VINDRAD, Project Report

31 March 2011 v1.0

A tool for calculation of interference from Wind Power Stations to Weather Radars

VINDRAD is a project by the Swedish Meteorological and Hydrological Institute and the Swedish Armed Forces, commissioned by the Swedish Energy Agency

Swedish Energy Agency: *www.energimyndigheten.se/en/*
Swedish Meteorological and Hydrological Institute: *www.smhi.se/en/*
Swedish Armed Forces: *www.forsvarsmakten.se/en/*

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Sammanfattning (Swedish Summary)

Det huvudsakliga målet för VINDRAD har varit att utveckla en modell för beräkning av störningar från vindkraftverk (WPS) mot väderradar (WR). Studierna har fokuserat på de tre olika typfallen, blockering, klotter och radiella vindar härledda från Dopplereffekten. I den beräkningsmodell som har utvecklats, har radiella vindar inte implementeras.

I den svenska samrådsprocessen avseende störningar mot väderradar, baseras analysen för närvarande på rekommendationer från internationella organisationer som WMO och EUMETNET. Det finns emellertid inga tillgängliga verktyg för att beräkna den totala störsituationen.

VINDRAD föreslår att den nuvarande samråds- och remisshanteringsprocessen behålls, men bedömningen av WPS störningar på WR bortom 5 km avstånd utförs med det utvecklade beräkningsverktyget. Den nuvarande 20 km-gränsen bör tas bort. Beräkningsmodellen hanterar större avstånd och risken för störningar från WPS på längre avstånd än 20 km bör inte ignoreras. Detta kommer att resultera i en mer korrekt bedömning av störningar mot väderradar, baserad på kontrollerade beräkningsmetoder. Onödigt överskydd för radar undviks samtidigt som en pålitlig nationell väderradartjänst bibehålls.

Samråds- och remisshanteringsprocessen kan förbättras ytterligare genom införande av ett verktyg för förhandssamråd, som kan nyttjas av vindkraftsplanerare eller operatörer. Ett webbaserat verktyg ger goda möjligheter för vindkraftsplanerare att få en preliminär bedömning av störningar mot väderradar, för att därigenom undvika att projekt som inte kommer att accepteras ur väderradarsynpunkt läggs fram i samråds- och remisshanteringsprocessen. Projektet betonar dock att väderradar är bara ett av flera system, funktioner eller verksamheter som måste beaktas i totalförsvarets övergripande samråds- och remisshanteringsprocess.

En teknisk dokumentation av beräkningsverktyget som utvecklats av SMHI, med den föreslagna nya störningsmodellen, redovisas i bilagan till denna rapport.

Det finns behov av ytterligare studier, inklusive effekter av anomala vågutbrednings-förhållanden och påverkan från vindkraftverk på vindmätningar genom Dopplereffekter.

Det finns åtminstone två möjliga vägar att utforska för att försöka minska påverkan på WR från WPS. Ett sätt är att använda "gap fillers", d.v.s. extra väderradar för att kompensera för förlusten i täckningen på grund av WPS. Det andra sättet är att minska radarmålytan (RCS) för WPS, främst på de roterande turbinbladen, när klotter är den dominerande orsaken till störningar.

1 Summary

The main objective for VINDRAD has been to develop a model for calculation of interference from Wind Power Stations (WPS) to Weather Radars (WR). The studies have focused on three different problem scenarios; blocking, clutter and radial winds derived from the Doppler effect. In the calculation model that has been developed, radial winds have not been implemented.

In the Swedish consultation and approval process concerning interference to WR, the analysis is presently based on recommendations from international organizations like WMO and EUMETNET. There is however no available tool to calculate the total interference situation.

VINDRAD suggests that the present consultation and approval process is retained but the assessment of WPS interference to WR beyond 5 km separation distance is performed with the developed calculation tool. The present 20 km distance value should be removed. The calculation model manages greater distances and the risk of interference from WPS at longer distances than 20 km should not be ignored. This will result in a more proper assessment of the interference to WR, based on verified calculation methods, avoiding unnecessary overprotection of the radars while still maintaining a reliable national weather radar service.

The consultation and approval process may be further enhanced by the use of a pre-consultation tool for the WPS planners or operators. A web based tool should provide an opportunity for wind power planners to get a preliminary assessment of interference to Weather Radars, thus avoiding any projects that will be unacceptable from the weather radar perspective to be put forward in the consultation and approval process. The project stresses the fact that weather radars are only one of several systems, functions or activities that must be considered in the overall total defence consultation and approval process.

