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DEVELOPMENT OF GUIDELINES FOR THE SITING OF WIND TURBINES NEAR TO GAS TRANSMISSION PIPELINES - SUMMARY REPORT

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Executive Summary

The failure of wind turbines has been identified as having the potential to threaten the integrity of buried gas transmission pipelines laid in the vicinity of the turbine. This report details the results of a high-level study, undertaken to determine whether the failure of a wind turbine leading to damage and subsequent failure of a transmission pipeline, is a credible scenario.

In order to assess the potential risk to pipelines from wind turbines, Gasunie Research were contracted to perform calculations with a spreadsheet model that they have developed for predicting the risk of pipeline rupture due to wind turbine failure. A survey was performed of wind farms currently operating in the UK, in order to gauge typical sizes of wind turbines and their locations. This information was used to supply Gasunie with the data necessary to run their spreadsheet model for a set of cases as specified by Advantica. The results from these calculations were then used to assess the risk posed to the buried natural gas pipelines by wind turbines.

Conclusions

- The rupture of a transmission pipeline that is situated close to a wind turbine installation, due to the failure of the wind turbine is a credible scenario.

- If a wind turbine is situated close to a pipeline (within approximately 1.5 mast heights) then the presence of the turbine could be a significant contributing factor to the expected failure frequency of the pipe.

- An appropriate exclusion zone for wind turbines around transmission pipelines is considered to be 1.5 times the turbine mast height.

Project Code : 1/06142-cm01

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1 INTRODUCTION

The failure of wind turbines has been identified as having the potential to threaten the integrity of buried gas transmission pipelines laid in the vicinity of the turbine. This report details the results of a high-level study, undertaken to determine whether the failure of a wind turbine leading to damage and subsequent failure of a transmission pipeline, is a credible scenario.

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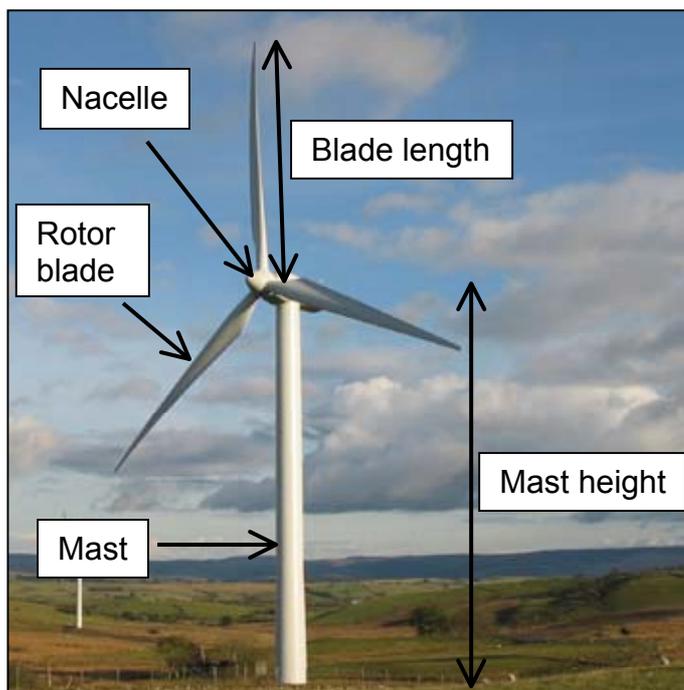
2 WIND TURBINES SURVEY

Information obtained from the British Wind Energy Association (www.bwea.com) suggests that there are currently 94 wind turbine projects operating in the UK, with a total of 1186 wind turbines. The locations of these wind farms are shown in Figure 1.

Figure 1: Location of wind farm projects within the UK

Of the wind turbines located in the UK, there are just over 1000 operating onshore in England, Scotland and Wales. These are listed in APPENDIX A and a typical wind turbine is shown in Figure 2, illustrating the characteristic features.

