link. The link which was the subject of this investigation had already been given an increased power over what would normally be required for reliable operation on such a path in an abortive attempt to overcome the interference. Radio telemetry links supporting SCADA (Supervisory, Control And Data Acquisition) systems are normally required to operate at an availability level approaching 99.9% (i.e. less than 525 minutes of cumulative outages per year).

(4) The scenario at Tappaghan is valuable from an investigative stand-point as the turbine blades do not intrude directly in the radio path between transmitter and receiver, but interrupt what is called the Fresnel zone. Because radio is a wave like phenomenon, large structures close to the radio path, particularly if they have large moving surfaces, can cause interference by reflection and diffraction if they intrude into this zone.

(5) Experience indicates that wind turbine interference on a telemetry link is not such as to cause the link to fail completely. The effect is to create intermittent failure of the signal path, reducing its availability and forcing the link to resend the lost data. This disruption of the link increases scan times, which ultimately causes the SCADA system to generate a fault alarm. These telemetry systems were never designed to accommodate this type of interference.

(6) The findings in this case were that the wind turbines were causing a variation in signal strength at the receiver of more than 40 dB, resulting in extreme unreliability in the operation of the link. The report provides experimental detail to support this conclusion.

(7) Since the Tappaghan sub-station cannot be supported by a UHF radio link to Pollnalaght, a solution has been devised in collaboration with NIE and Airtricity whereby the outstation antenna will be swung around to be served by another scanner and this path monitored in the same way to ensure it offers the desired availability.

(8) Because of the interest and helpful attitude of NIE and Airtricity, the site affords the opportunity to conduct further tests to improve our understanding of the interaction between wind turbines and UHF radio telemetry links, and attempt to validate the theoretical analysis of the interaction.

(9) Rigorous analysis of this interaction is important as some organisations assert that wind turbines do not cause any detrimental effects to radio telemetry links, and claim to have experimental work to support these conclusions.

(10) An important conclusion from this study is that the current practice of assessing UHF radio telemetry links on an individual basis is essential if one needs to ensure compatibility between wind energy and fixed radio communications.

Background

(11) The current Government drive to find renewable sources of energy has resulted in the rapid development of wind farms. Wind energy is likely to be the single greatest contributor to the Government's "10% by 2010" renewable energy target and "20% by 2020" renewable aspiration. But there is a downside: by virtue of the size of modern wind turbines and their location on the landscape, they have the potential to obstruct radio paths and act as massive reflectors of radio energy.

(12) Because of their large moving surfaces, the effect of wind turbines is difficult to predict, and constantly changing. Although the turbines will have a detrimental effect on all radio communications, their effect on mobile systems, such as cell phones, will not be as great as on fixed systems as mobile systems are designed to operate in a rapidly changing environment. Radio communication systems designed to interact with mainly fixed infrastructure are more vulnerable to the detrimental effects of wind turbines. The systems most affected are those which are optimised for a static environment, such as aircraft radars, television and fixed data systems.

(13) The interference effects of wind turbines on radar systems and analogue terrestrial TV systems have been investigated extensively. Ofcom, and its predecessor, the Radiocommunications Agency undertook some theoretical work on the potential for wind turbines to interfere with microwave fixed links, but because of the relatively small size of the market for utility telemetry radio systems, less research has been directed at this service. Although the turbine blades are not of metallic construction, they can nevertheless reflect and diffract radio waves. The lightning protection schemes built into turbine blades may further enhance their radio reflective properties.

(14) JRC has been assessing the potential for wind farms to cause interference to gas and electricity industry Ultra High Frequency (UHF) telemetry links for over three years. In the last 18 months, JRC has co-ordinated over 1500 wind farm applications. In most cases, these telemetry links are an integral part of the Supervisory Control And Data Acquisition (SCADA) systems used by utilities for monitoring and controlling their networks. Interruption to the reliable operation of these links compromises the integrity of the UK energy generation, transmission and distribution systems.

(15) Frequencies for these telemetry links are assigned according to the specification developed by the former Radiocommunications Agency in collaboration with the industry. The basic parameters were conceived in 1989 on the basis that designed system availability would be approaching 99.9% over paths of up to 30 km in length. UHF frequencies are particularly attractive for this application as it is not necessary to have a line-of-site path from transmitter to receiver, and on an individual basis, links can be assigned to operate over paths of up to 50 km in one hop.