A technical documentation of the calculation tool developed by SMHI, with the suggested new interference model, is presented in the Appendix to this Report.

A need for further studies exists, including effects of anomalous propagation and of the impact of Wind Power Stations on Doppler wind measurements.

There are at least two possible ways to explore when trying to reduce the impact on WR from WPS. One way is to use “gap fillers”, i.e. extra weather radars to compensate for the loss in coverage due to WPS. The other way is to reduce the radar cross section (RCS) of the WPS, primarily on the rotating blades, when clutter is the predominant reason for disturbances.

2 Background

2.1 Introduction

VINDRAD is a project by the Swedish Meteorological and Hydrological Institute (SMHI), financed by the Swedish Energy Agency. Through the close cooperation that exists between SMHI and the Swedish Armed Forces (SAF), the military weather service is also participating in the project.

The project has focused on the development of a calculation model to assess the interference created by Wind Power Stations (WPS) to Weather Radars (WR) belonging to SAF and SMHI. Deployment of WPS shall be made without the risk of harmful interference to the WR function. The calculation model shall be implemented in computerised decision support systems.

Swedish Energy Agency has issued two Project Decisions, 04 Dec 2009 [Ref 1] concerning the first phase of the project, and 23 Feb 2010 [Ref 2] for the go-ahead of the second and third phases.

2.2 Project Organisation

The Project Management has been allocated to SAF by Swedish Energy Agency. SAF has delegated most of the authority to an Assisting Project Manager from the Swedish Defence Materiel Administration (FMV), but the formal responsibility is still owned by SAF. SMHI and FMV have formed a Project Management Group of four persons, for the day-to-day running of the project. A Steering Group chaired by Swedish Energy Agency, with representatives from Swedish Energy Agency, SMHI and SAF has given support and instructions to the Project Manager in ten recorded meetings.

Detailed information about the project can be found in [Ref 4], the most recent VINDRAD Project Plan.

2.3 Project Objectives

The main objective for VINDRAD has been to develop a model for calculation of interference from WPS to WR. The model shall be realizable in computer based decision support systems to be applied in the consultation and approval process by the authorities. It should also be possible for the WPS planners and operators to use the model as a planning tool, e.g. in a generally available web based service. Other objectives are:

- estimation of interferences from WPS to WR
- study acceptable levels of interference for WR
- find an acceptable physical model that gives scientifically reliable calculations of the interference

- implementation of the results in VINDLOV.SE[1] (project deliverables include algorithms, source code and documentation)

For details on project objectives, terms and guidelines, see the most recent VINDRAD Project Plan [Ref 4]. Some initial study objectives have been deprioritized in agreement with Swedish Energy Agency, in order to focus on the main project objectives. The omitted study items include effects from atmospheric conditions on the interference situation and possible future developments in WR networks and weather prediction models.

2.4 Previous work on Radar and WPS

Swedish Energy Agency has sponsored other projects and studies on effects from WPS to radar systems. One study, including measurements and practical tests has been reported in [Ref 5]. The task for that project was to make a technical and operational/tactical analysis of sea based WPS influence on the radar coverage of air and sea surveillance radar stations. The radars concerned were fixed land based stations for air and sea surveillance. The project included computer simulations, measurements of a radar deployed near a sea based wind farm and actual flight tests.

The results from these activities were consistent and showed that there is a negative influence on the radar coverage from WPS, in particular as far as small targets are concerned. The study formed a basis for an updated calculation and analysis tool, WRAP Obsman, as well as new guidelines for assessment of the influence on radar coverage with an operational perspective.

Although surveillance radars and WR use the same basic radar technology, there are differences in operation that make it necessary to perform a separate study for WR. WRAP Obsman must be developed further, in order to perform calculations on WPS interference to WR.

2.5 The Swedish consultation and approval process

According to Swedish law, the Environmental Code implies a strong protection of national total defence interests (military and civil defence) in the consultation and approval process, also for wind power projects. The Swedish military weather service is coordinated with SMHI and together they constitute the national contribution in the international cooperation within Europe and WMO[2].

