Modelling the Impact of Offshore Wind Farms on Safety Radars onboard Oil and Gas Platforms

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***Abstract*—Radar Early Warning Systems (REWS) are safety critical radars installed onboard offshore Oil and Gas (O&G) platforms to monitor nearby surface traffic to provide asset and personnel protection and management. Wind turbines near REWS can interfere with the system due to their large and varying returns, radar shadows and overloading of the track table. This paper highlights some of the key parameters affecting the modeling of the potential interference on REWS. This paper will also present some modeling result for generic wind turbines nearfield scattering, simplified shadowing effects and finally a scenario to illustrate the compound effects on the REWS detection performance.**

***Index Terms*— Wind Farm, Radar Impact, Radar Shadowing.**

I. Introduction

Wind farms located within the line-of-sight (LOS) of radars may interfere with the radar performance and degrade the ability to distinguish between turbines and returns from targets of interest [1 - 3]. The potential interference of wind farms with aviation, marine and other radar systems could be considered a significant concern to the regulating authorities and radar operators [1,2]. Radar Early Warning Systems (REWS) located on oil and gas platforms are subject to potential interference due to the presence of large offshore wind farms in their area of coverage.

REWS are used to detect and track all vessels on the radar horizon. One of the main functions of a REWS is to protect offshore assets from collision with errant vessels and has preset collision alarm rules. Typically, an Orange alarm is raised if a collision course is detected with Closest Point of Approach (CPA) of 0.5 NM or Time to Closest Point of Approach (TCPA) of 35 minutes and Red alarm is raised if the CPA is 0.27 NM or TCPA is 25 minutes. Should a vessel breach these rules an automatic alarm is raised to alert the operator.

The radar coverage and the list of detected targets are transmitted to other assets including nearby Emergency Response and Rescue Vessels (ERRVs) via ultra high frequency (UHF) radio links. It is noted that UHF links use a low-bandwidth telemetry system and have a limit on the total number of tracks that can be transmitted. Overly large targets list may need extended time to be transmitted and may cause untimely update of the radar feed.

The impact of wind farms on REWS may arise from a number of factors such as; high radar returns from the turbines, increased number of detections, false alarm/track generation and radar shadowing. High radar returns due to the large RCS of turbines may cause target spreading at extended ranges and potential detections through the sidelobes at close ranges. This will cause smearing and cluttering of the radar screen and potentially mask other targets in the area. Additionally, depending on the thresholding techniques used within a radar system, the presence of wind farms may increase the threshold over parts of the wind farm area, which potentially may cause smaller targets to be lost.

Degradation of the REWS performance may also be caused by the turbines radar shadow. Shadowing may cause smaller targets to temporarily disappear from the radar display as it moves in and out of the shadow regions. This may cause the tracker software to lose tracks and potentially degrade the ability of the REWS to issue collision warning in a timely manner. The extent of the impact caused by shadowing depends on the size and height of the turbine and the target of interest, i.e. different effects may be observed if looking at surface targets or air targets.

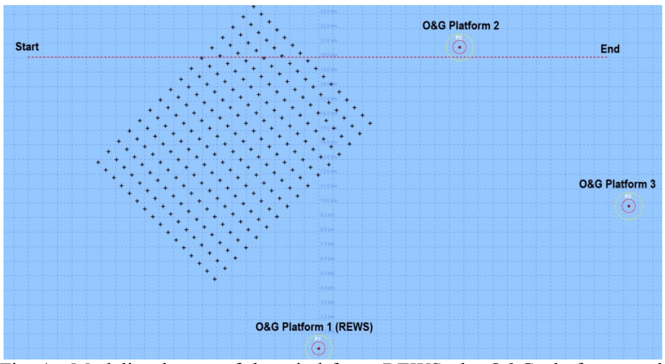

Fig. 1. Modeling layout of the wind farm, REWS, the O&G platforms and the proposed vessel route

Large offshore wind farms can be located very close to O&G platforms and may impact the efficiency of the REWS to provide reliable detection and tracking. Therefore, there is a need to model and investigate the potential impact of wind farms on REWS during the planning process and prior to construction. However, due to the electrical size of wind turbines which extend over thousands of wavelengths at radar frequencies the use electromagnetic (EM) solvers and Finite Element Analysis (FEA) tools are impractical and require very large computing resources and extended run-times.

