FEASIBILITY OF MITIGATING THE EFFECTS OF WINDFARMS ON PRIMARY RADAR

Figure 1 Primary radar plays a vital role in air safety[1]

OBJECTIVES

A study has been conducted to determine if it is feasible to modify radars to remove any effects caused by wind turbines. The overall objectives were:

- To determine the technical feasibility of filtering wind turbine echoes from a radar system, without compromising the other radar functions.
- To determine the technical and practical feasibility of implementing such a filter into civil and military radar systems.
- To estimate the cost of developing and implementing any appropriate wind turbine radar filters.
- To generate text suitable for direct inclusion in UK guidelines on Wind Energy, Defence and Civil Aviation Interests.

SUMMARY

The study was conducted under 6 work packages that can be summarised as follows:

1. Obtain information from manufacturers and operators of wind turbines including data on dimensions, materials and construction.
2. Model the turbines to estimate the radar cross sections and Doppler effects.
3. Obtain technical data on civil and military ATC radars in the UK.
4. Estimate the effects of wind turbines on the performance of these radars.
5. Select candidate filtering methods and estimate the effectiveness at removing the effects of the wind turbines.
6. Estimate the costs of fitting these filters to the identified radars.

By following this sequence of tasks, an understanding of the characteristics of wind turbines has been reached. Using this understanding, the effects upon radar performance have been established and hence methods of mitigating these effects have been investigated.

To establish the costs of performing modifications to radars if required, it was necessary to understand the process by which planning approval is granted to wind farm development, and to follow this through to the procedures that are followed when radars are modified, to ensure the maintenance of air safety.

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COST

The total cost of the project, £71,811, is being met by the Department of Trade and Industry (DTI).

DURATION

The study was conducted between June 2002 and May 2003.

Further renewable energy information from the Sustainable Energy Programmes, and copies of publications, can be obtained from:
Renewable Energy Helpline
Tel: +44 (0)1235 432450
E-mail: NRE-enquiries@aeat.co.uk
Web: www.dti.gov.uk/renewable/index.html

BACKGROUND

The UK, at the end of 2002, has nearly 1000 wind turbines installed; under the UK government renewable energy obligations this number will increase significantly. There is justifiable concern amongst the aviation industry and within the Ministry of Defence that these turbines will reduce the effectiveness of radars used for air traffic control and for defence surveillance purposes. Consequently these interests often raise objections to new planning applications for windfarms.

The DTI have set up a 'Wind farms, civil aviation and defence interests working group' to address the issues of concern and generate public domain guidelines. As part of the activity of this group, AMS were commissioned to undertake this study.

This study has aimed to quantify the effects that wind turbines might cause and to investigate the feasibility of modifying radars in some way to reduce or eliminate these effects. The intention is to aid those involved in the planning process with a more scientific approach to resolving objections and this will assist the continuing development of wind energy sources.

There is evidence that unwanted effects do occur, reports from the operators of a number of radar systems that currently operate in the vicinity of wind turbines have identified problems.

[1] Dun Law windfarm photo courtesy of RES, other photos courtesy of AMS UK Ltd

We have been able to identify in this study the mechanisms that cause these effects, and have identified a number of other mechanisms that are probably prevalent but do not present obvious effects to the controller. In some ways these mechanisms are more worrying since the effects are more insidious and may cause some reduction in performance that could possible affect air safety.

By conducting a detailed study we have been able to reveal the specific issues and we hope this will aid a more scientific approach to the interactions between wind turbines and radars.

THE CHARACTERISTICS OF WIND TURBINES

This study recognised that turbine designs are undergoing rapid change. These changes are driven by the need to reduce the capital cost of manufacture and installation, and to lower operating costs. The result is that future turbines will tend to become bigger, be mounted on higher towers and be constructed from different materials.

Any solutions to the radar issues identified in this study must be as robust as possible against a wide range of turbine characteristics including projections of future turbine designs.

There are basically two features of any reflecting object that are significant to the receiving radar. The first is the magnitude, i.e. the strength, of the reflection and the second is the Doppler frequency shift caused by movement of the reflecting surface.

- The reflection characteristic is measured by the Radar Cross Section (RCS), measured in square metres and often expressed in the logarithmic decibel scale in dBm^2 (decibel-metre-squared). Objects do not reflect the energy equally in all directions, so the RCS of the object is different when observed from different directions.

- The Doppler effect causes small changes in the wavelength of the reflected energy by virtue of any movement of the reflecting surface. By comparison of the received signal with the frequency that was transmitted, this Doppler effect can be detected and used to identify an object that is moving.

By generating a mathematical model of a typical large and highly reflective wind turbine, we have established a number of interesting characteristics of these objects.