In the consultation and approval process, SAF manages all WR in the national radar network. SAF is responsible for giving an opinion about WPS deployment in the vicinity of WR, after a technical analysis performed by FMV in each case. The SAF opinion on WR interference

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[1] VINDLOV.SE: *www.vindlov.se* is a website for WPS consultation and approval process issues. The website has been established by ca 20 authorities and organisations. The Swedish Energy Agency is coordinating the project.

[2] WMO; World Meteorological Organization, a United Nations specialized agency

consequences is added to other aspects of possible disturbances from a WPS project on military planning and activities, as described in [Ref 6].

The consultation with SAF on WPS projects (including WR aspects) can be one of three different kinds:

Consultations at an early project stage, from WPS planners

From 1 July 2010, this consultation can only be performed for planned areas for WPS, not for individual WPS. A summary assessment is done for any potential conflicts with total defence interests in the given area. The consultation is managed by SAF, with technical analysis support from FMV. The consultation is forwarded to military units and FRA[3] if they may be affected by the WPS project. The consultation response is given by SAF as a preliminary assessment and is only delivered to the WPS planner concerned as an indication on potential conflicts with total defence interests.

Consultations according to the Planning and Building Act, from municipalities

Municipalities shall send applications for building permits for WPS, wind measurement masts and other high objects to SAF. The consultations are managed similar to consultations at early project stages but often have very short response times and are given priority.

Consultations according to the Environmental Act, from county administrations

The County administrations send applications for environmental permits on consultation to SAF, often at two different project stages; early consultation from the WPS operator and consultation when the full application to the County administration is ready.

All decisions on building permits or environmental permits must be sent to SAF, in order to give SAF the possibility of appeal against the decision.

Possible interference to WR is only one aspect in the consultation, other systems and activities involved are:

- Air and sea surveillance radars and radio navigation systems
- Radio relay links and networks
- Signals intelligence
- Exercise areas and artillery ranges on land or at sea
- Flight operations

[3] FRA; National Defence Radio Establishment, is the Swedish national authority for signals intelligence

3 Basic Facts

3.1 National weather services

The military weather service is providing weather forecasts and other weather related services to the national military forces, concerning the weather impact on military operations. SMHI is a governmental authority with expertise in meteorology, hydrology, oceanography and climatology. SMHI provides weather forecasts to the public and issues warnings for severe weather and water incidents. SMHI shall contribute to the community planning, to the reduction of vulnerabilities and in achieving the national environmental goals. A prerequisite for this is a well planned meteorological infrastructure.

For this reason, SMHI and SAF have, in a total defence perspective, a well established and regulated cooperation in providing Sweden with the best possible meteorological infrastructure, regardless of ownership of single weather sensors. An example of this is the national WR network. The cooperation is based on an agreement between SMHI and SAF and is implemented by a governmental decision on a cost-effective resource management for the national weather services.

The result of products from the WR network can be viewed every day on the TV weather forecasts. Information from the existing twelve WR in the radar network is not only of local interest, but also of national and international interest.

3.2 Weather radar

3.2.1 Radar in the weather service

Weather radar is a type of radar used to locate precipitation, calculate its motion and estimate its type (rain, snow, hail, etc.). It has become an important tool for the weather service, for the observation of precipitation and winds. Weather radar data is used for Nowcasting and Very Short Range Forecasting, warnings and as input data in Numerical Weather Prediction (NWP) and Hydrological models. Areas of precipitation can be tracked by weather radar and winds at different altitude levels can be studied. It is possible to get warnings for heavy precipitation, icing, wind shear and turbulence.

Figure 1: Swedish Weather Radar PV-883/EWR

3.2.2 Technology and deployment

The technology used by weather radars is basically the same as in other radar applications. A transmitter radiates pulses of high frequency electromagnetic waves into the atmosphere. Any “target” hit by the electromagnetic wave, will reflect some of the energy back to the radar receiver antenna. For surveillance radars, the target may be a boat, a ship or an aircraft. Targets for weather radars are made up by e.g. water drops or ice and other small particles.

Normally, the weather radar transmitting and receiving antenna is different from an air or sea surveillance radar antenna. A surveillance radar has a “slice-shaped” antenna beam (narrow in azimuth, wide in height angle), covering all heights as it rotates one revolution. The weather radar antenna beam is pencil shaped and narrow in azimuth as well as in height. The weather radar therefore, has to rotate several revolutions with different elevation angles in order to cover a full volume.