(16) The ability of UHF telemetry systems to operate over obstructed paths is the feature which creates the greatest potential for incompatibility with wind turbines. Because the wind turbines frequently occupy the higher ground and protrude above the landscape, they have the potential to act as massive radio reflectors such that the reflected path via the wind turbine is much superior to the intended path over the landscape.

(17) Because of the increasing incidence of reported cases of interference to telemetry links attributed to wind turbines, JRC sought a site whereby the phenomena might be investigated. Thus when Northern Ireland Electricity reported severe interference to a telemetry link from a scanner at Pollanaght to an outstation near the wind farm at Tappaghan, it was agreed that a more thorough investigation would be undertaken.

(18) In 2000, the Radiocommunications Agency issued a paper that attempted to model the environment with respect to line-of-sight (LOS) microwave (above 1 GHz) links and wind farms.

(19) In order for JRC to assess the potential effect of a wind farm on existing telemetry links, it was necessary to develop a methodology that, as accurately as possible, model the situation. It is desirable that the model is as accurate as possible as there is a lot of investment on both sides and imprecise co-ordination could prove very costly in later mitigation. A rigorous approach to the subject is essential. The method used by JRC is an adaptation of this LOS Microwave method [3].

Technical data

(20) Tappaghan wind farm is situated on Tappaghan Mountain, Glenarn, near Lack in County Fermanagh, Northern Ireland and operated by Airtricity. The wind farm has thirteen GE 1.5 MW turbines installed.

(21) The wind farm is connected to the Northern Irish Electricity Grid via a local substation that is located on the wind farm.

(22) The Turbines have a hub height of 52.6 m and a rotor diameter of 70.5 m.

(23) The installed turbine locations are as follows (Irish Datum):

Tappaghan Wind Farm Turbine Locations

Easting	**Northing**	**Turbine number**
228439	368822	1
228762	368785	2
229077	368702	3
229485	368431	3
229304	368576	4
229662	368290	5
229127	369049	6
229470	368885	7
229763	368645	8
229785	368110	9
229888	367924	10
229243	367618	11
229582	367716	12
229485	368431	13

(24) The telemetry for the site is connected by UHF radio link to Pollnalaght.

(25) Northern Ireland Electricity have two completely separate scanning telemetry systems; one controls and monitors the electricity grid the other is used to monitor the output of wind farms.

(26) The wind farm telemetry system is becoming more important as more wind farms are being constructed and connected to the Northern Ireland grid.

(27) The link to Tappaghan wind farm is unreliable even though the link is running at higher power levels than those outlined in the OFW49 [1] formally RA 375 [2] assignment criteria document. A plan is already in place to switch it to another scanner to overcome the interference.