Figure 2: Wind turbine

Mast heights of the turbines listed in APPENDIX A range in size from 25m to 85m and rotor blade lengths vary between 12.5m and 40m. From this information, three typical wind turbine sizes were chosen to use throughout the analysis, as shown in Table 1.

Wind turbine	Mast height (m)	Blade length (m)
Turbine 1	30	13.5
Turbine 2	35	22
Turbine 3	50	26

Table 1: Typical wind turbine sizes used in the analysis

3 GASUNIE WIND TURBINE RISK ASSESSMENT MODEL

Gasunie Research have developed a spreadsheet model for predicting the risk of pipeline rupture due to wind turbine failure. Gasunie were subcontracted by Advantica to undertake a series of specified model runs. This section gives an overview of the accident scenarios considered within the model and the principles behind the calculations. A detailed description of the model and results of the specified model runs were provided by Gasunie [2].

3.1 Accident Scenarios

Three accident scenarios are considered within the wind turbine model:

- The rotor blade breaking off

- Fall of the wind turbine due to mast failure

- Fall of the nacelle or of the rotor

The failure frequencies associated with these scenarios are shown in Table 2 below.

Accident scenario	Failure frequency per turbine per year
Rotor blade breaking off:	**Total: 8.4 x10^{-4}**
Blade breaking off during normal use (nominal rotational speed)	4.2 x10^{-4}
Blade breaking off by mechanical braking (~1.25 times the nominal rotational speed)	4.2 x10^{-4}
Over rotation (~2.0 times the nominal rotational speed)	5.0 x10^{-6}
Fall of the wind turbine due to mast failure	**1.3 x10^{-4}**
Fall of the nacelle or of the rotor	**3.2 x10^{-4}**

Table 2: Wind turbine failure frequencies

3.2 Overview of the Model

The model calculates both the hit frequency and critical hit frequency of underground gas transmission pipelines. These frequencies are defined by Gasunie as:

- **Hit frequency**: frequency with which the pipeline route is hit by the wind turbine, or part of the wind turbine

- **Critical hit frequency**: frequency with which a serious gas calamity (pipeline rupture) occurs due to the pipe being hit by the wind turbine, or part of the wind turbine.

These frequencies are calculated for each of the three accident scenarios to give the total frequency with which a wind turbine is expected to cause pipeline rupture. The methodology used to perform the calculations is described below.
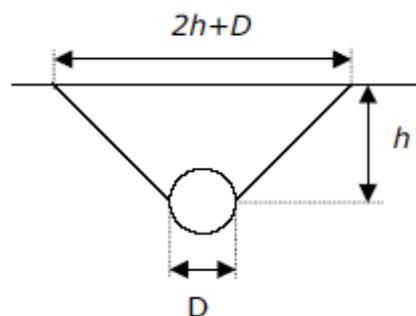
3.2.1 Rotor blade breaking off

It is assumed that a broken blade can only impact a pipeline if its centre of gravity hits the pipeline route. The width of the pipeline route is defined as:

$$W_r = 2h + D \qquad\qquad [1]$$

where: *h* – depth of the pipeline (depth of cover + half the diameter)

   D – diameter of the pipeline

Figure 3: Underground pipeline, showing pipeline route width

The hit frequency is expressed as:

$$f = (2h + D)\int_S p_{cg}(s)\mathrm{d}s \qquad [2]$$

where: p_{cg} - probability per m^2 that the centre of gravity of the blade reaches a specific 1m x 1m square at ground level (calculated using a ballistic model), assumed to be constant along the width of the pipeline route

   s - length parameter along the pipeline route

It is further assumed that a broken blade can only damage the pipeline if it satisfies the following conditions:

- The blade will only penetrate the ground if the angle between the velocity vector of the centre of gravity and the longitudinal axis of the blade is not too large. The probability that the blade hits the ground with the correct angle is assigned a value of 0.1 within the Gasunie model.

- To hit the pipeline, the longitudinal axis of the blade must approximately hit the centre line of the pipeline, otherwise it will only graze it. This is assumed to happen 1/10th of the time.

