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Wind Turbine Noise

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Wind Farm Noise Optimisation Tool

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Summary

This paper presents a Wind Farm Noise Optimisation tool to find optimal turbine operational modes such that maximum energy yield can be obtained whilst still meeting relevant noise constraints.

AECOM's Acoustics Team has developed a Wind Farm Noise Optimisation Tool which determines the optimal power modes a set of turbines can operate at, for any given wind speed and wind direction, and remain compliant with noise planning conditions. Turbine noise propagation utilises the appropriate methods detailed ISO 9613-2 Acoustics – Attenuation of Sound During Propagation Outdoors, and includes propagation directivity. The tool allows complex solutions of multiple variations in operational modes across wind speeds and directions to be assessed that would be impractical and time consuming to calculate using standard noise modelling software. Moreover, given the constraints that developers increasingly have to contend with this optimisation tool is more often likely to be needed in order to determine whether a development can be made financially viable from a noise perspective.

1. Introduction

As a result of the cumulative effect of the number of wind farms in many high yielding wind areas the noise budget in these areas is becoming ever more constrained. Developers must conform to noise regulations but wish to maximise the yield within a given area to ensure the site is financially viable. The technology of wind turbine design has advanced in recent years to allow each turbine to be individually controlled, if required, in non-standard modes of operation. Thus noise emission levels for individual turbines can be controlled. Although turbines can be operated in quieter modes it is in the interest of the wind farm operators to minimise the time that each turbine is operated in these modes as the wind energy yield is also reduced. Accordingly, operators of wind farms are becoming more interested in how they can exploit the sophisticated control mechanisms of modern wind turbines to maximise the power yield of the development and simultaneously comply with noise constraints.

As a result of this evolved technology the creation of a robust wind farm turbine control strategy is becoming ever more complex. With this problem in mind AECOM's Acoustic Team have created a Constrained Wind Yield Optimisation Tool. It provides a developer with the optimal operating strategy for its development that

meets with ETSU-R-97 and the latest Institute of Acoustics' Good Practice Guidance (IOA GPG) for all wind directions and for wind speeds ranging from 3 – 12ms^{-1}.

2. Implementation

There are already existing very good proprietary noise modelling software that can be used to assess noise impacts from wind farms. However, it can become time consuming if a large number of modelling scenarios are to be assessed. For example, for a seven turbine wind farm with each turbine having 3 modes of operation there are 2,187 possible mode operation combinations. Obviously it would be advantageous to automate the process.

To create a tool that can both automate the process of evaluating the various combinations of turbine modes of operation and provide an optimised wind farm noise control strategy it is necessary that the following elements are incorporated into the tool:

- The location of the wind turbines;
- The location of Noise Sensitive Receptors;
- The inclusion of sound propagation directivity;
- The inclusion of the necessary elements of ISO 9613 *Acoustics – Attenuation of Sound Propagation Outdoors* so that the tool is compliant with the IOA GPG guidance on sound propagation

Given that the foregoing elements are spatial in nature the optimisation tool is implemented using Geographic Information Systems (GIS), in particular ESRI's ArcGIS software and the ArcPy Python package. The tool undertakes all calculations, checks for exceedances of the ETSU-R-97 derived noise limits and optimises the turbine modes, if necessary, until a solution is found. The process is fully automated and because the optimisation tool has been tested against existing proprietary noise modelling software the tool produces results that are consistent and reproducible.

3. An example of the tool's workflow

The following section outlines a typical work flow when using the tool. Firstly, the following inputs are required.

Table 1: Required Information

Description	File Type
Turbine Locations	Shapefile
Noise Sensitive Receptors	Shapefile
Noise Monitoring Locations	Shapefile
Turbine Sound Power Levels for each octave band	Excel Table
Background Noise Levels	Excel Table

Once the input data has been input to the tool, via a series of prompts, the tool runs in the background and requires no further input from the user until it is completed.

