Renewable Energy 63 (2014) 255–262

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Options to mitigate utility-scale wind turbine impacts on defence capability, air supremacy, and missile detection

Trisha Auld [a], Mark P. McHenry [a,*], Jonathan Whale [a,b,**]

[a] School of Engineering and Information Technology, Murdoch University, 90 South Street, Murdoch, Western Australia 6150, Australia
[b] National Small Wind Turbine Centre, Murdoch University, 90 South Street, Murdoch, Western Australia 6150, Australia

ARTICLE INFO

Article history:
Received 29 May 2013
Accepted 14 September 2013
Available online 10 October 2013

Keywords:
Radar
Defence
Wind turbines
Airspace
Meteorology

ABSTRACT

There is an increasing interest in, and concern over, the impact that the growing number of utility-scale wind farms are having on air supremacy and early warning missile detection in relation to radar clutter and shadow, seismic noise, and flight obstructions. This work focuses on US defence industry concerns in relation to wind developments and conducts US industry interviews with representatives from the field of radar, the wind development industry, and government defence agencies. The results of the interviews provide detailed insights defining radar and military concerns raised around wind turbines and reveal that the US Department of Defense (DOD) have invested US $3 million to date on developing a suite of solutions to these concerns. This research discusses selected solutions available for the US DOD approval and alternative options that may be introduced to mitigate the impact of utility-scale wind turbines on defence and security. Implementing solutions will require greater cooperation between government agencies and wind developers, dedicated funding, a common research plan, and streamlined processes.

1. Introduction

Wind turbines affect radar as their echo characteristics often match those of an actual aircraft or storm pattern, which radar seeks to track. Wind turbines cause two main types of interference with radar: direct interference and Doppler interference. Direct interference is caused by the high reflectivity of the turbine components: towers, nacelles, and blades, reducing the sensitivity of the radar via increased background noise, creating false readings and shadowing areas of radar coverage. Doppler interference is caused by the moving blades of a turbine that can generate false targets, false Moving Target Indication/Detection (MTI/D), and impacts both airborne and fixed radar [1]. Existing research investigating wind turbine impact on Air Traffic Control (ATC), Long Range Radar (LRR), Early Warning Radar (EWR), and weather radar are summarised in Table 1.

1.1. Shadowing and clutter

Objects including wind turbines can completely and partially block, and diffract electromagnetic waves. The US DOD describes the shadowing effect of wind turbines on radar as: “Objects in the path of an electromagnetic wave affect its propagation characteristics. This includes the actual blockage of wave propagation by large individual objects or interference in wave continuity due to diffraction of the beam by individual or multiple objects” [6]. Clusters of wind turbines typically cause diffraction of radar electromagnetic energy and therefore create ‘shadow zones’ or ‘blind spots’ where radar is less efficient. The amount of shadow incurred is dependent on the size of the wind farm and the topographical features which surround it.

The DOD defines radar ‘clutter’ as “any unwanted reflected signal that enters the radar receiver and can interfere with the determination of the desired attributes of the target of interest” [6]. Ian Chatting, Head of Research in Britain for wind turbine manufacturer Vestas explained in a public interview that wind farms can make it difficult to identify if an aircraft flying in and out of the clutter is the same aircraft or an alternative aircraft [7]. The DOD [6] states radar clutter from wind turbines could occur if any portion of the turbine appeared in the radar’s line of sight and its level of electromagnetic energy reflectivity, given by its radar cross-section (RCS), exceeds accepted thresholds. The amount of clutter is in direct proportion to the number of turbines within the line of sight of the radar, and the RCS for some turbines can be greater than that of a long haul aircraft [6,8]. While a single turbine located at a distance from the radar will have minimal impact, a large number of turbines over a wide sector of the radar’s coverage will significantly reduce performance [4].

* Corresponding author. Tel.: +61 4 3048 5306.
** Corresponding author. School of Engineering and Information Technology, Murdoch University, 90 South Street, Murdoch, Western Australia 6150, Australia. Tel.: +61 64 8 9360 2102.
E-mail addresses: mpmchenry@gmail.com (M.P. McHenry), j.whale@murdoch.edu.au (J. Whale).