This paper will present a modeling methodology used to estimate the effect of shadowing and radar returns from wind turbines on REWS target detection. This paper will highlight the need to account for nearfield RCS of wind turbines and the partial shadowing effects on larger vessels. The paper will present modeling results for the scenario shown in Figure 1. The model will consider three offshore O&G platforms with the REWS installed on Platform 1 and vessel travelling through the wind farm on a path that would breach the Orange TCPA alarm. The 0.27 NM and 0.5 NM CPA alarm zones are shown as red and yellow circles respectively around each of the platforms.

II. Modeling Turbine Returns

The impact of wind farms on radar systems depends on the type and location of radar, the size and orientation of the turbines, the distance of the farm to the radar, target type (air/sea) and other parameters relating to the local environment [4]. For non-Doppler based radars such as the REWS the potential impact may arise due to the large radar returns. This depends on radar cross-section (RCS) of turbines at different orientations, ranges and geometries [4,5].

The ReMeRA modeling tool accounts for all the aforementioned factors and is designed specifically to model the scattering profile from each turbine within the wind farm [4]. The RCS of each turbine is modeled individually based on its orientation and location giving the RCS either farfield or nearfield.

The precise detail of the RCS will depend largely on the wind turbine geometry. Within this study a good representation was achieved using a generic 5MW turbine geometry that includes the blades airfoil profile, tower and nacelle geometry [6]. The 5MW turbine has a hub height of 70m and a rotor diameter of 120m. Additionally, to represent future offshore wind turbines the 5MW turbine geometry was scaled-up to represent a 7MW turbine with a hub height of 80m and a rotor diameter of 140m. Figures 2 and 3 show the variation of the RCS with range for the 5MW and 7MW turbines respectively at two orientation angles. At 0° yaw angle the radar would illuminate the front face of the turbine while 90° yaw would result in side illumination of the turbine.

The results show a significant variation of the turbine RCS in the nearfield, especially within the first 30km where the RCS varies rapidly with range. Additionally, by examining the scenario presented in Figure 1, it can be noted that the turbines are generally located 7 – 25 km away from the radar (which is not uncommon in real life). Therefore it becomes apparent that the returns from the turbines are largely site specific and it is important to model the RCS of each turbine individually based on its orientation and range from the REWS when assessing their impact.

III. Turbine Radar Shadowing

When turbines are placed within the LOS of radar systems radar shadowing will occur behind the structure. The extent and length of the shadow region depends on the size of the turbine, the distance to the radar antenna, the height of the radar and the height of the target of interest. The severity of the shadow will also depend on the distance of the target from the turbine. Radar diffraction around the turbine will result in a reduced effect of the shadow as the range between the shadowed target and the turbine is increased [7].