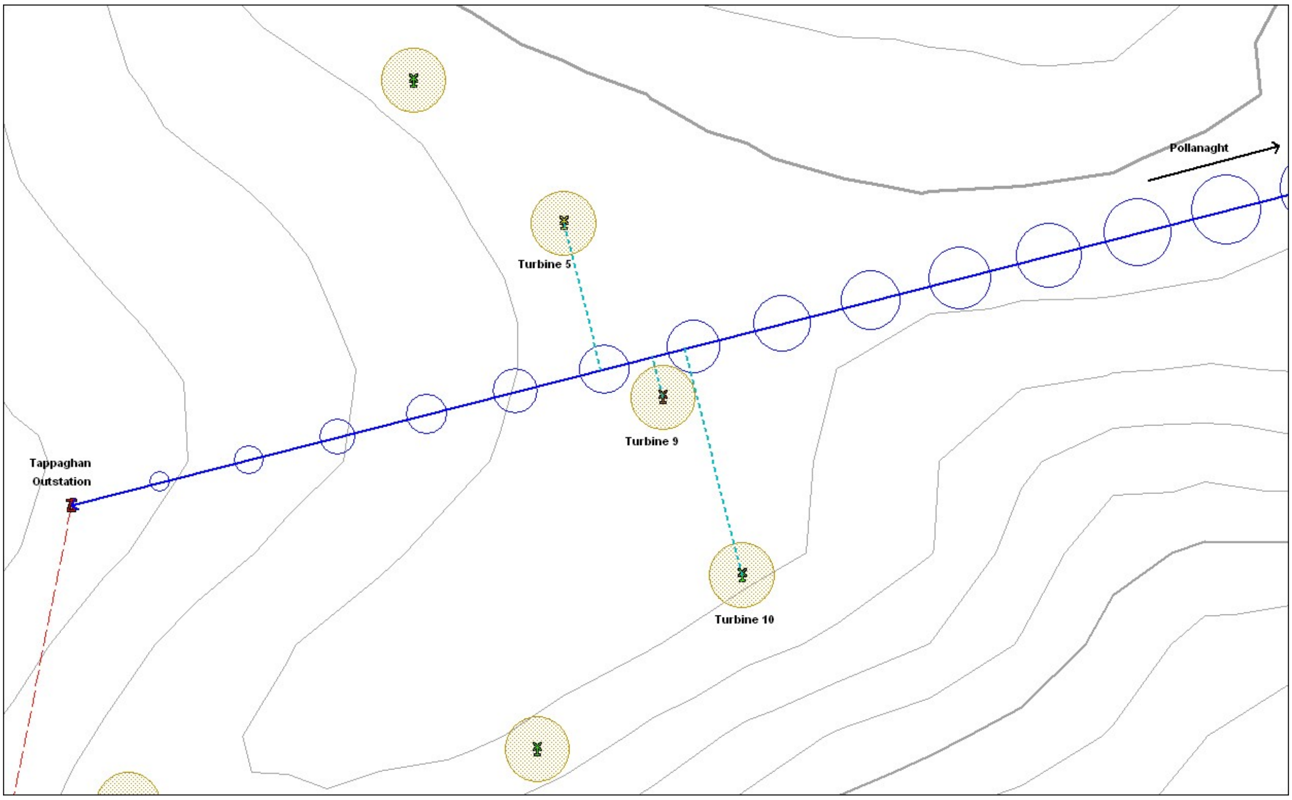
(28) JRC has been aware of the need to test the effects of wind turbines on the performance of UHF radio links to confirm or otherwise the criteria used for protection of the radio links against proposed wind farm developments.

(29) JRC carried out the tests described in this report in conjunction with Cable and Wireless (NIE's communications contractors) and NIE engineers.

(30) The link was plotted against the wind farm layout using the JRC wind farm GIS system. The second Fresnel zone is plotted on the link every 100m. The horizontal turbine blades of the nearest turbines are then plotted and this is indicated on the diagram below.

Figure 2 - Tappaghan Wind Farm

Link and horizontal second Fresnel zone (at 100m intervals) schematic



(31) The details of the link (shown in Figures 3 & 4) are as follows:

- Pollanaght. i E237370 N370800. Aerial; Jaybeam 7356 Omni Co-Linear Aerial Height; 53m
- Tappaghan i E229153 N367938. Aerial: Jaybeam 7014 12 Element Yagi Aerial Height; 6m

(32) The Grid References were acquired using GPS. At Tappaghan, since the GPS would have had to have been positioned between the wall and a security fence, it was considered unlikely that a reliable fix could be obtained; the position was taken on the road to the east of the substation at a known distance and bearing from the substation. The GPS indicated 5m accuracy. The location on the road was 11m from the aerial at an angle of 75.6° EGNGB (East of Grid North GB datum), 70.7° Irish Grid. This gave a location of 229162E 367928N (Irish Grid) and the aerial Grid Reference used was derived from this.

(33) Two different GPS units were used in the compound. These indicated 229154E, 367927N and 229156E, 367928N respectively. These are 11.4 m different from the calculated NGR that was used but the calculated one is deemed to be more accurate. JRC normally use a link uncertainty of 15 m when 1 m resolution Grid References are obtained using consumer grade GPS at both ends.

Figure 3: Path profile and analysis of the link from Pollnalaght to Tappaghan.