- To damage the pipeline, the blade must also have enough kinetic energy when impacting. It is assumed that the probability of the blade having sufficient kinetic energy decreases with increasing depth of the pipeline. For a depth of cover of 1m, the probability is assumed to be 0.1.

The critical hit frequency of the pipeline is therefore:

$$F_{cr} = 0.1*0.1*0.1*f = 0.001f \qquad [3]$$

3.2.2 Fall of the wind turbine due to mast failure

The model only takes account of the case where the mast breaks at the flange of the foundation and the nacelle or the blades roots (the section of blade from the rotor to
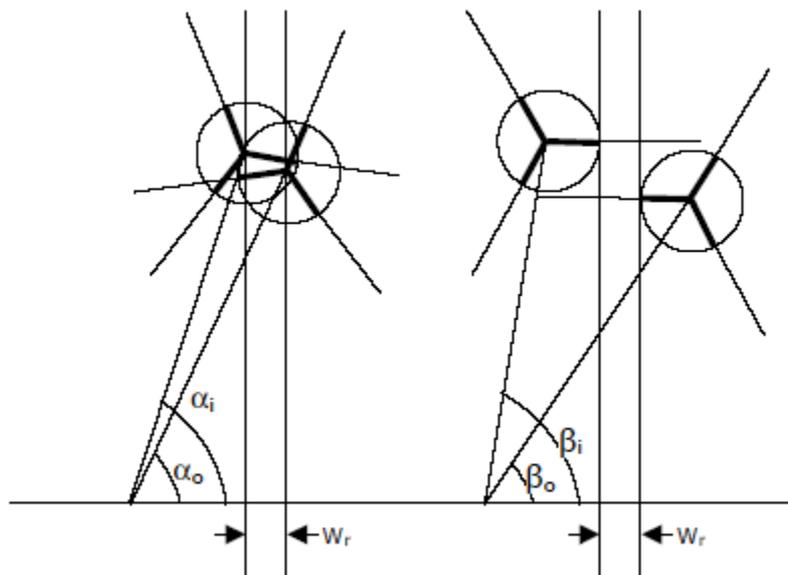
the centre of gravity) fall on the pipeline route. Therefore no account is taken of cases where the nacelle and blades' roots fall next to the pipeline.

The frequency with which the pipeline route is hit is given by:

$$f = 2 \cdot f_{mb} \cdot \frac{\left(\frac{\beta_i - \alpha_i}{2} + \alpha_i - \alpha_o + \frac{\alpha_o - \beta_o}{2} \right)}{2\pi} = 2 \cdot f_{mb} \cdot \frac{\left(\frac{\beta_i - \beta_o}{2} + \frac{\alpha_i - \alpha_o}{2} \right)}{2\pi} \qquad [4]$$

where: f_{mb} – failure frequency of the mast

α *and* β are the angles shown in Figure 4

Note: the root portion of the blade (the section of blade from the rotor to the centre of gravity) is shown by the thick line on the diagram

Figure 4: Situations in which the nacelle or the blades' roots fall on the pipeline route

It is assumed that a 1m depth of cover would be insufficient to protect the pipeline and therefore the critical hit frequency is considered to be equal to the hit frequency.

3.2.3 Fall of the nacelle or of the rotor

For the scenario whereby the nacelle or the rotor falls from the turbine, the same method is employed as used for the previous case of mast failure, except that the mast height is assumed to equal zero. This means that the hit frequency will only be non-zero if the wind turbine is on the pipeline route, or very close to it.

4   SCENARIOS CONSIDERED IN THE ASSESSMENT

The wind turbine model calculates the rupture frequency of the pipeline due to the failure of a nearby wind turbine. A number of different cases were analysed using the model in order to assess adequately whether the failure of a pipeline due to wind turbine failure is a credible scenario and if so, what zoning around pipelines is

necessary to control the risk posed from wind turbines. This section details the cases that were considered using the model.