The RCS of a turbine is highly variable which is surprising when one considers that one of the dominant reflectors is the supporting tower, which is very smooth. However further examination using the mathematical model revealed that a number of effects occur.

The height of the tower causes the reflected energy to be focussed into a beam that is very narrow in the vertical direction. Very small movement (fractions of a degree of arc) of the tower cause with beam to move in elevation, potentially passing over the radar antenna. In extreme cases the level of signal may be sufficient to cause the radar receivers to be driven into limit or other processing function to behave in non-linear ways, thus reducing or even blanking the radar's ability to detect anything in the vicinity of the turbine.

The radar cross section of a tower is proportional to the square of its height so the trend to bigger and higher turbines escalates the effects rapidly.

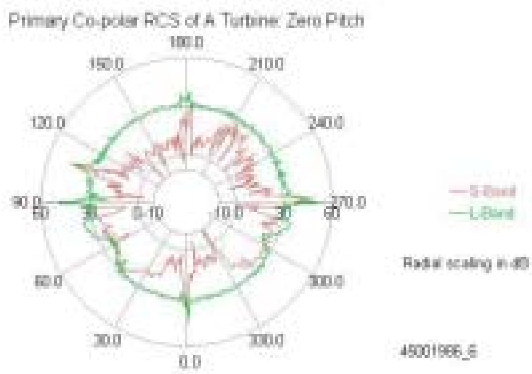

Figure 2. Radar Cross Section predictions at two radar frequency bands

In directions away from the peak tower reflection, the RCS of the turbine is very large but generally within the capability of most radars. The blades themselves are very large, with current designs reaching 65 metres long. Because of their aerodynamic shapes, the reflection characteristics are complex to predict accurately. Any attempt to do so becomes very specific to one blade design and so is not of general use to a study such as this. The blades produce directional reflections and their rotation causes RCS "flashes". The duration of a flash depends on the speed of rotation of the blades and so will be variable under different wind conditions and subject to variations as the turbine head moves to follow the wind direction. Because of the curvature of the blade surfaces, more than one flash per blade per revolution might occur.

Assessment of the Doppler effects was initially done empirically. The velocities at which the blades rotate are known for most current designs and information from the wind turbine industry indicated the highest speed that is likely to be used in the future. Because the velocity of any point on a blade will depend on its radius from the hub, blades produce a continuous spectrum of Doppler frequencies. Much of this spectrum falls inside the velocity range that ATC radar are optimised to detect. It is inevitable therefore that, given the right set of environmental conditions, an ATC radar will detect the blade movement and will allow the detection to pass through the radar processing.

Supporting evidence for this conclusion was provided by measured results gathered by QinetiQ under a separate contract from the DTI[2]. These results, albeit from a smaller turbine than the one modelled for this study, show the expected Doppler signals modulated as the blades rotate towards and away from the observing radar.

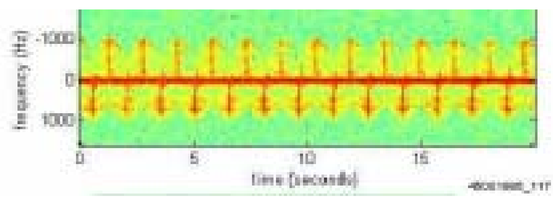

Figure 3. Doppler signals reflected from a 3-blade turbine, showing the modulation by the blades. (Underlying data supplied by QinetiQ)

[2] DTI contract number W/14/00614/00/00

THE EFFECTS ON RADAR

When a radar is operating, it illuminates the space around it with a beam that is narrow in the horizontal plane (azimuth) and wide enough in the vertical plane (elevation) to cover the altitudes that are used for air traffic. All the objects that are illuminated reflect some of the energy back to the radar, and the energy is modified in various ways by the reflection process. Radars can exploit these modifications to differentiate between certain types of objects. Various differentiators are used, some relate to statistical variations in the reflected signals, other exploit the Doppler frequency shift.

In general civil and military radars are not able to measure the Doppler frequency itself, but merely detect that fact that an appropriate Doppler exists. By design of the signal processing algorithms, the radar can differentiate between objects that are stationary and those that are moving. This enhances the detection of aircraft and suppresses the detection of the terrain surface, buildings, etc.

In this way the radar is able to detect an aircraft even though it may be travelling over land that reflects more energy that it does.