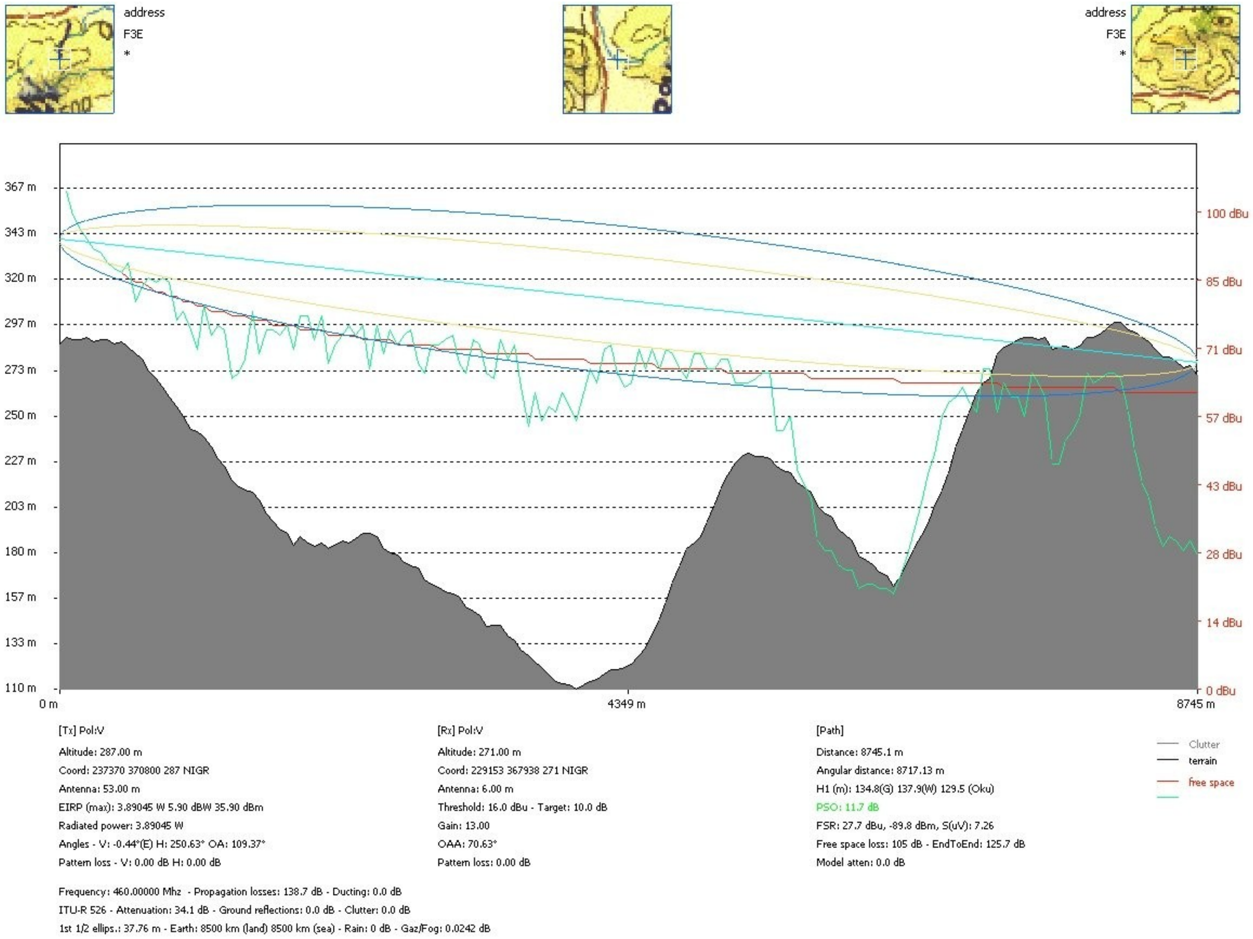
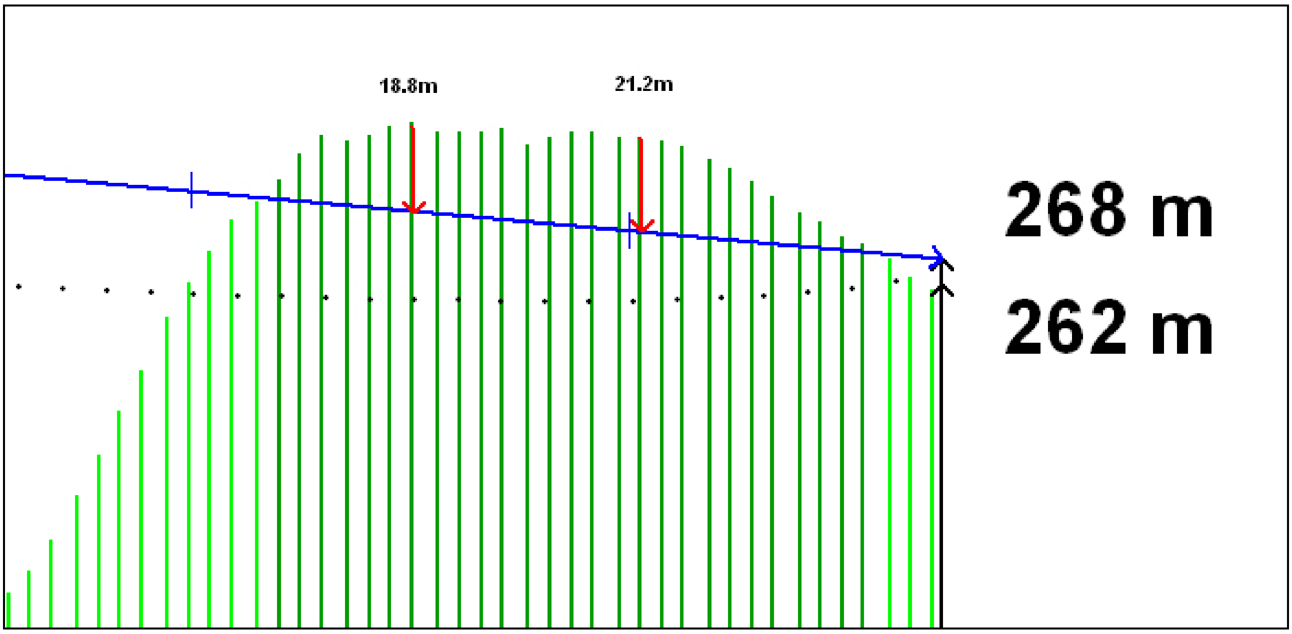