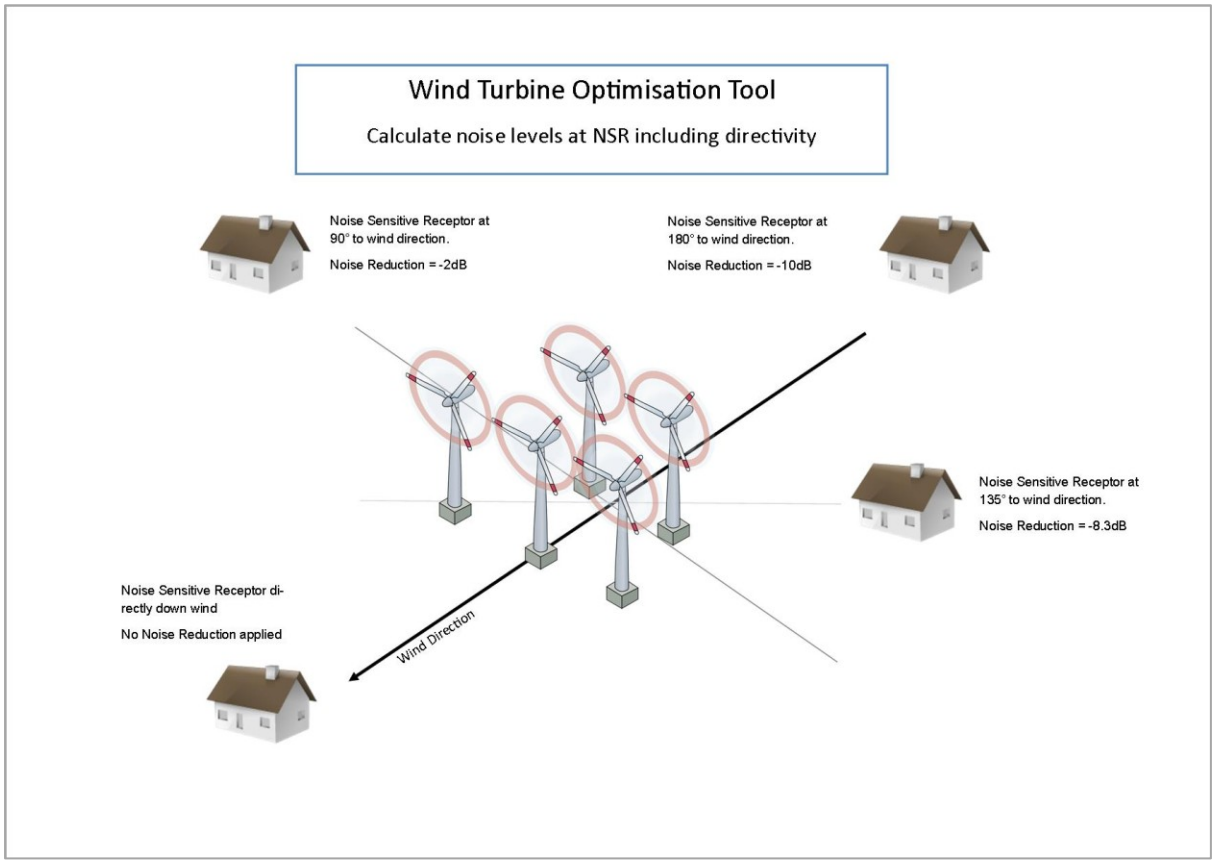
The tool begins by running the turbines at full power to determine the immission noise level at each NSR for all the turbines at each integer wind speed from 3ms^{-1} – 12ms^{-1}.

Because the current guidance (IOA GPG) on sound propagation when assessing the impact of wind farms on NSR only uses the geometric spreading and air absorption

elements of the ISO 9613-2[1], it is a relatively simple task to implement the propagation of sound in the Python programming language.

In addition, due to meteorological effects a wind turbine's radiated sound energy does not necessarily propagate equally in all directions. This artefact is included in the optimisation process through the inclusion of turbine propagation directivity.. The propagation directivity used in the tool follows the guidance from the IOA GPG, which states that *"based on evidence from the Joule project (Bass Bullimore 2010) in conjunction with advice in BS 8233 and ISO 9613-2, current practice suggests that for a range of headings from directly downwind (0°) up to 10 degrees from crosswind (80°), there may be little to no reduction in noise levels; once in crosswind directions (90°) then the reduction may be around 2 dB(A); and when at sufficient distance upwind the reduction would be at least 10 dB(A). For intermediate directions between crosswind to upwind, a simple linear or polynomial interpolation can be used. Such reductions (due to "shadow zone" refraction effects) will in practice only progressively come into play at distances of between 5 and 10 turbine tip heights."* **Error! Reference source not found.** outlines directivity graphically, and Table 2 presents the directivity as a function of wind direction in 15°.segments..

Figure 1 - The Effects of Directivity



[1] Although the IOA GPG does provide for attenuation of sound due to screening the guidance advises that, rather than using the method presented in ISO 9613, a constant should be subtracted from the immission level at an NSR if the a turbine's tip height is screened.