The parameters required for the wind turbine model are as follows:

- **Wind turbine:** Mast height and blade length

- **Pipeline:** Diameter and depth of cover

- **Location of pipeline with respect to wind turbine:** Coordinates of the wind turbine and pipeline start and finish points

The values chosen fore each of the parameters are detailed below.

4.1 Wind Turbine Parameters

Three typical sizes of wind turbine were selected from those recorded in the survey, as shown in Table 3.

Wind turbine	Mast height (m)	Blade length (m)
Turbine 1	30	13.5
Turbine 2	35	22
Turbine 3	50	26

Table 3: Typical wind turbine sizes used in the analysis

The calculations were performed for each of these wind turbines to see the effect that the turbine size has on the resulting risk to the pipeline.

4.2 Pipeline Parameters

Three pipeline diameters were considered in the analysis, as shown below:

- 457mm

- 914mm

- 1219mm

These were considered to be representative of transmission pipelines routed through Type R areas. A depth of cover of 1.1m was selected. It is noted that material grade and wall thickness are not required inputs to the model, but would be expected to have an effect on the likelihood of damage to the pipeline, should it be struck by part of the wind turbine.

4.3 Location of Pipeline with respect to the Wind Turbine

In order to determine the proximity of the pipeline to the wind turbine, the location of the wind turbine and the pipeline start and end points must be defined on a coordinate system. For this analysis, the wind turbine was defined to be at (0,0) and the pipeline was assumed to be routed in a straight, horizontal line past the wind

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turbine. The pipe was assumed to extend for 200m in the x-direction, and the y-coordinates were defined in multiples of the turbine height, from half the turbine height to double the turbine height.. For example, for a turbine with mast height h, the failure frequencies were calculated for a 200m section of pipeline, located at four distances from the wind turbine, as shown in Figure 5.
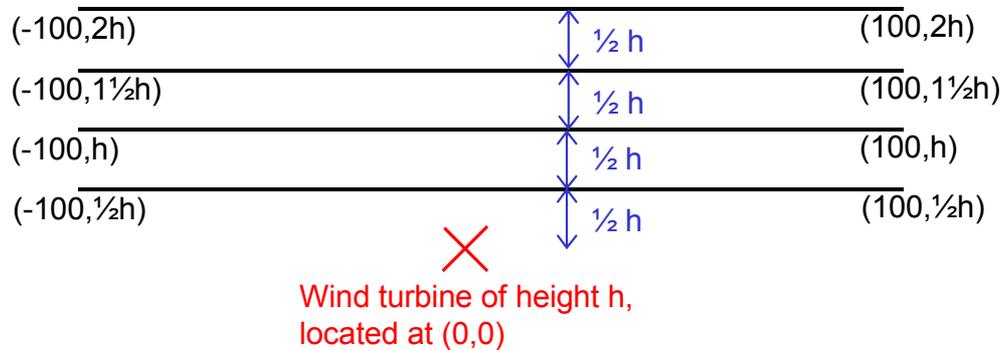
Figure 5: Location of pipeline in failure frequency calculations

Calculations were performed for each set of parameters and the results are discussed in the following section.

5 RESULTS AND DISCUSSION

Detailed results from the calculations are given in [3]. The variation in the expected pipeline rupture frequency due to the wind turbines is shown as a function of distance from the turbine in Figure 6, Figure 7 and Figure 8 for the 457mm, 914mm and 1219mm diameter pipelines respectively. The failure frequencies are given in units of 'per year' as they have been calculated for the 200m sections of pipeline. Also shown on these graphs for comparison purposes, are typical 3rd party R area rupture frequencies calculated using FFREQ. The pipeline parameters assumed in the calculation of these values are shown in Table 4 and have been chosen to represent typical pipelines that would be expected to operate in R areas in the vicinities of the wind turbines.