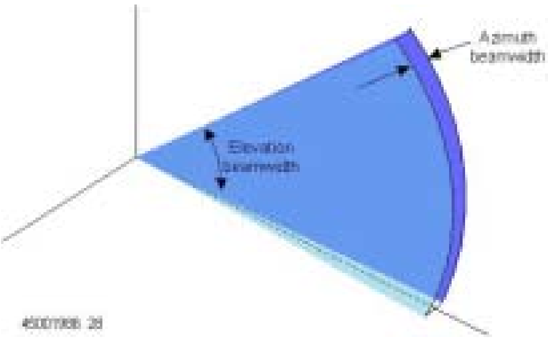

Figure 4. Idealised illumination from an ATC radar

The motions of turbine blades lie in similar velocity bands to aircraft, so if the blades are visible to the radar then they cannot be distinguished from a moving aircraft. Doppler filtering is not an effective means of filtering turbine blades. Sophisticated types of radar that are capable of fine differentiation of Doppler may be modified to distinguish higher speed aircraft from turbines, but there are currently no ATC radars that have this capability. It has to be accepted that these signals will pass through the radar processing and other methods need to be applied to filter them out as explained below.

The effects caused by the potentially very large RCS of each turbine in a windfarm are much more difficult to quantify. The effects are dependent on the internal design details of the radar, on the particular characteristics of the turbines and on the disposition of all of these.

There is the potential for a number of effects to occur; some of these are:

- Suppression of the sensitivity of the radar: all modern radars are designed to deal with varying background clutter levels. Potentially, very high signal levels may exceed the filter design limits.
- Reduction in the ability to track aircraft close to wind farms. Very large signal levels reduce the ability of the radar to resolve closely spaced objects and aircraft may become "lost" in the vicinity of a windfarm.
- False plots may be generated where the RCS of a turbine is large enough to generate "ghost" from pulse compression filters.
- True aircraft returns being reflected from turbines causing incorrect positional information to be reported.

METHODS OF MITIGATING THE EFFECTS

The two principle effects reflection identified above can conveniently be dealt with in separate ways.

The moving blades, although exhibiting similar characteristics to aircraft, do not of course move their location. Some ATC radars are already fitted with processors that track the physical movement of objects over time. Once an object has been characterised in this way, then this information can be used to select which detections are to be passed to the controller. In this context these devices are known as plot filters, and are simply interposed between the signal processing function of the radar and the controller as shown below.

Many military radars, especially when used for defence purposes, employ similar filters. For military use these filters are often known as track extractors.

Advances in the filter algorithms over recent years have enabled much higher performance to be achieved, especially when tracking aircraft close to or within areas of very high clutter returns. These advances are particularly effective at differentiating wind turbines from aircraft.

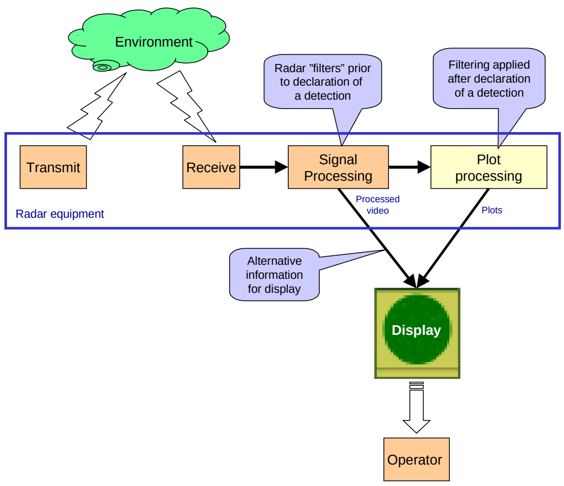

Figure 5. Radar filters in the radar processing chain

Plot filtering also is effective against blade flash. Intermittent detection, if associated with a stationary object by the plot filter, will be removed from the information passed to the controller.

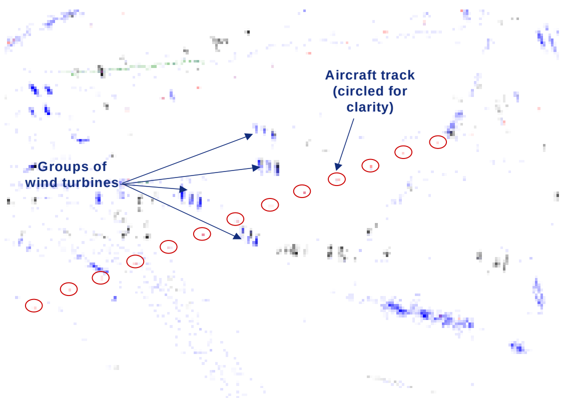

Figure 6. Advanced plot filtering algorithms tracking an aircraft close to windfarms

The effects of very large signals (larger than normal design limits) present a much more difficult problem, one that in some respects it is much more important to solve. Any reduction in radar performance will reduce the effectiveness of a radar to provide the air traffic controller with the information needed.