Figure 4: Expanded profile close to the outstation



(34) The predicted path loss for this link is 104.6 dB FSL plus 34.1 dB intrusion loss making a total loss of 138.7 dB. using ITU-r 525/526 algorithm. This does not include any scanner aerial clutter loss.

- The Scanner TX output is 30 dBm the EIRP for the scanner is 35.9 dBm
- The projected Rx Signal at Tappaghan is -89.8 dBm
- The outstation TX output is 37 dBm the EIRP is 50 dBm
- The projected RX at signal at Pollnalaght is -82.8 dBm
- The radio equipment installed at Pollnalaght is an unprotected MDS 4790M
- The radio equipment installed at Tappaghan is an MDS 4710.

(35) The actual path loss cannot be measured as the link level is too unstable for accurate measurements.

(36) This path is a non-line-of-sight diffracted path but within the 143 dB maximum path loss criteria as laid down in OFW 49. The projected receive signal is above the -92 dBm set down in the same document. The closest turbines have a line of site path to both ends. This is the type of scenario that JRC believes amplifies the problems associated with wind turbines to UHF links (and UHF television).

Figure 5 - Path profile of the link in relation to the closest turbine (T9)

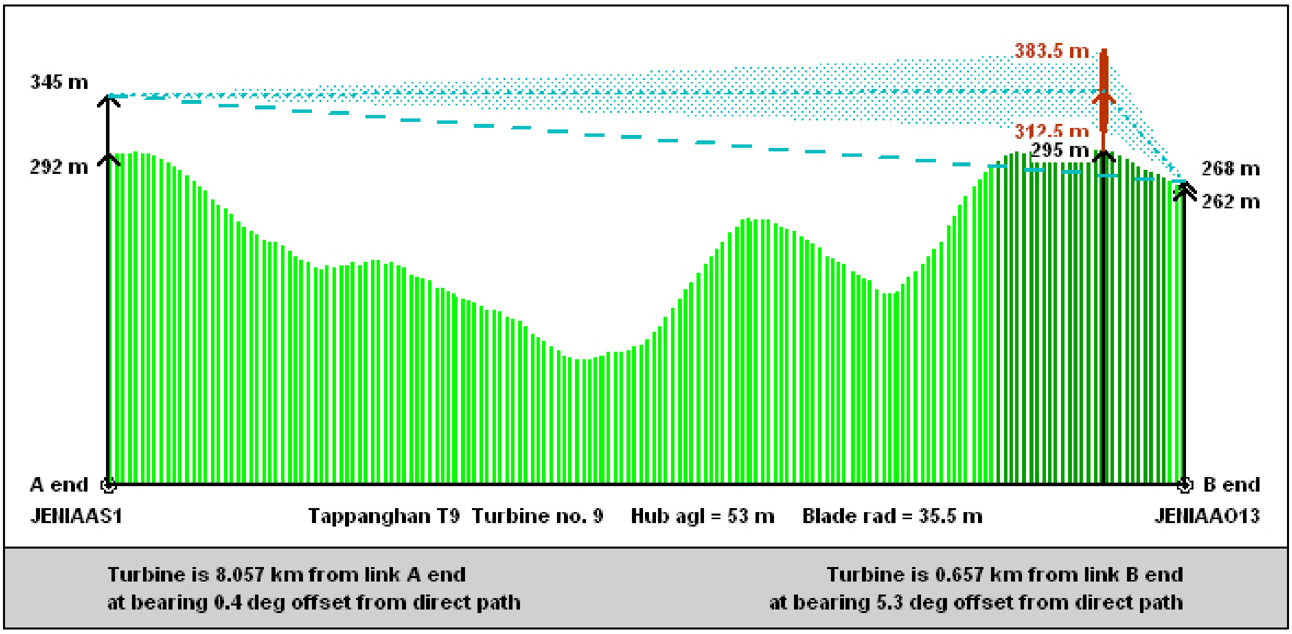
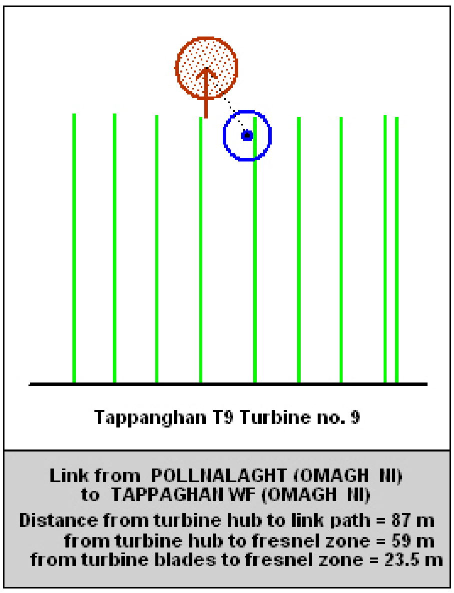