A Swedish WR performs a full cylinder or volume search of the area surrounding the radar. The WR searches around the full horizon and in increasing elevations. The full volume is scanned at four elevations up to 2° out to a distance of 240 km, and at six elevations out to 120 km for elevations above 2°, each scan lasting about 30 seconds. A full volume coverage may take up to 7 minutes, depending on search mode, and includes calculations and presentation. The number of antenna revolutions (elevations) and elevation increments depends on the data collection needs for the particular mode of operation.

A WR is designed for one of several internationally allocated frequency bands. The Swedish WR stations are all working at a frequency slightly below 6 GHz (5 cm wavelength), which is in one of the frequency bands studied in [Ref 5].

All radars are susceptible to anomalies, reflected energy from unintended targets, e.g. fixed ground echoes (terrain, high buildings etc.), sea waves, birds and insects. Fixed echoes can be reduced by a Doppler filter, whereas moving objects are more difficult to distinguish from real meteorological targets. Rotating turbine blades of a WPS therefore, implicate problems for a WR.

3.2.3 National and international networks

WR data is a very important source of information for making weather assessments and forecasts in a short time frame, particularly in extreme weather situations, like heavy rainfall and snow storms.

Every WR is a part of the national weather radar network. Presently, there are twelve WR in the Swedish network, SWERAD. They are located to cover most of the country, deployed from Karlskrona in the south to Kiruna in the north.

SWERAD is also a part of a Nordic cooperation within the Nordic Weather Radar Network, NORDRAD**.**

BALTRAD is an EU financed project over the years 2009-2011. SMHI has the lead in this project, which is studying the next generation weather radar network. The goal for the project

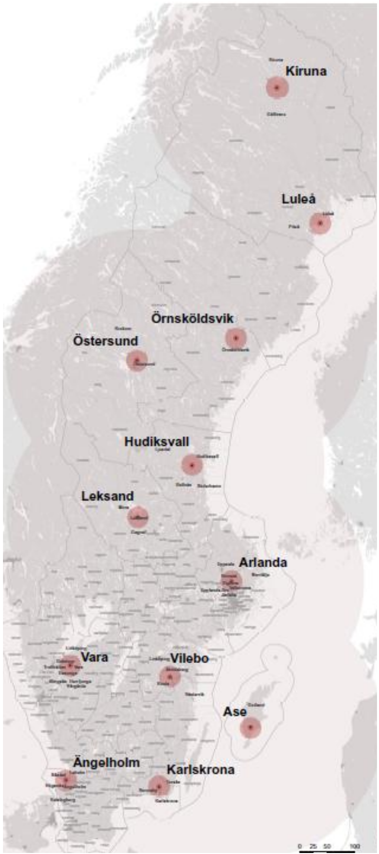

Figure 2: SWERAD, the Swedish Weather Radar Network. From www.vindlov.se

is to create a sustainable radar network with high quality radar data exchange in real time between the Baltic region countries.

BALTRAD is cooperation between the weather services in Sweden, Denmark, Finland, Estonia, Latvia, Poland and Belarus.

The Swedish WR network is a part of a larger experimental network[4], comprised of WR stations in countries around the Baltic Sea, the BALTEX Radar Network. This radar network covers most of the Baltic region and in the west, a part of the Norwegian Sea. All WR data is collected, processed and archived at the BALTEX Radar Data Center.

3.3 Wind Power

Swedish energy policy aims are to facilitate the transition to an ecologically sustainable society through making the electricity power consumption more effective, facilitate the transition to renewable energy sources and ensure that the electricity production technology used is environmentally acceptable. In early 2009, a new directive was adopted on the promotion of renewable energy. It establishes a goal of Sweden in 2020 to have 49 percent renewable energy.

Figure 3: WPS of the type used in the calculation model

The present national planning goal for wind power production[5] is 30 TWh by the year 2020. 20 TWh are assumed to be produced by land based wind power, 10 TWh by sea based wind power. The total production from wind power in 2010 was 3.5 TWh. The total installed power by the end of 2010 was 2 163 MW. 603 MW was installed during 2010, in real figures the greatest yearly expansion so far.

Even though sea based wind power shows a great potential in studies made, and several large wind farms have been projected, the present focus on wind power establishment seems to be on land based projects. There are also new projects for very large wind farms on land.

This situation will lead to an increasing number of projected wind turbines and as a consequence, more conflicts between WR and WPS. It is therefore important to create the best possible conditions for cohabitation, without imposing unnecessary restrictions on either party.