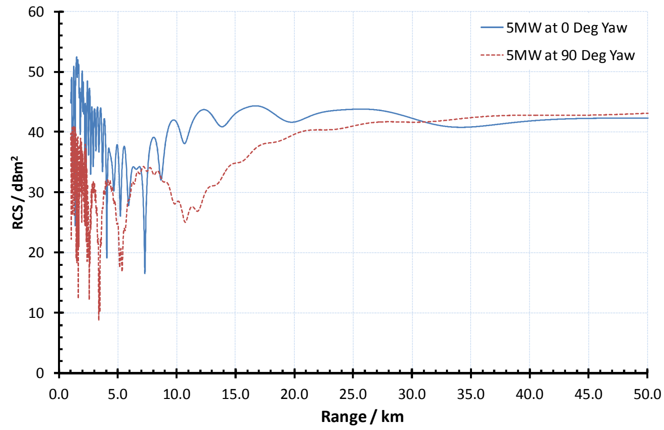

Fig. 2. 5MW Turbine nearfield RCS variation with range at yaw angles 0° and 90°

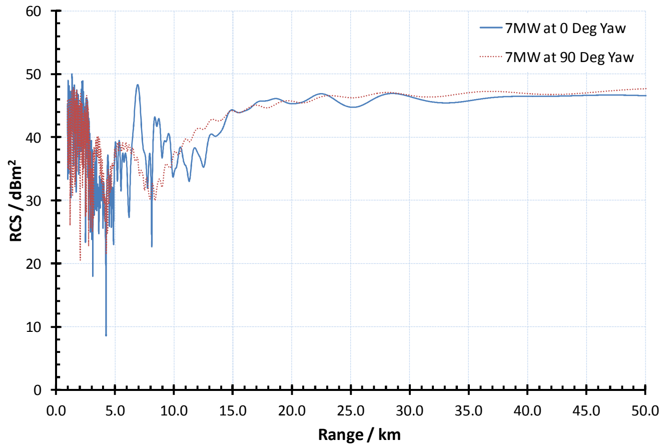

Fig. 3. 7MW Turbine nearfield RCS variation with range at yaw angles 0° and 90°

Modeling the compound radar shadowing of large wind farms while accounting for the diffraction effects is complex and requires extended runtime and detailed knowledge of the turbine geometry and surrounding environment. Within this paper the radar shadows were modeled based on optical shadowing as shown in Figure 4. Optical shadows assume no diffraction effects and therefore ignore the improvement in the shadow region at extended ranges. Depending on the turbine size and radar height, the optical shadows may extend to the radar horizon. Optical shadows will also assume that a point scattering target falling within the shadow will have no returns at all (detection null).

It is recognized that using optical shadowing is a conservative assumption and may produce pessimistic results when modeling the effects on large targets that are more than 10km away from the shadowing turbines. It is also noted that optical shadowing may not be applicable to all scenarios and radar frequencies. However it is still very useful when assessing worst case scenarios and safety critical situations. Figure 5 shows the resultant shadowing generated from a wind farm located near a REWS at 60m above sea level (ASL).

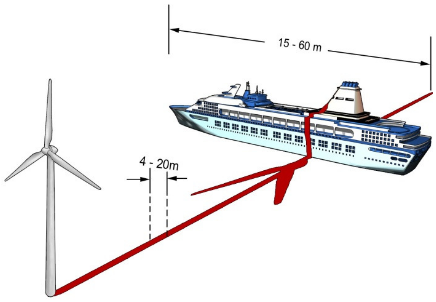

Fig. 4. Turbine optical shadowing and partial shadowing of large vessels °

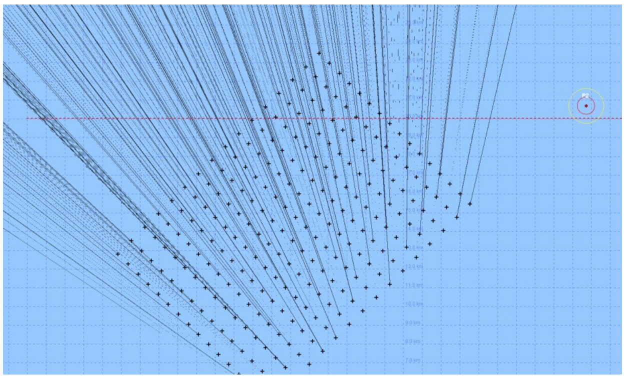

Fig. 5. Optical shadowing caused the wind farm

Typically, the optical shadow region cast by a turbine can be between 4 – 20m in width. When considering larger vessels, the width of the shadow region may be significantly smaller than the vessel length and will cause a small portion of the vessel to fall within the shadow while the remainder of the vessel's hull will reflect radar signals back to the REWS as shown in Figure 4. To give a more realistic representation of the radar returns from shadowed vessels the length of the vessel was considered.

IV. Vessel Returns Modeling

The REWS constantly monitors traffic near the O&G assets to warn the operator against possible breach of the alarm conditions. All detectable radar returns from the surrounding vessels are tracked and displayed to the operator. However, the operator may specify the vessel size of interest when building the safety case for the REWS site. The size of the vessels of interest varies depending on the platform function and whether it is manned or unmanned. Large vessels in excess of 1,000 Gross Tons (GT) are typically the main concern to the safety of the offshore platforms while smaller vessels are deemed to be of reduced risk to the platforms.

Vessels that are rated at 1,000GT and above can vary significantly in length (typically 15 – 60m) and speed (5 – 30 knots). While the speed of the vessel is important to consider when assessing the impact on the TCPA alarm, the length of the vessel is important to consider when assessing the effects of partial shadowing. Within this paper a vessel with a length of 25m and RCS of 35 dBm^2 is considered.

Typical radar modeling scenarios assume targets as point scatterers located in the geometrical centre of the vessel. Such assumptions will cause total detection nulls when the target is moving within the shadow region. This assumption may not be valid when assessing the effects of large vessels moving within narrow shadows. Thus, the vessel was assumed as a large number of scattering points that are equally spaced along the length of the vessel. The RCS of each scattering point is assumed to follow a normal distribution (bell-shape) centered at the midpoint of the vessel as shown in Figure 6. The total RCS of the modeled vessel was defined as $35dBm^2$ (which is given by the area under the graph). The height of the scattering points was assumed to be 10m.