Figure 6 – Schematic relationship of Turbine 9 to the ray.



(37) The actual ray height is difficult to establish as the path is a diffracted path. The prediction indicates the ray to be 20.6 m lower than the local ground. This is obviously not true as from a two dimensional horizontal view at hub height the turbine is 47 m from the path. If the ray is at ground level then this is 70.8 m. In reality it will be somewhere between the two. Even allowing for absolute **worst case** 15 m uncertainty this makes the ray between 32 and 55.8 metres from the centre of the turbine.

(38) The ray has in excess of 2 Fresnel zones clearance from the turbine tower. Any effect on the link will be caused by the turbine blades.

(39) If the wind direction was the same as the link then the turbine blades would be 90 degrees to the link and this would be the worst case from a clearance point of view. The anemometer mast was not operational on the day of the visit so wind direction is not known accurately. JRC has subsequently obtained data from Lough Hill wind farm 8 km away at 10 minute intervals. This indicates a wind direction of between 204.9 and 249.9 degrees EIGN (223.7 average of all samples) at a wind speed of 3.2 to 13.3 m/s between 13:30 and 14:30 hrs (GMT +1). If this is so the turbine will be presenting a horizontal profile to the link of between 0.7 and 1.0 (0.89 average) of the rotor diameter. From the pictures taken prior to the test, the wind appears to be coming **about** 30 degrees off of the direction of the link aerial. The turbines appeared to be synchronised and operating at normal rotational speed.

(40) The rotational speed of a GE 1.5 turbine is 12 to 22.2 RPM (44.6 to 82.5 m/s). On the day, the turbines were estimated to be rotating at about 18-20 RPM (derived from video evidence).

(41) The two next closest turbines to the link path are Turbine 5 (164 m horizontal clearance) and Turbine 10 (256 m horizontal clearance) – with no allowance for uncertainty.

(42) Diagrams illustrating the path profiles and relationships between these turbines and the ray path (illustrated in Figure 2) are shown in Annex A.

Figure 5 - View of turbine direction in relation to the link.

Note: Turbine 9 is next to the power feed.

Figure 6 - The aerial at Tappaghan.

Figure 7 - The mast at Pollnalaght. The UHF co linears are at the top of the mast.

Test Method

(43) At Tappaghan the MDS radio was put into diagnostic mode and the input signal monitored.

(44) With NIE permission the site was taken off line.

(45) An Agilent E4402 B spectrum analyser was used to measure the incoming signal

(46) The settings were:

- Ref. level -40 dBm
- Span 100 kHz
- RBW 3 kHz
- VBW 3 kHz

(47) The Analyser was connected to the aerial using a 1.2 m RG213 lead.