Pipe diameter (mm)	Operating pressure (barg)	Wall thickness (mm)	Material grade	Area Type	Failure frequency (per million km years)	Failure frequency of 200m section (per year)
457.2	38	9.52	X52	R	1.416	2.83×10^{-7}
	70	9.52	X52	R	10.012	2.00×10^{-6}
914.4	70	12.7	X60	R	3.569	7.14×10^{-7}
1219	75	14.3	X80	R	1.891	3.78×10^{-7}

Table 4: 3rd party interference rupture failure frequencies

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Figure 6: Failure frequency for a 200m section of pipe due to wind turbines as a function of the distance from the turbine (457mm pipeline)

Figure 7: Failure frequency for a 200m section of pipe due to wind turbines as a function of the distance from the turbine (914mm pipeline)

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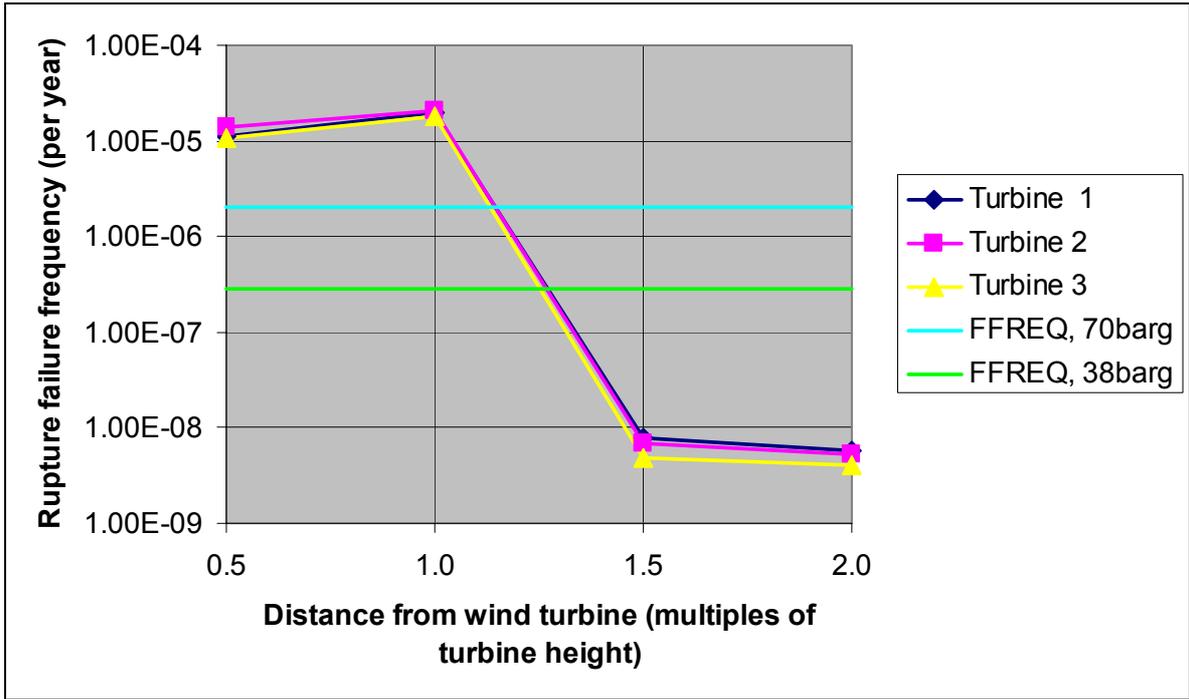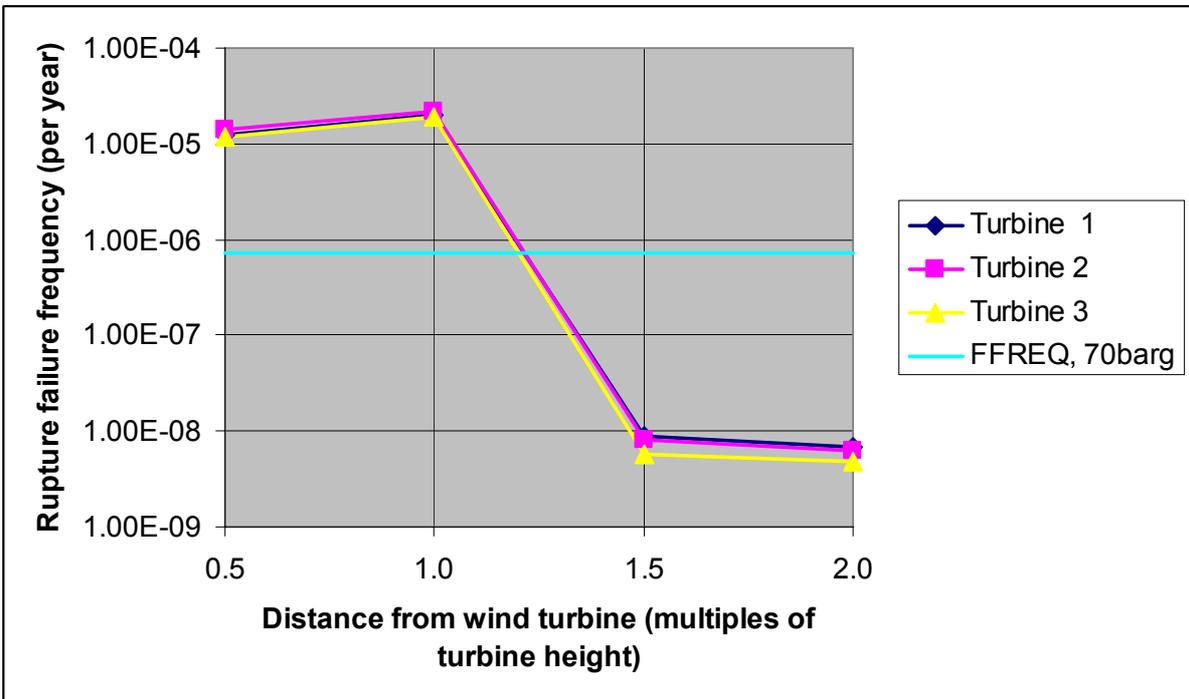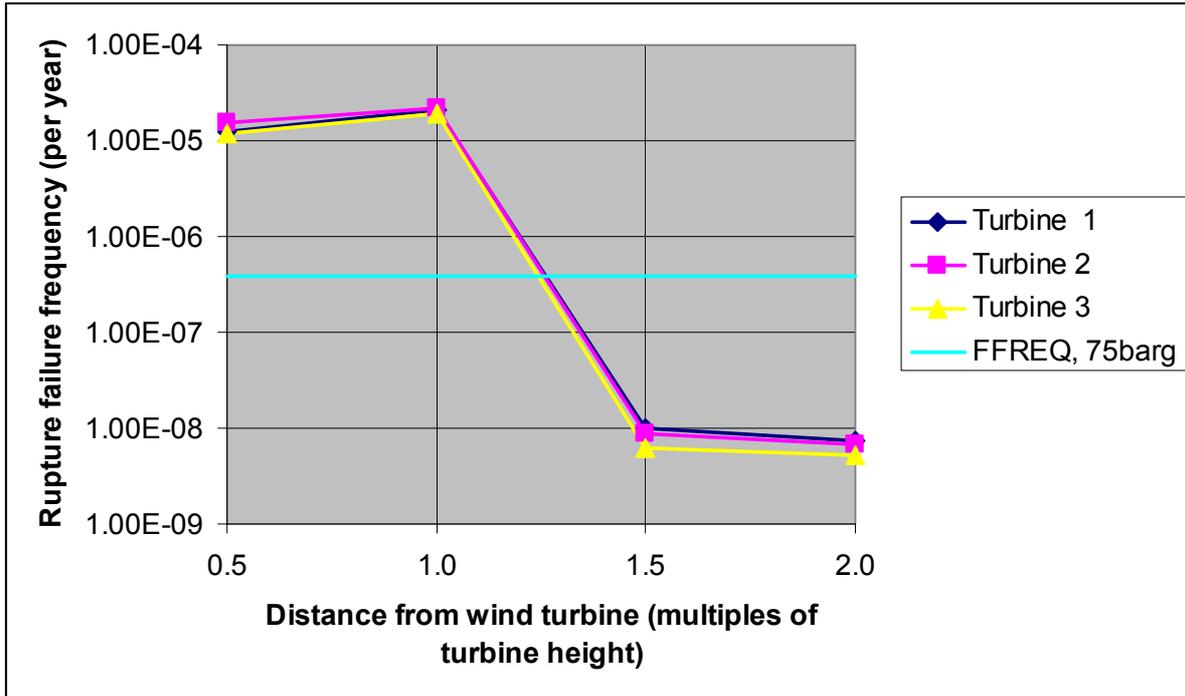**Figure 8: Failure frequency for a 200m section of pipe due to wind turbines as a function of the distance from the turbine (1219mm pipeline)**