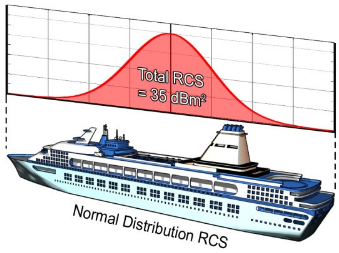

Fig. 6. Vessel RCS as multiple points normally distributed along the vessel length

Normal distribution was chosen as it may represent the typical shape of a ship where the front and the back of the vessel are typically curved surfaces and hence reflects less radar energy than the mid section of the vessel (which is typically more flat). With multiple scattering points, s the vessel moves through the shadow of a turbine, the scattering points that are within the shadow region reflect no energy back to the radar, while the rest of the scattering points are considered and their returns are added. To assess the effect of vessel movement on the tracker a worst case speed of 20knots was assumed on the modeled route.

V. Modeling Results

For the scenario shown in Figure 1, the main parameters of the radar used are listed in Table 1. The model uses the turbine RCS computations along with the shadow and target models to compute the radar returns. Once the returns from all the turbines and targets are computed over a full antenna rotation the model outputs the results as a scan-converted plan position indicator (PPI) display showing the locations and magnitudes of the power received as shown in Figure 7. The results show clearly the returns from each turbine and the path of the target through the wind farm towards P2 –breaching the orange CPA alarm criteria.

TABLE I. Radar Modeling Parameters

Gain	31.5 dB
Transmitter Power	25 kW
Frequency	9.4 GHz
Pulse Width	230 ns
Noise Figure	5.0 dB
Dissipative Losses	1.0 dB
Beam-shape Losses	1.0 dB
Azimuth beam width	0.8°

Elevation beam width	21.0°

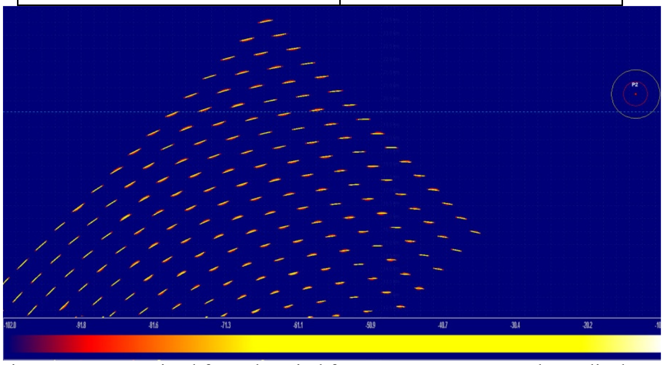

Fig. 7. Power received from the wind farm on a scan converted PPI display

The scan-converted PPI view can animate the dynamic blade movements and moving targets to provide good visualization of the scenario. However, to better assess the impact of the wind farm and its shadow on the detection of the vessel, the power received from the target along the given route is calculated. Figure 8 shows the power received from the target competing against the noise level and the returns from the wind farm. The range axis denoted the distance travelled by the vessel from the starting point along the route towards the end point 40 km away. The dips in the vessel returns are due to the turbine shadows while the pronounced peaks in the noise level denote the returns from the turbines along the route. Figure 9 is an enlarged segment of Figure 8 showing the effects of shadows and turbine returns in more details.

For the presented scenario, the modeling results show that the radar returns from two turbines will overpower the returns from the vessel causing masking of the vessel at multiple points along the route. Also, using optical shadowing along with the normal distribution of the vessel RCS is shown to reduce the returns from the vessel by 3 – 10 dB which corresponds well with conclusions by [7]. The shadowing effect did reduce the vessel returns on some occasions below the returns from the turbines but not under the system noise level. Smaller vessels are expected to experience more reductions and possible causing them to fall below the detection and tracking levels of the REWS.

VI. Conclusions

REWS is an integral part for the safety and management of offshore O&G assets. There is a high dependency on REWS to alert the operator of any vessel that is travelling in a direct vector towards the assets or the presence of unauthorized vessels within the exclusion zones around the platforms. It is therefore of paramount importance to ensure reliable detection and tracking of all vessels on REWS radar horizon.