0960-1481/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.renene.2013.09.017

Glossary of acronyms

AEDS	Atomic Energy Detection Systems
ARSR	Air Route Surveillance Radar
ASR	Airport Surveillance Radar
ATC	Air Traffic Control
AWEA	American Wind Energy Association
CFAR	Constant False Alarm Rate
CTBT	Comprehensive Test Ban Treaty
DHS	Department of Homeland Security
DOD	Department of Defense
DOE	Department of Energy
EWR	Early Warning Radar
FAA	Federal Aviation Administration
IMS	International Monitoring Systems (Nuclear)
LRR	Long Range Radar
MIT	Massachusetts Institute of Technology
MTI/D	Moving Target Indication/Detection
NERL	National Air Traffic System En-Route Ltd
NEXRAD	Next Generation Weather Radar
NOAA	National Oceanic Atmospheric Administration
PSR	Primary Surveillance Radar
Radar	Radio detection and ranging
RAG	Range Azimuth Gating
RAM	Radar Absorbing Material
RCS	Radar Cross-Section
SSR	Secondary Surveillance Radar
UK	United Kingdom
US	United States
WSR-88D	Weather Surveillance Radar-1988 Doppler

1.2. Military concerns

Beyond radar interference, Dougherty [9] identifies obstruction and safety as additional concerns the DOD have related to wind turbines, and Möller et al. [10] note that the expansion of wind farms into new locations requires an unprecedented level of planning to cater for the growing scale and range of technological and institutional considerations. Like conventional energy systems, long term policies are a fundamental requirement for sound renewable energy investments that integrate well with existing infrastructure and regulations [11–16], and as wind power capacity is rapidly expanding it is fast approaching technical and institutional impediments [10,17]. For example, dense development of wind turbines near airspace, test ranges, and training ranges used by the US military can occupy the same altitude as aircraft. Seismic and infrasound noise is another publicly stated area of concern for military operations. The seismic and infrasound noise produced by wind turbines may affect sensitive military monitoring operations.

Table 1
Selected research confirming wind turbine interference.

Organisation	Radar research summary
Network of European Meteorological Services	French radar research into wind farm capacity to block beams, causes clutter, and causes Doppler interference on weather radar showed farms up to 30 km from the radar have a high potential to degrade meteorological data and impact weather readings and forecasts [2].
US Department of Commerce – National Telecommunications and Information Administration	US research into wind turbines higher than 250 ft (76 m), on ATC and Federal Aviation Administration (FAA) radar showing numerous documented 'cases of deleterious effects' [3].
UK Royal Air Force	UK tests to determine wind farm effects on ATC Primary Surveillance Radar confirmed shadowing and clutter effects can be 'highly detrimental to the safe provision of Air Traffic Services' due to a decrease in 'probability of detection' and the inability to differentiate between turbine-induced clutter and actual aircraft [4].
Keele University Applied and Environmental Geophysics Group (UK)	The research demonstrated wind farms in the vicinity of the Eskdalemuir seismic monitoring site in Scotland, generated seismic and infrasound noise that influenced site data. However, the interference influence could be controlled through the allocation of a 'noise budget'; within which detection capabilities are not compromised [5].

Studies by Styles et al. [5] confirm that sophisticated equipment such as seismic arrays can detect seismic noise caused by wind turbines.

1.3. DOD existing approved solutions

The utility-scale wind industry acknowledges there is no single solution to radar and military site concerns due to variables such as: location, radar type, mission type, and terrain type in each proposal [18]. In contrast, the DOD in '*Effect of Windmills on Military Readiness*' [6] concluded non-technical solutions are the only proven mitigation means to avoid the degradation of radar capability and interference with military training due to wind turbines. Non-technical solutions involve avoiding placing wind turbines in the line of sight of radar via zoning, terrain masking or terrain relief.

1.3.1. Zoning

Zoning refers to placing turbines a predetermined distance from a radar to avoid interference. The DOD report [6] recommends a distance of 30 nautical miles (nmi) for turbines with blade tips that protrude over 300 ft (91 m) above the local terrain. Zoning is a common mitigation measure supported by policies pertaining to wind turbine siting in many European countries. In Austria, wind farms greater than 10 km from an air defence radar will receive no objections. In the Netherlands, only wind farms within 15 nmi (approximately 24 km) from a military radar require review. In Germany, policy enforces a protection zone of 10 km around all ATC radars, with an area of interest up to 18 km from ATC radars. These zoning policies address both military and civilian concerns over radar shadowing (for Germany and the Netherlands), and electromagnetic interference and obstacles to low flying routes (in Austria) [6]. Zoning is also a mitigation measure used in UK Civil Aviation Authority policy as a means to manage shadowing and false plots on secondary surveillance radar (SSR). Turbines placed over 24 km from an SSR are not thought to impose an issue [19]. However, Primary Surveillance Radar (PSR) zoning policy in the UK still requires wind farm developers that have proposed installation of wind turbines in the line of sight of the radar to undergo consultation with the UK Ministry of Defence, regardless of distance [6]. Zoning is also a technique that has been used to overcome seismic noise interference for nuclear explosion monitoring in the UK. Studies in Eskdalemuir in the UK, site of the longest operating seismometer array and a very good wind development area, found that turbines within 10 km of nuclear monitoring sites should be prohibited [5]. Research by Styles et al. [5] concluded that wind