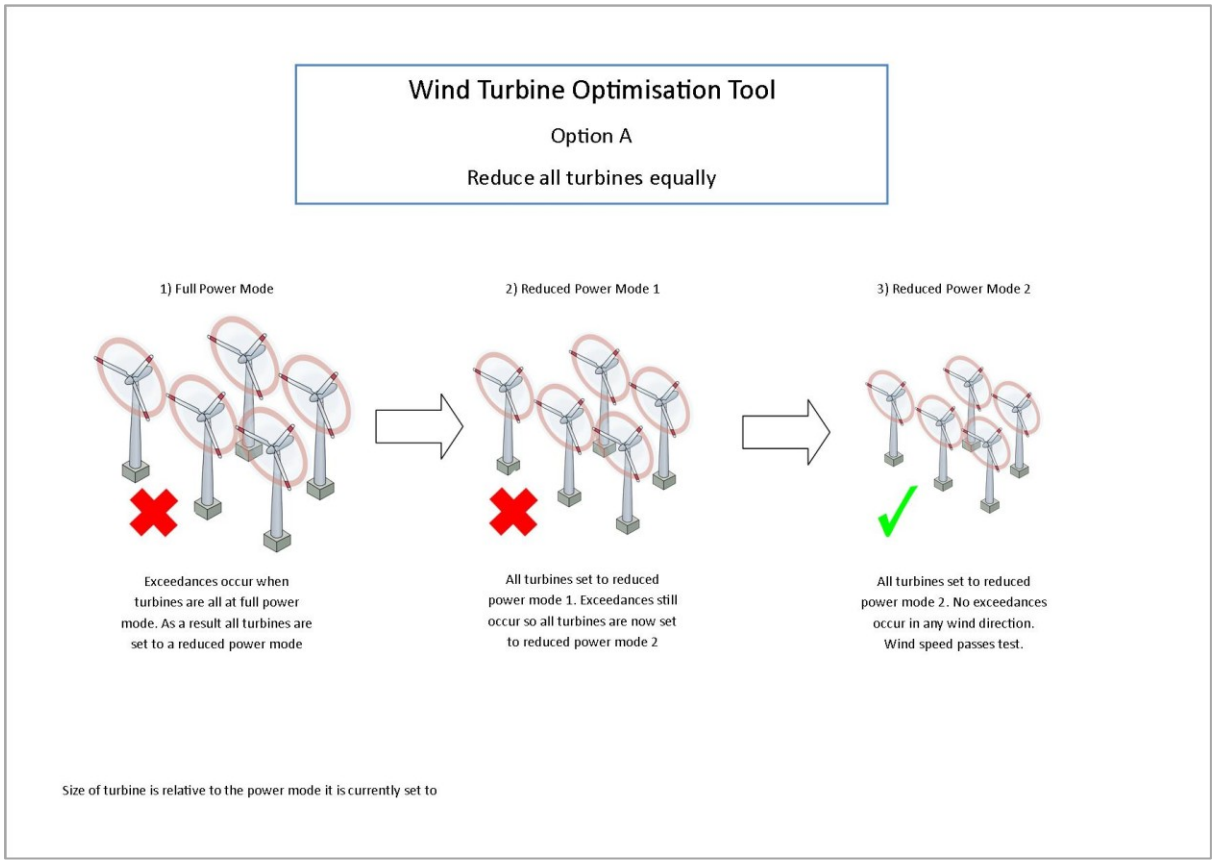
Table 2: Wind Turbine Directivity Factors													
Direction from directly upwind of turbine (°)	0	15	30	45	60	75	90	105	120	135	150	165	180
Attenuation (dB(A))	-10	-9.9	-9.3	-8.3	-6.7	-4.6	-2	0	0	0	0	0	0
Direction from directly upwind of turbine (°)	195	210	225	240	255	270	285	300	315	330	345	360	
Attenuation (dB(A))	0	0	0	0	0	-2	-4.6	-6.7	-8.3	-9.3	-9.9	-10	

The overall wind farm noise immission noise level is compared to the ETSU-R-97 derived noise limits at each NSR.. Then, if an exceedance occurs in any wind direction for one or more NSR for a particular integer wind speed then the next iteration of the tool will include an additional turbine operating at a reduced mode. This iterative process will continue until either a solution is found, at which point the tool will provide details of the optimised noise control strategy, or continue until all possible turbine configurations have been tried and no solution is found. Should no solution be found with the original number of turbines and operating modes the tool will, as necessary, turn off individual turbines and systematically begin the process of determining a solution with turbines operating either in reduced mode or switched off. Once an optimised noise control strategy has been found the program will present the solution in tabular format to the user

4. Optimisation

Optimisation can be performed in either of two ways, depending on the needs of the wind farm developer. Option A is:.

