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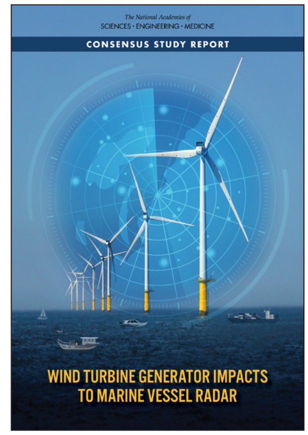
# Wind Turbine Generator Impacts on Marine Vessel Radar




Offshore wind energy development is poised to expand rapidly across the U.S. Outer Continental Shelf (OCS) over the next decade, from the U.S. Atlantic OCS to areas in the Gulf of Mexico and Pacific, notably including the northern and central coasts of California. Responding to a January 2021 Executive Order from the Biden Administration, the U.S. Departments of the Interior, Energy, and Commerce announced the shared goal to deploy 30 gigawatts of U.S. offshore wind energy by 2030, while ensuring biodiversity and co-use of the ocean by various stakeholders. To that end, the U.S. Departments of the Interior's Bureau of Ocean Energy Management (BOEM) announced a plan in March 2021 to complete a review of at least 16 operations plans for offshore wind energy facilities by 2025. By September 2021, lessees of 14 offshore wind energy projects submitted operational plans for review by BOEM.

Because wind turbine generators are constructed predominantly of steel, they generally have significant electromagnetic reflectivity and the capacity to interfere with radar systems in their vicinity. As the rotating blades move relative to a receiving radar system, the blades return large, numerous Doppler-shifted reflections. The maritime community has expressed concern that wind turbine generators could interfere with radar, complicating navigation for both large vessels passing through shipping channels adjacent to offshore wind farms, and smaller vessels navigating through or near the structures. Previous studies on radar and wind turbines relied on data from European wind farms—however, wind turbines located in or planned for the U.S. Outer Continental Shelf are larger, wider, and laid out in a different configuration than those previous studies. The installation of wind turbine generators towering several hundreds of meters above the sea surface with blade lengths exceeding 100 meters therefore poses potential conflicts with a number of radar missions supporting air traffic control, weather forecasting, homeland security, national defense, maritime commerce, and other activities relying on this technology for surveillance, navigation, and situational awareness. A particular concern is their impact on marine vessel radar (MVR), which is a critical instrument for navigation, collision avoidance, and other specialized purposes such as small target detection and tracking, especially in low visibility conditions.

Conducted at the request of BOEM, this report identifies and characterizes the impacts of wind turbine generators on the efficacy of MVR operated on vessels both within and near existing offshore wind facilities, as well as those facilities anticipated to be installed over the next 15 years on the U.S. outer continental shelf. The report also identifies actions that could be taken to reduce the impacts on marine vessel radar to preserve its use as a navigational aid for vessels both in and adjacent to wind turbine generator facilities.

## WIND TURBINE GENERATOR IMPACTS TO MARINE VESSEL RADAR

Wind turbine generators have grown in size and capacity over the past decade, and taller wind turbine generator towers with longer blades and higher capacities are planned for deployment. Recent innovations, including new turbine configurations and foundations, have been aimed at maximizing efficiency. As noted above, the towers, which are the largest part of the turbine, are made of steel and highly conductive, resulting in large, aspect-independent radar reflections. In contrast, returns from the turbine blades are aspect-dependent and can appear even larger than reflections from the tower for certain geometries. It is important to note that blade composition, construction, and orientation all affect the magnitude of the blade contribution to the overall signal visible on a vessel operator's display.

The International Maritime Organization requires that MVRs be installed on a multitude of commercial vessels for navigation safety. The past decade has seen a shift in MVR design from magnetron-based transmission to solid-state transmission, resulting in the production of radar systems with faster response times, lower transmit power, longer lifespans, and greater frequency stability. Solid-state radars can also accommodate the incorporation of more sophisticated processing techniques, such as Doppler processing used to measure the velocity of moving targets with respect to the radar, and Doppler beam sharpening to improve the resolution of the features of distributed, stationary targets.