(48) A Marconi 2955 radio test set was used to check the calibration of the spectrum analyser.

(49) This was set at the nominal input frequency (457.61875 MHz) carrier only, at a level of -80 dBm.

(50) This was connected with an additional 0.9 m RG214 lead to the lead used for measurement.

(51) This indicated -80.3 dBm on the analyser.

(52) To cross check the MDS calibration the 2955 was connected to the MDS, the signal read out on the MDS was -79.2 dBm.

(53) The scanner is used in continuous carrier mode and the input signal was measured on the analyser.

(54) Having measured the variation in the signal strength of the carrier for the telemetry serving the Tappaghan wind farm, the span of the spectrum analyser was increased and the second scanner at Pollnalaght displayed (457.84375 MHz) on the same scan. As a consequence, the scan time increased due to the greater frequency span displayed on the analyser.

(55) When all the measurements had been completed at Tappaghan, the telemetry radio was reconnected to the link and control returned to NIE. When confirming re-establishment of the link, the control room was asked for any comments on its performance.

(56) The test equipment was then moved to the scanner site at Pollnalaght and connected to a spare aerial mounted on the tower. The reference level was adjusted so that the measured signal was 40 dB lower than the top of the display (as at Tappaghan).

(57) Measurements were then carried out at Pollnalaght on the same basis as at Tappaghan, ie to measure the characteristics of the scanner serving Tappaghan, and to observe the stability of both carriers on the Pollnalaght mast visually on the spectrum analyser display.

(58) The spectrum analyser traces both at Tappaghan and Pollnalaght were recorded using a video camera to aid subsequent analysis of the data.

Test Results

(59) When the received signal level at the Tappaghan outstation was measured using using the MDS radio in diagnostic mode, the signal was recorded as varying between -81dBm and -109dBm during an interval of one minute. [Measuring fluctuating signals accurately using the MDS radio is unreliable as it takes a snapshot of the input approximately every second.]

(60) When the received signal level at the Tappaghan outstation was measured using the Agilent spectrum analyser, variations between -80 dBm and in the extreme > -120 dBm were observed.

(61) When viewing the received carrier signals from both scanners at Tappaghan on a single spectrum analyser display, the same variation in signal levels as noted above on the main link was apparent. However, the peaks and troughs in the signal strength occurred at different times indicating that the mechanism causing the link degradation was probably not intrusion but diffraction/reflection.

(62) In observing the traces, it was not possible to determine if the degradation was being caused by Turbine 9 alone or multiple turbines. [All other turbines are well outside of the second Fresnel zone of the link. (2^{nd} Fresnel zone is approximately 28m on a LOS link)].

(63) When measurements were made at the scanner site at Pollnalaght, there was no perceivable variation in signal level from either scanner carrier.

(64) When the telemetry radio at Tappaghan was reconnected to the link and the control room asked to report its quality, the control room advised that the link was repeatedly failing and then clearing.

Further Work

(65) JRC considers that it would be desirable to conduct extended tests at this location to determine in more detail the mechanism that is causing this degradation of the telemetry link.

(66) JRC would like to correlate any changes in the link degradation with different wind directions. Ideally, the three closest turbines would be shut down (ie stopped) individually under similar wind conditions as tested here. It would be desirable but probably impractical to determine the actual path loss of this link without any turbine influences.

(67) JRC would like to use a portable monitoring system, and with the same aerial height and similar path move further away from the turbine to determine the effects of different clearances.

(68) JRC would then like to elevate the aerial to reduce the diffraction angles and compare the results up to the point when there is no diffraction (approximately 35 m).

(69) Ideally, JRC would wish to increase the height at which measurements are taken until level with the rotor hub. It is accepted that this is most probably impractical at this site, although may be possible at another site.

Conclusion

(70) Rotating turbine blades have the potential to seriously degrade 460 MHz radio links even when not in the direct radio path. Until further meaningful long-term tests are carried out, JRC proposes to continue to evaluate wind farms to the criteria currently prevailing. It is JRC's view that wind farm applications need to be analysed individually against the actual links that are close to them and that there can be no blanket figure used for clearance zones.

Acknowledgements

(71) JRC acknowledges the assistance of Airtricity and Northern Ireland Electricity in facilitating access to the sites, and especially Cable & Wireless for transportation, loan of equipment and related services.