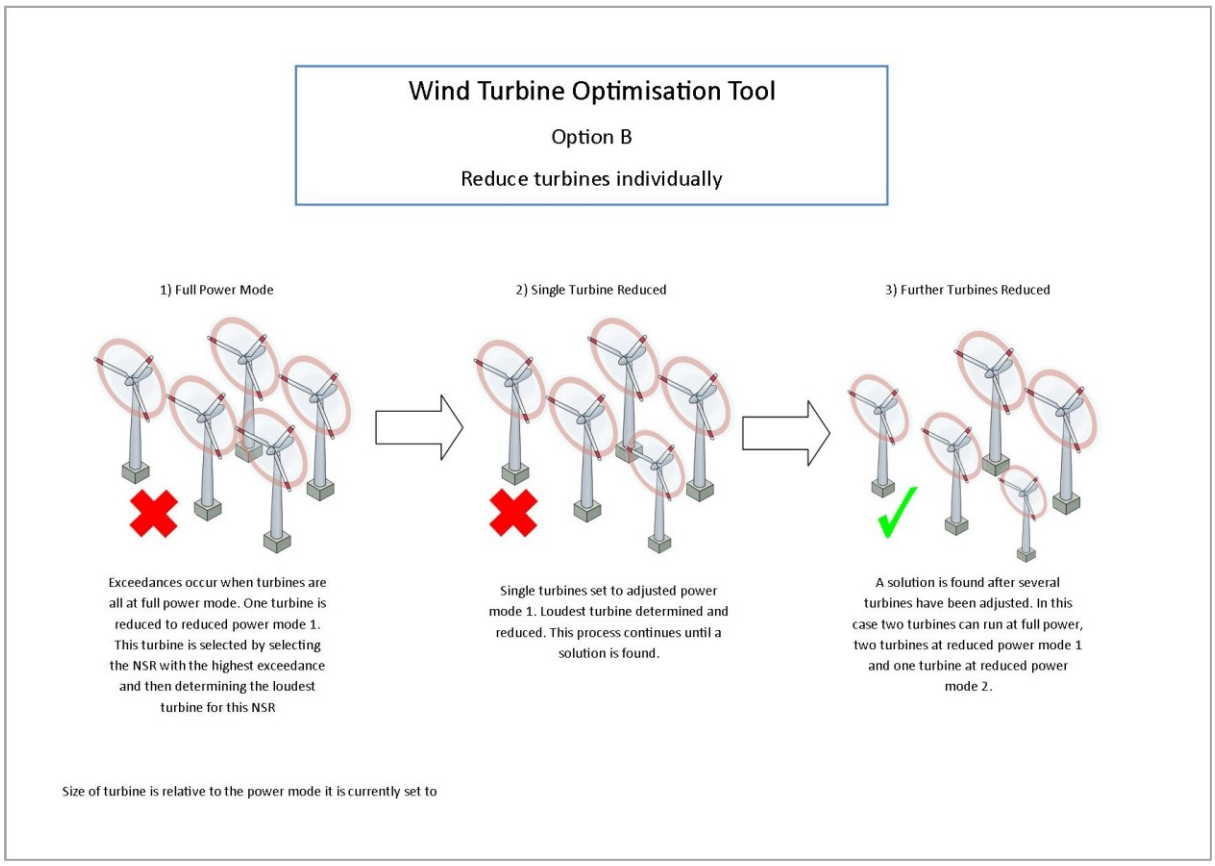
Figure 2 - Option A



In summary, for each iteration of the Option A the mode of operation for all turbines is reduced. That is, for each iteration all turbines are operating at the same mode at any given speed or direction. However, it is possible that there may be a variation of modes for a given wind speed. For example, at a wind speed of 7 ms^{-1} the turbines may be able to run at full power when the wind direction is 0˚ to 90˚ but must be reduced to reduced noise mode 1 between 90˚ and 180˚.

The second optimisation process (Option b) is:

Figure 3 - Option B



In summary, for each iteration of the Option B, a singleturbine has its mode of operation reduced whilst all other turbines operate in the mode for the previous iteration . Accordingly, at any given wind speed and direction turbines may operate in different modes from each other. This provides for a more highly optimised and complex optimisation strategy, but does facilitate the operation of individual turbines such that at all times maximum energy production can occur within the noise constraints.

For both Options a solution is found but the optimised noise control solution will be different. The selection of an optimisation option is dependent on the developer's requirements based on the number of turbines, overall yield, output at the time and turbine cost. The developer may select option A based on the turbine characteristics at the site which would make individual changes impractical. Or they may prefer to use option B because it allows for the potential for more turbines to remain at full power or increased operating modes. The developer can be supplied with both options to determine the best solution for their site.

5. Conclusion

The wind yield optimisation tool developed by AECOM provides noise optimised solutions to the major challenges facing wind farm developers in relation to noise, namely maximising yield whilst complying with noise level limits at nearby noise sensitive receptors. By utilising ArcGIS, Python and ArcPy our tool provides two optimisation options that will provide wind farm developers with noise mitigation strategies such that the proposed wind farm can operate whilst remaining compliant with ETSU-R-97 and incorporates the latest guidance contained in the IOA GPG.

References

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ISO 9613 (1996) Acoustics – Attenuation of Sound During Propagation Outdoors