The WPS that can be managed in the present calculation models are of the presently most common version, i.e. a high tower, nacelle and a horizontal axis turbine. Values for the dimensions of tower height, turbine diameter, and number of blades are used in the calculations.

[4] WMO World Climate Research Programme, Baltic Sea Experiment - BALTEX
[5] The Government Offices of Sweden; *www.sweden.gov.se/sb/d/12245*

3.4 WR/WPS cohabitation restrictions

The studies so far have focused on three different problem scenarios; blocking, clutter and radial winds derived from the Doppler effect.

3.4.1 Blocking

A blocking of the WR antenna beam by any obstruction may result in the WR not being able to achieve its purpose, i.e. to monitor rain or snow fall and wind. Even a partial blocking can be serious because the radar is calibrated in absolute terms of precipitation and errors in the estimation of precipitation will occur.

Beam blocking, in this context, occurs when one or more WPS appears in the WR antenna beam. Even though the antenna beam is narrow (less than 1º), the area affected by a single WPS may be considerable, from a hydro-meteorological point of view.

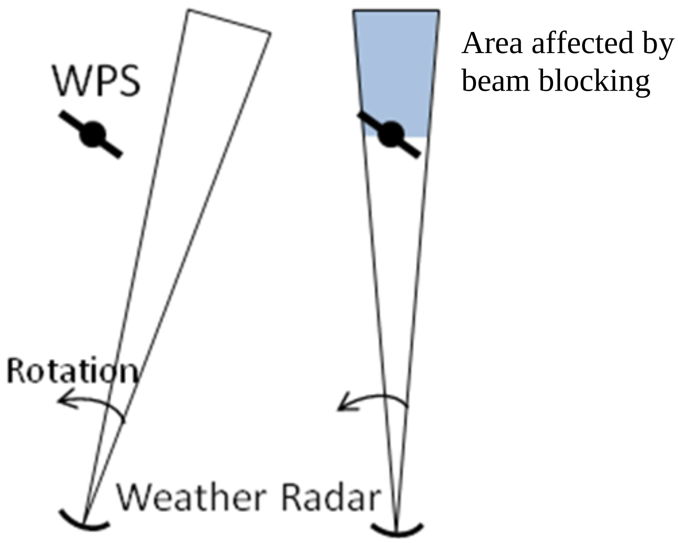

Figure 4: Impact of a wind turbine on a radar beam

Beam blocking of up to 20% has been shown in some studies[6], with a single modern WPS at a distance of 2 km from a WR. This value should be regarded as an indication only, the actual value depends on several factors, e.g. radar configuration (beam width) and operating mode, WPS physical size, distance from radar and existing terrain.

It has to be considered also, that several WPS may be grouped together, which will increase the total blocking area as seen from the radar.

3.4.2 Clutter

A WR performs precipitation measurements expressed in reflectivity, i.e. measurements are made of the intensity of the signal. To determine the impact of the clutter produced by WPS,

[6] Meteo France CBS/SG-RFC 2006/Doc. 3.1(6) submitted to WMO meeting Geneva 16-18 March 2006

it is necessary to know the Radar Cross Section (RCS) of the WPS, which corresponds to the size and ability of a target to reflect radar energy. RCS is expressed in m^2. Previous studies[7] have measured or estimated RCS to between 200 and 2000 m^2 for a WPS.

By measuring the Doppler effect, static echoes can be filtered out, such as the tower of a WPS. The turbine blades, however, cannot be ignored and clutter effects from the turbine will be experienced by the WR and the effects appear in the radar data products.

3.4.3 Radial Winds (Doppler)

All Swedish WR are equipped to measure and process Doppler velocities. The derived velocities are both used for filtering, as mentioned above, and in studies of atmospheric winds at different altitudes.

The impact of WPS on Doppler wind measurements has been analysed during the first phase of the project. The impact is however very complex, especially in case of precipitation, because the individual radial velocities of the hydrometeors and the blades superpose. Figure 5 shows an 18-month time series of clear-air radial wind velocities for a radar cell in which three WPS are located. The significant increase of the Doppler velocity variance coincides with the sudden rise of the reflectivity noise level (Figure 6).