Wind turbines located near REWS may degrade the performance of the radar due to their large size and variable radar returns. The large radar returns may clutter the display, mask nearby targets and may increase the detection threshold causing loss of detection of smaller targets. Additionally, detections of wind turbines will increase the size of the track table which is often transmitted to ERRVs over a limited bandwidth UHF communication link causing delays and untimely update of radar feed. Turbines also cast a large radar shadow behind the structures causing vessels passing through the shadow region to have fluctuating returns or even momentary loss of detection. Such interferences may have a direct impact on the REWS tracker causing it to drop existing tracks and potentially lose its ability to issue an alarm to the operator in a reliable and timely manner.

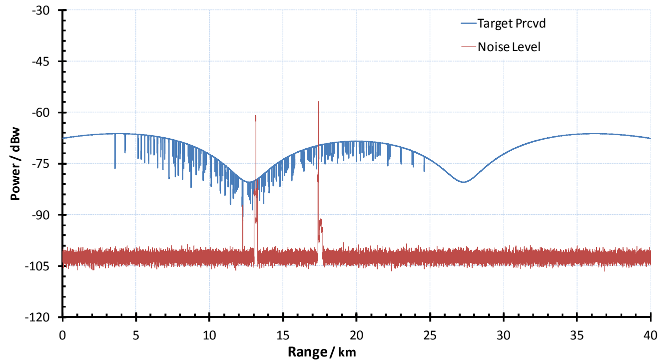

Fig. 8. Power received from the modeled vessel along the modeled route

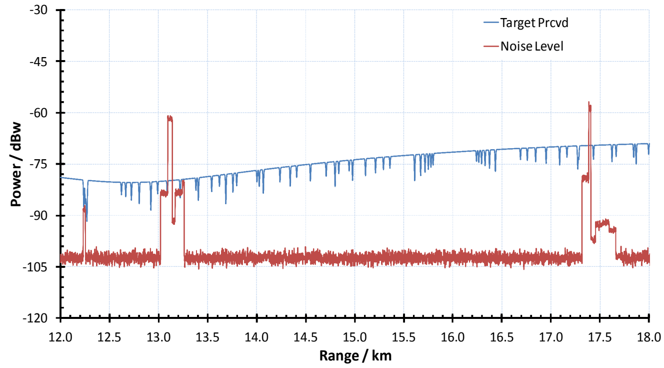

Fig. 9. Details of the effects of shadowing on power received by the vessel vs. the returns of the wind farm

The models presented in this paper aim to predict the impact of wind farms on REWS in a computationally efficient manner using standard desktop computing environment. As the range of REWS extends only up to 10s of kilometers, the radar turbines will always be within the nearfield of the turbine. Therefore, the use of simplified meshing algorithms to compute the nearfield RCS of each turbine along with optical shadowing provides reasonable approximation of these potential effects. Also assuming a normal distribution of RCS along the length of larger vessels was used to approximate the effects of partial shadowing and hence the detection of larger vessels travelling within a wind farm. The results from the modeled scenario gave a good indication of the radar detection performance in such environments and further work may look at the overall effect on the tracker.

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REFERENCES

[1] Jago, N. Taylor, “Wind Turbines and Aviation Interests - European Experience and Practice”, ETSU W/14/00624/REP, DTI PUB URN No. 03/515, 2002

[2] G. J. Poupart, “Wind Farms Impact on Radar Aviation Interests”, BWEA Radar Aviation Interests Report, DTI report number W/14/00614/00/REP, September 2003.

[3] Wind Energy, Defence & Civil Aviation Interests Working Group “Wind Energy and Aviation Interests – Interim Guidelines”, ETSU W/14/00626/REP, October 2002.

[4] L Danoon and A K Brown, “Modeling Methodology for Computing the Radar Cross Section and Doppler Signature of Wind Farms”, IEEE Trans on Antennas and Propagation, Vol. 61, No. 10, October 2013.

[5] Olatz Grande, Josune Cañizo, Itziar Angulo, et al., “Simplified Formulae for the Estimation of Offshore Wind Turbines Clutter on Marine Radars,” The Scientific World Journal, vol. 2014, 2014. doi:10.1155/2014/982508

[6] Supergen. Supergen Wind Energy Technologies Consortium (Supergen Wind) 2009 July 2009 [cited December]; Available from: http:// www.supergen-wind.org.uk.

[7] Butler, M.M. and D.A. Johnson, Feasibility of Mitigating the Effects of Wind farms on Primary Radar. 2003, Alenia Marconi Systems Limited