References

[1] OfW49 - Fixed Point-to-Point and Point-to-Multipoint Scanning Telemetry Radio Services with Analogue Modulation Operating in the Frequency Ranges 457.5 to 458.5 MHz paired with 463.0 to 464.0 MHz, UK Office of Communications (Ofcom), September 2004.

[2] RA375 Version 1.0 FREQUENCY ASSIGNMENT CRITERIA for Scanning telemetry radio services operating in the frequency bands 457.5 to 458.5 MHz and 463.0 to 464.0 MHz in which spectrum is managed by Radiocommunications Agency, July 2001.

[3] Wind Farm Clearances Zones used by the JRC when turbine sizes and locations are accurately known. Joint Radio Company Ltd, May 2006.

28 June 2006

Annex 1 - Additional Turbine diagrams.

Figure 10 - Path profile of the link in relation to turbine 5.

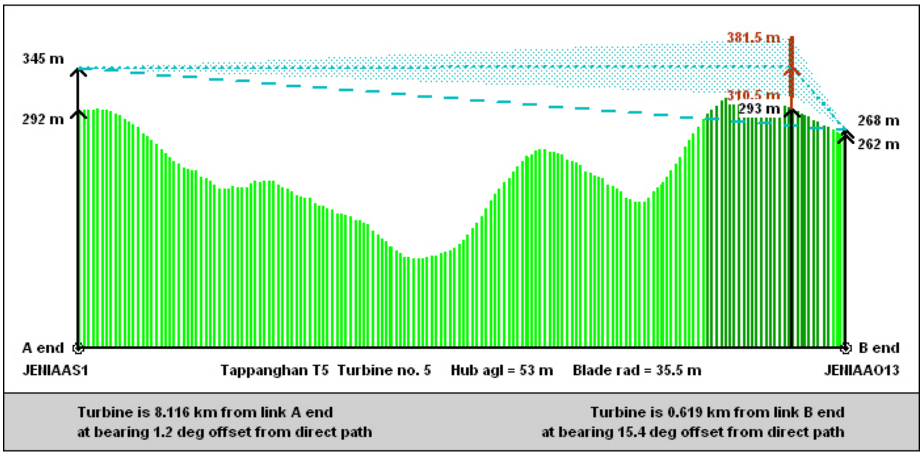


Figure 11 – Schematic relationship of turbine 5 to the ray.

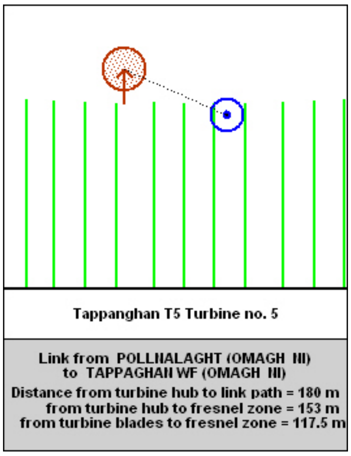


Figure 12 - Path profile of the link in relation to turbine 10.

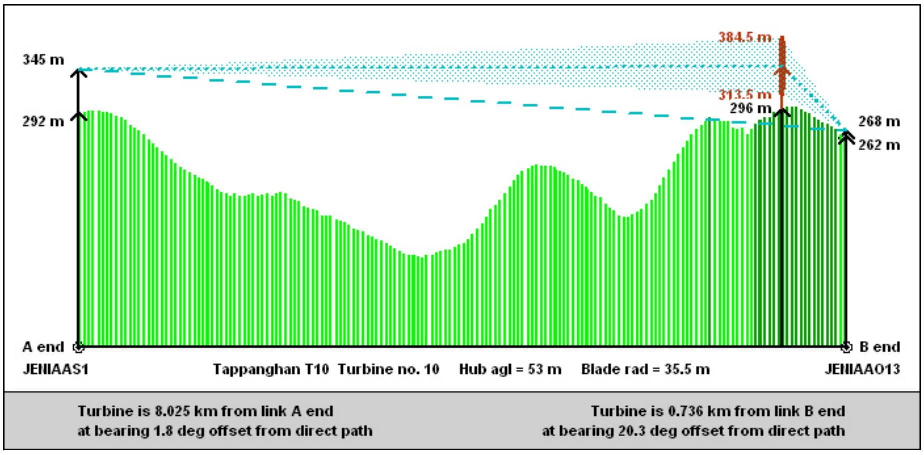


Figure 13 – Schematic relationship of turbine 10 to the ray.