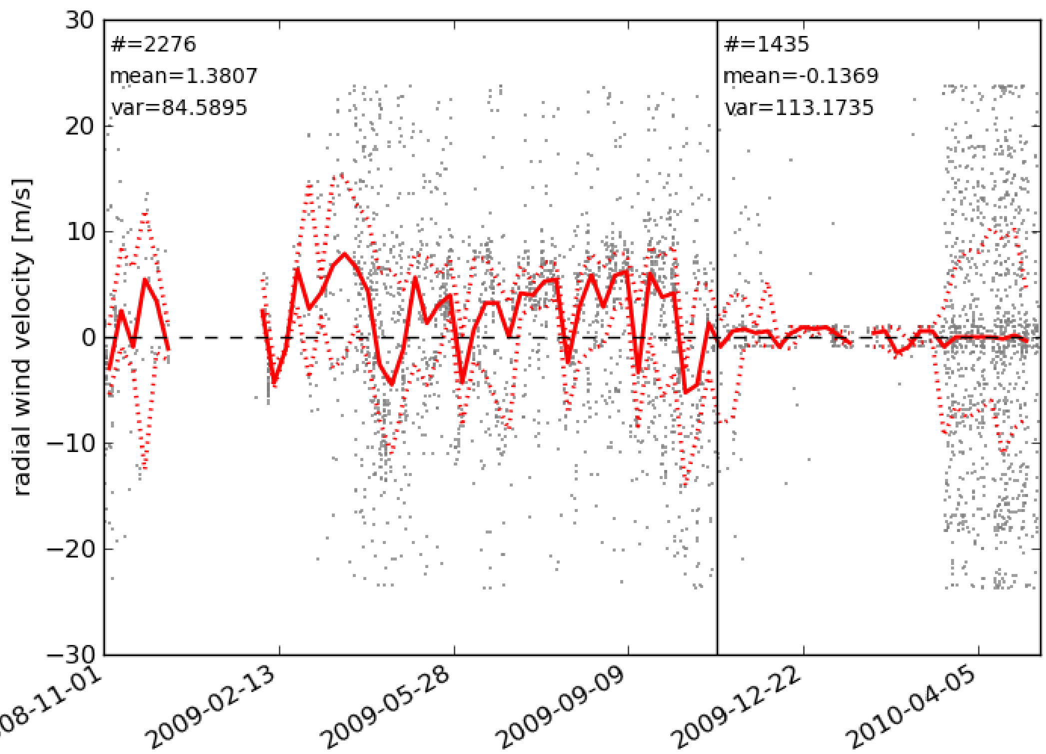

Figure 5: Time series of radial wind velocities from a radar cell containing WPS[8].

[7] Renewable UK; Wind Farms Impact on Radar Aviation Interests. www.bwea.com/aviation/radar.html

[8] G Haase et al, Analyzing the impact of wind turbines on operational weather radar products, ERAD 2010

Modelling of the impact of the rotating blades on Doppler measurements was not part of the project.

4 International recommendations

4.1 EUMETNET and OPERA

EUMETNET is a network grouping 26 European National Meteorological Services. EUMETNET provides a framework to organise co-operative programmes between the Members in the various fields of basic meteorological activities such as observing systems, data processing, basic forecasting products, research and development and training. Through EUMETNET Programmes, the Members intend to develop their collective capability to serve environment management and climate monitoring and to bring to all European users the best available quality of meteorological information.

OPERA (Operational Programme for the Exchange of weather RAdar information) is a EUMETNET programme. The fundamental objective of OPERA is to provide a European platform wherein expertise on operationally-oriented weather radar issues is exchanged and holistic management procedures are optimized. With the establishment of its Data Hub, OPERA is now organized to support the application of radar data from the European Weather Radar Network. Another important objective of OPERA is to act to harmonize data and product exchange at the European level.

Based on national and international studies, OPERA has issued a report [Ref 7] and a statement in 2006 on the cohabitation between WR and WPS as a recommendation to the EUMETNET countries. Concerning the type of radar (frequency band around 6 GHz), the recommendations are that ***no wind turbine should be deployed at a range from radar antenna less than five km. Projects of wind parks should be submitted to an impact study when they concern ranges less than 20 km***.

These guidelines are presently used in the Swedish consultation and approval process and are implemented in the computer based decision support system WRAP Obsman at FMV. In this tool, beam blocking can be calculated, based on the actual topographical situation. Existing objects, e.g. masts, high buildings or other WPS that may affect the calculations of the visible part of the WPS, are also taken into account.