From these results, it can be seen that the calculated failure frequencies are all of the order of 10^{-5}/year for the 200m section of pipeline within approximately one mast height of the turbine, and therefore it can be concluded that the failure of a pipeline due to a wind turbine is a credible event. The failure frequencies predicted by the model are the sum of the contributions from three failure scenarios discussed in Section 3.2. The way in which the individual scenarios have been treated in the model suggests that the combined failure frequency for all three scenarios should reduce gradually from 1 to 1.3 times the mast height and then more steeply between 1.3 and 1.5 times the mast height.

The 3rd party interference failure frequencies shown on the graphs also suggest that for certain separation distances between the pipeline and a wind turbine, the turbine may be a significant contributing factor to the expected failure frequency of a pipeline.

Within the Gasunie model, the pipeline parameters do not have a significant effect on the predicted failure frequency due to failure of a nearby turbine. However, it should be noted that the model only requires details of the diameter of the pipeline and its depth of cover, and therefore factors relating to the likelihood of pipe damage if the pipe is hit (for example wall thickness and material grade) have not been taken into account.

In addition, several modelling assumptions have been made by Gasunie that could be refined. For example, the probability that a turbine blade has enough kinetic energy to damage the pipe is assumed to be 0.1, based on an assumed depth of cover of 1m. However, this factor will be dependent on the depth of cover of the pipeline and as the depth of cover is a parameter that is currently used within the

model (to define the width of the pipeline route), the factor could be improved to take into account the specified pipeline depth of cover.

It can be seen from the graphs that the size of the wind turbine makes very little difference in terms of the magnitude of the expected pipeline failure frequency due to the turbine. However, it is noted that the failure frequencies have been calculated at distances that are multiples of the wind turbine height, and therefore the hazard range due to the turbine increases with increasing turbine mast height. The failure frequency does, however, fall away very quickly at around 1.5 mast heights away from the turbine (to below 10^{-8} per year for the 200m section) and therefore an appropriate exclusion zone for wind turbines would be a minimum distance of 1.5 times the turbine mast height.

6   CONCLUSIONS

- The rupture of a transmission pipeline that is situated close to a wind turbine installation, due to the failure of the wind turbine is a credible event.

- If a wind turbine is situated close to a pipeline (within approximately 1.5 mast heights) then the presence of the turbine could be a significant contributing factor to the expected failure frequency of the pipe.

- An appropriate exclusion zone for wind turbines around transmission pipelines is considered to be 1.5 times the turbine mast height.

7   REFERENCES

[1]   Obtained from www.bwea.com.

[2]   'Calculations of wind turbine effects near gas transmission pipelines' TET 2005.R.0055 K.H. Kutrowski. Gasunie Research.

[3]   'Development of guidelines for the siting of wind turbines near to transmission pipelines' Advantica Report R 7811 February 2005.