Wind turbine generators cause radar returns that may appear as interference to MVR, including strong stationary returns from the wind turbine tower, the potential for a strong blade flash return for certain geometries and relative radar-vessel positions, and Doppler-spread clutter generated along the radial extent of the blade, which could obfuscate the radar returns of smaller watercraft or stationary objects, such as buoys. Additionally, multipath reflection from an observer's own shipboard MVR (also known as "own vessel") platform is a significant challenge for returns from wind turbine generators, leading to ambiguous detections and generating a potentially confusing picture for the operator.

As presently deployed, wind turbine generators can reduce the effectiveness of both magnetron-based and Doppler-based MVR; however, similarities and differences exist between both radar classes as to the actual mechanisms leading to degradation. MVR strives to detect both moving and stationary objects to aid safe navigation. While vessel operators can control the radar detection threshold (via changes to the receiver gain) to mitigate strong returns and manage the number of targets shown on the plan position indicator display, this will frequently lead to the unintended consequence of suppressing detections of small targets in and around wind farms, thereby affecting navigation decision-making and situational awareness.

It is noteworthy that there are no published studies of wind turbine generator interference on Doppler-based, solid-state radar used for marine navigation. Previous studies, such as the 2007 British Wind Energy Association study of the U.K. Kentish Flats Wind Farm, collected wind farm data using magnetron-based radar and did not measure a Doppler signal. Therefore, assertions of the suitability of solid-state radar, or lack thereof, for operation in a wind turbine generator environment are inconclusive from these experiments.

Wind turbine generator interference decreases the effectiveness of MVR mounted on all vessel classes, and the larger sizes of anticipated marine wind turbine generator farms across the U.S. Outer Continental Shelf will exacerbate this situation. Interaction with MVRs at the scale of the proposed U.S. deployment will lead to unforeseen complications due to heightened effects of propagation, multipath, shadowing, and degraded Automatic Radar Plotting Aid performance. Maritime search and rescue assets rely on MVR to search for smaller boats as their primary targets in the conduct of ordinary search and rescue operations. A loss of contact with smaller vessels due to the various forms of MVR interference could complicate operations, and is therefore particularly consequential when conducting maritime surface search and rescue operations in and adjacent to an offshore wind farm.

**Conclusion 1: Wind turbines in the maritime environment affect marine vessel radar in a situation-dependent manner, with the most common impact being a substantial increase in strong, reflected energy cluttering the operator's display, leading to complications in navigation decision-making.**

**Recommendation 1: The Bureau of Ocean Energy Management and other relevant federal agencies (e.g., members of the federal Wind Turbine Radar Interference Mitigation Working Group) should pursue any practicable opportunities to fill gaps in understanding of wind turbine generator impacts on marine vessel radars operated in and adjacent to wind farms, giving attention to**

- **comprehensive test planning, data collection, and evaluation over a range of expected, operational conditions;**
- **innovative and collaborative approaches to facilitate data collection, such as the establishment of a marine vessel radar "sensor integration lab" for all classes or types of marine vessel radars and the development of a validated modeling and simulation capability;**
- **research, development, and characterization of a reduced radar-cross-section wind turbine generator for marine vessel radar;**
- **improvements to operator training models based on verification with physics- based models**

**anchored by field collected data;**

- **data collection and analysis using prototype systems, preceding the full deployment of vertical axis wind turbines, if and when they become economically feasible for offshore applications, as a means of characterizing their impacts to marine vessel radars; and**
- **data collection and analysis on floating wind turbine generators, which may pose additional challenges for marine vessel radars through their wave-induced movement that will likely provide a less-consistent radar return overall and may also increase clutter and complicate Doppler return interpretation.**

## MITIGATION ACTIONS

MVRs are not optimized to operate in the complex environments of a fully populated, continental shelf wind farm. There is no simple MVR modification resulting in a robust wind turbine generator operating mode. Additionally, in contrast to investments by developers and operators of air traffic control and military radar systems, compelling mitigation techniques for MVR have not been substantially investigated, implemented, matured, or deployed. Approaches external to the MVR radar design successfully employed for radar applications used elsewhere to deal with strong clutter returns from objects with a large radar cross section, however, could be considered as a low-cost or alternative means of mitigating wind turbine generator interference.