The OPERA Report from 2006 has since then been validated through experience and is internationally recognised, in particular within the ITU[9] Recommendations[10].

4.2 Pros and cons of the recommendations

The present recommended guidelines for assessment of WPS influence on WR operations are simple and legible. They are easy to implement in any national consultation and approval

[9] ITU; International Telecommunications Union, a United Nations specialized agency
[10] ITU-R M.1849 Technical and operational aspects on ground based meteorological radars, June 2009

process, whether computer based decision support is used or not. The guidelines are applied by a large number of countries, i.e. within EUMETNET, even though they are not obligatory.

The guidelines can be regarded as best practice, based upon studies and measurements, albeit to a limited extent.

On the negative side, there is no recommended procedure or measurement basis for the impact study, where the distance between WPS and WR are 5-20 km. This implies that the enforcement of the guidelines in this particular area is up to each administration. The 5 and 20 km limits are, in them self, static and leaves little room for flexibility. This may in some cases impose unnecessary restrictions on the deployment of WPS within 20 km from a WR, or give inadequate protection to WR from WPS, also at longer distances.

4.3 Consultation and approval process in other countries

It is assumed that most EUMETNET countries are using the OPERA recommendations in their national consultation and approval process. The assessment of WPS in the 5 to 20 km range however, differs between countries. Some examples[11]:

- Denmark and Germany use only a fixed minimum separation distance.
- UK Met Office performs calculations of beam blocking, and uses a 1% max allowed value for any WPS as a rule of thumb. Some consideration is taken of the topography and it is recommended that the WPS are deployed in radial lines, as seen from the WR. In that case, only the first WPS in the line will be calculated.
- Meteo France, apart from the OPERA recommendations, also applies
    - Max 10 km extension of the measured area interfered by a WPS
    - Min 10 km between two wind farms
    - Min 10 km between a wind farm and some particular areas (e.g. cities, industrial areas)
    - A wind farm must not block the radar beams more than 10%
    - WPS shall deploy in radial lines as seen from the radar and in such a way that all non-precipitation radar returns can be masked. WPS are not allowed in the prevailing wind direction

The calculations presently made by FMV for the Swedish WR in the 5 to 20 km range allow a max beam blocking of 2% for any WPS, and the actual topograhic situation is considered; i.e. only the visible part of the WPS seen by the radar is used in the calculations.

5 Main Project results

5.1 Clutter

In order to investigate the amount of clutter caused by WPS to WR in the Swedish radar network a comprehensive data analysis was made, using more than three years of data from

[11] From SMHI 2008-08-06 Beslut 2008/1654/241

November 2007 to December 2010. The WPS existing in Sweden during this period and deployed within the radar line-of-sight were concentrated around two WR; Karlskrona and Vara.

The impact WPS may have on reflectivity measurements can be seen qualitatively by examining a time series of such data from a radar cell containing WPS. One such time series is shown in Figure 6. In this figure weather phenomena have been filtered out. A striking feature in the figure is the sudden increase in measured reflectivity coinciding with the start date of the WPS operations.