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APPENDIX A   ONSHORE WIND FARM PROJECTS IN ENGLAND, SCOTLAND AND WALES

Wind Farm	Location	Number of turbines	Mast height (m)	Blade length (m)
3Hs - Hare Hill	County Durham	2	60	40
3Hs - High Volts	County Durham	3	60	40
3Hs - Holmside Hall	County Durham	2	60	40
Ardrossan (Busbie Muir)	North Ayrshire	12	60	40
Askam	Cumbria	7	40	23
Bears Down	Cornwall	16	35	22
Beinn an Tuirc	Argyll & Bute	46	40	23
Beinn Ghlas	Argyll and Bute	14	35	22
Blaen Bowi	Carmarthenshire	3	46	30
Blood Hill	Norfolk	10	30	13.5
Blyth Harbour	Northumberland	9	30	12.5
Blyth Offshore	Northumberland	2	60	33
Bowbeat	Borders	24	-	30
Bryn Titli	Powys	22	30	18.5
Carland Cross	Cornwall	15	32	17
Carno	Powys	56	31.5	22
CAT (Centre for Alternative Technology)	Powys	1	40	20
Caton Moor	Lancashire	10	30	14
Causeymire	Highlands	21	60	40
Cemmaes II	Powys	18	50	26
Chelker Reservoir	Yorkshire	4	25	16
Coal Clough	Lancashire	24	-	17
Cold Northcott	Cornwall	21	25	17
Cold Northcott	Cornwall	1	25	17
Cruach Mhor	Argyll & Bute	35	40	26
Crystal Rig	Borders	20	60	40
Delabole	Cornwall	10	32	17
Deucheran Hill	Kintyre	9	60	23
Dun Law	Borders	26	40	23.5
Dyffryn Brodyn	Carmarthenshire	11	35	18
EcoTech Centre	Norfolk	1	66	33
Ford Dagenham	London	2	85	33
Forss	Caithness	2	-	31.0
Four Burrows	Cornwall	15	30	15.5
Goonhilly Downs	Cornwall	14	30	17
Great Eppleton	Sunderland	4	50	22

Great Orton II	Cumbria	6	-	23
Haffoty Ucha	Clwyd	1	40	22
Haffoty Ucha II	Clwyd	2	44	26
Hagshaw Hill	Lanarkshire	26	35	20.5
Hare Hill	Ayrshire	20	40	23.5
Harlock Hill	Cumbria	5	35	18
Haverigg 1	Cumbria	5	30	13.5
Haverigg II	Cumbria	4	40	21
High Hedley Hope	County Durham	3	46	25
Kirkby Moor	Cumbria	12	-	17
Kirkheaton	Northumberland	3	45	23
KS Winscales	Cumbria	3	40	23.5
Lambrigg	Cumbria	5	43	31
Llangwyryfon II	Ceredigion	11	-	26
Llyn Alaw	Anglesey	34	31	22
Lowca	Cumbria	7	40	23
Lynch Knoll	Gloucestershire	1	43	20
Mablethorpe	Lincolnshire	2	65	22
Mablethorpe Extension	Lincolnshire	8	65	22
Moel Moelogen	Conwy	3	43	31
Mynydd Gorddu	Ceredigion	19	33	17
Myres Hill	Galloway	2	50	26
Novar	Highlands	34	35	20
Oldside	Cumbria	9	40	21
Out Newton	Yorkshire	7	49	31
Ovenden Moor	Yorkshire	23	32	17
P & L	Powys	103	31	14.5
Parc Cynog	Carmarthenshire	5	46	24
Rheidol	Ceredigion	8	30	15
Rhyd-y-Groes	Anglesey	24	30	15.5
Royal Seaforth Dock	Merseyside	6	50	22
Royd Moor	South Yorkshire	13	35	18.5
Siddick	Cumbria	7	-	21
Somerton	Norfolk	1	67	33
St Breock	Cornwall	11	30	18.5
Swaffham extension	Norfolk	1	66	33
Taff Ely	Mid-Glamorgan	20	35	18.5
Tangy	Argyll & Bute	15	49	26
Tow Law	County Durham	3	40	23.5
Trysglwyn	Anglesey	14	25	18
Windy Standard	Galloway	36	35	18