The environmental complexity that an offshore wind turbine generator farm presents to the MVR, its plan position indicator display, and other output products necessitates careful evaluation of training methods and tools to properly assess real-world performance of MVR operators, incorporating realistic scenarios and verified, physics-based and effects-based models.

Solid-state radar technology allows for the application of coherent signal processing methods to filter out both static and dynamic wind turbine generator clutter returns to improve detection of moving targets and stationary objects, such as buoys. Thus, solid-state radar offers greater potential in overcoming interference than magnetron-based radar. The stakeholder community could incentivize innovation in MVR products by manufacturers to promote radar designs with increased immunity to wind turbine generator interference.For example, development of new, Doppler-based, solid-state MVRs with wind turbine generator resilience is possible. However, the majority of MVRs in operation today are still magnetron-based systems, and widespread adoption of solid-state radars will, at present, likely be a gradual process due to the cost of replacement, the long life cycles of existing MVRs, and a lack of regulations that require the functionality provided by solid-state radars.

Additionally, modifications to the wind turbine generators themselves could potentially reduce their radar signature. Previous modelingand simulation efforts have shown, for example, that incorporation of radar absorbing materials and tower shaping can reduce the radar cross section of wind turbine generators. Preliminary research and development of a reduced- radar cross section wind turbine generator shows promise. However, with the exception of one study (the 2018 QinetiQ Stealth Wind Farm Case Study), to which the committee did not have full access, those efforts have not been fully proven and are not available in the near term.

**Conclusion 2: Opportunities exist to ameliorate wind turbine generator–induced interference on marine vessel radars using both active and passive means, such as improved radar signal processing and display logic or signature-enhancing reflectors on small vessels to minimize lost contacts.**

**Recommendation 2: The Bureau of Ocean Energy Management (BOEM) and other relevant federal agencies (e.g., members of the federal Wind Turbine Radar Interference Mitigation Working Group) should pursue any practicable options to mitigate wind turbine generator impacts on marine vessel radar. BOEM and partners should give attention to the following:**

- **The International Maritime Organization's Standards of Training, Certification and Watchkeeping (STCW) Knowledge, Understanding and Proficiency standards of competence to include operating in or adjacent to multiple structures at sea. Similar radar observer training should be considered for U.S. credentialed mariners not subject to STCW code who operate vessels equipped with radar in the vicinity of wind turbine generators.**
- **Updated requirements for vessels less than 150 gross tonnage to exhibit a radar reflector of suitable size and design while underway in or adjacent to a wind farm to improve their detectability when practicable.**
- **The deployment of reference buoys adjacent to wind farms to provide mariners a reference target to appropriately adjust marine vessel radar gain and other control settings to assist in the detection of smaller targets operating in the vicinity of wind farms.**
- **The evaluation and standardization of radar mounting procedures on marine vessels to mitigate the impact of near-field platform interfenece**

**(i.e., multipath) on radar performance.**

- **The promotion of radar designs with increased immunity to wind turbine generator interference, such as new, Doppler-based, solid-state marine vessel radars with wind turbine generator resilience.**
- **Research and development to prove the performance and feasibility of fieldable material and structural wind turbine generator design components to reduce the radar cross section of wind turbine generators and mitigate their effects on marine vessel radar.**

## THE COMMITTEE ON WIND TURBINE GENERATOR IMPACTS TO MARINE VESSEL RADAR

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For More Information . . . This Consensus Study Report Highlights was prepared by the National Academies of Sciences, Engineering, and Medicine based on the Consensus Study Report Wind Turbine Generator Impacts To Marine Vessel Radar (2022). The study was sponsored by Bureau of Ocean Energy Management. Any opinions, findings, conclusions, or recommendations expressed in this publication do not necessarily reflect the views of any organization or agency that provided support for the project. Copies of the Consensus Study Report are available from the National Academies Press, (800) 624-6242; http://www.nap.edu or via the Ocean Studies Board web page at http://www.nationalacademies.org/oceanstudiesboard/osb.

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