The measures required to overcome large signal problems for these effects are required to modify the internal processing characteristics of the radar, by increasing dynamic signal range where required, by modernising processing circuits, etc. These measures are effectively required to remove the effect that causes the problem and so they cannot be regarded as filters to be added to the radar.

These modifications are invasive; whilst a plot filter can effectively be simply added to the output of an existing radar, modification to overcome saturation effects are only realisable with intimate knowledge of the design and characteristics of a particular radar installation.

THE COSTS OF MODIFICATIONS

Costs will be incurred over a wide range of activities and phases of any windfarm development. The activities follow a sequence that is depicted in the diagram below.

Activities have been broken down into a series of work packages in order that risks and development might be assessed. Although it is not possible to cost each activity separately because of the wide variations in content, this work package structure allows an overall spread of coats to be estimated.

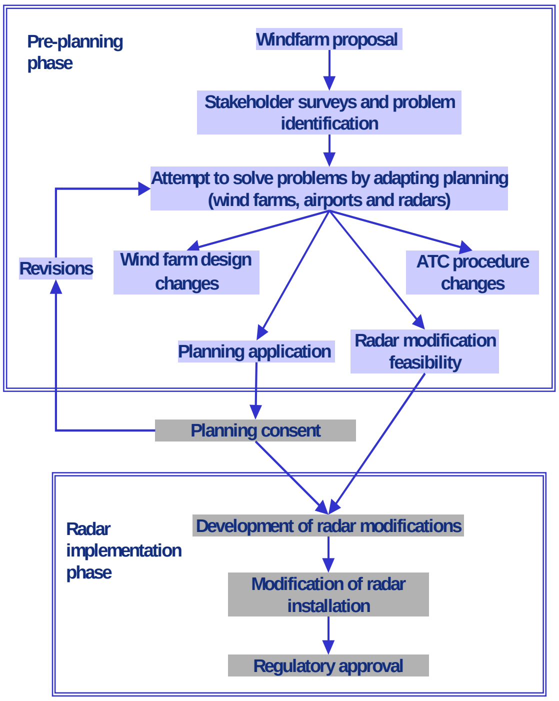

Figure 7. Sequence of activities that results in a radar operating satisfactorily with a windfarm

The activities shown above range from early examination of each situation, to implementation of any modifications that are required. Mitigation measures can include changes to the windfarm layouts and to the design of individual turbines. Simple changes for instance to surfaces and shapes can have significant benefits as far as the radar is concerned.

CONCLUSIONS

- Wind turbine designs will become larger, be developed in larger and denser sites and will be constructed of new materials that are more reflective in radar frequency bands. This trend will increase the levels, but not change the nature, of the problems turbines potentially cause to radars.
- Turbines cause two principal effects: Doppler modulation of the reflected signal at frequencies similar to those from aircraft and very high potential reflection levels causing limiting and numerous other effects in the radar signal processing.
- Very large reflected signals can, in certain sets of circumstances, cause loss of radar performance which reduces the ability of the radar to detect aircraft. The severity of these effects depend on a complex set of circumstances and will vary according to the internal design of the radar itself. Overcoming this problem is a matter of internal design changes that would be subject to an evaluation of the operating circumstances of a radar in a particular situation with regard to proposed turbine installations
- Radars often incorporate Doppler filters that reduce signals from targets that are not moving. These enhance the signals from moving objects so that they can be more clearly seen over stationary ground objects, terrain and sea. Because of the nature of the movement of turbine blades, these filters will pass their signals causing the radar to present the Air Traffic Controller with false information.
- Adding plot filters to the output of the radar can successfully eliminate this second effect. These filters have recently been developed and proven for use in military systems.
- This study concludes that radars can be modified to ensure that air safety is maintained in the presence of wind turbine farms. Individual circumstances will dictate the degree and cost of modification required, some installations may require no change at all whilst others may require significant modification.
- With the correct knowledge of the design and manufacture of a particular radar, and the configuration used in a particular situation, these issues can be investigated and the likely success of a modification can be established at the planning stage, allowing the stakeholders to proceed with confidence in the outcome.

POTENTIAL FOR FUTURE DEVELOPMENT

Studies have been conducted into the effects of wind turbines on radio communications and now on primary radar. These are not the only services that are likely to be affected, many other navigation aids for instance use radio frequency waves for precision control, for navigation beacons, and of course for important defence needs. Whilst much of the knowledge generated by this study is applicable to those systems, they all have their own characteristics that will required to be studied.

This study has provided an opportunity for the UK to establish a world lead in the understanding of the effects of wind turbines on radar. In a world where renewable energy sources will become increasingly necessary, this work can be developed further to reduce Air Traffic and Defence concerns with windfarm developments.