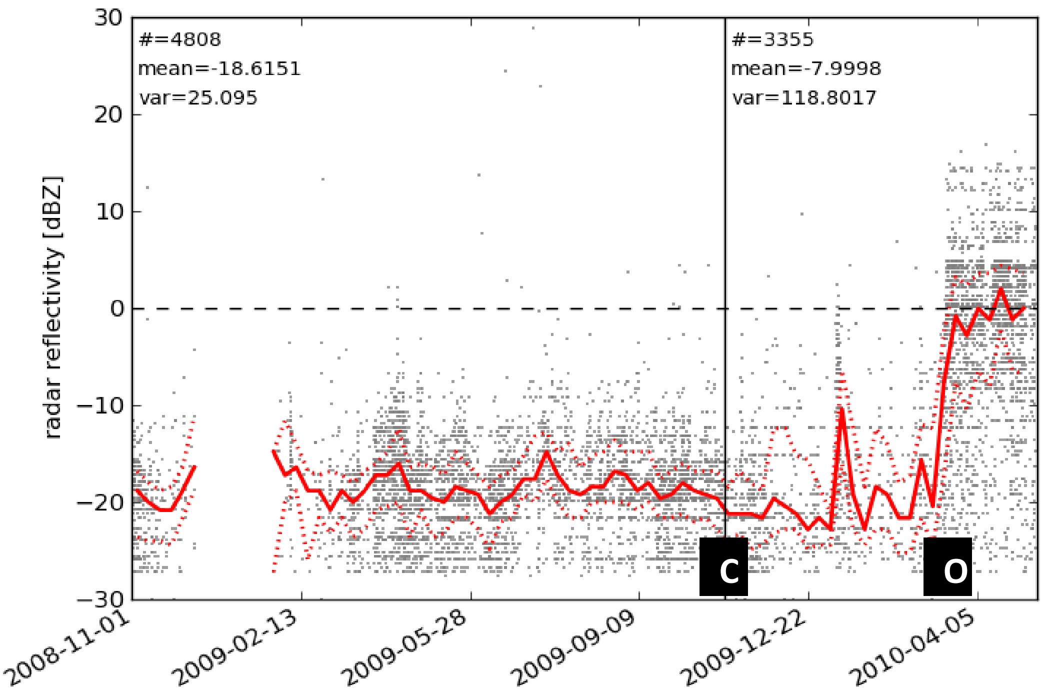

Figure 6: Time series of the radar reflectivity factor from a radar cell containing WPS[12]. "C"=Construction starts, "O"=Operation starts

A closer look at an area containing several WPS reveals that not only the radar cells in which the WPS are located show an increase in clutter but also several radar cells behind the WPS are affected. In Figure 7, clutter originating from five WPS is shown. Such tails of clutter behind WPS have been noted in previous works. A possible explanation is that the tails are caused by multiple scattering effects.

[12] G Haase et al, Analyzing the impact of wind turbines on operational weather radar products, ERAD 2010

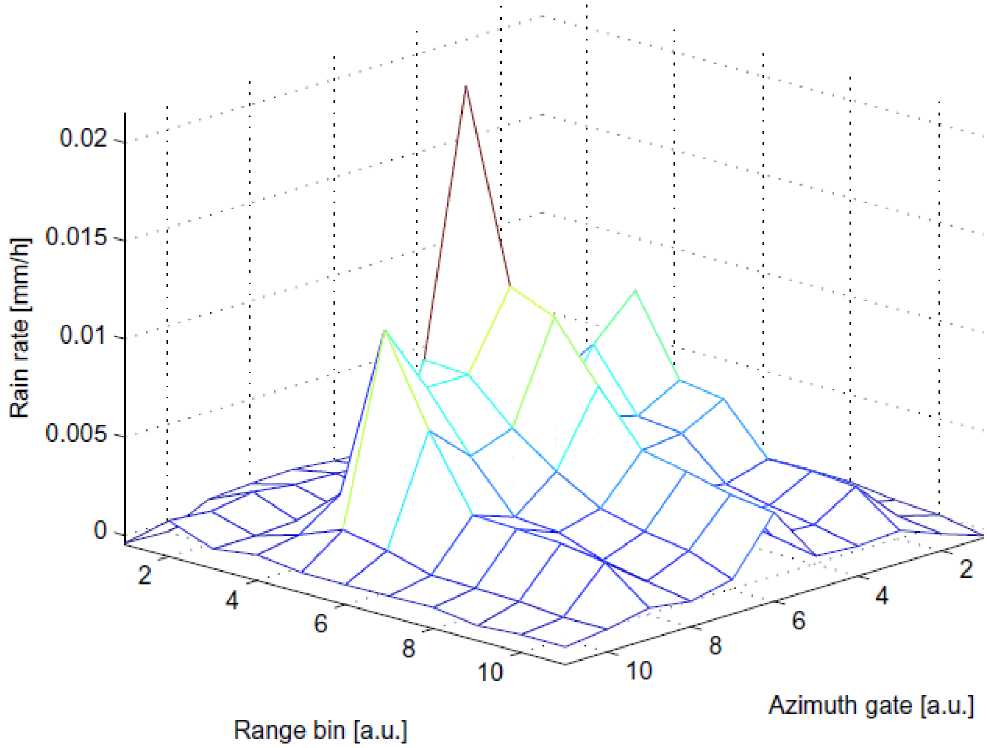

Figure 7: Clutter from a group of five WPS. Distance from WR is approximately 13 km (corresponding to range bin 4 in the figure). One WPS is located in azimuth gate 3, three are in gate 6 and one is in gate 9. Note the long tails of clutter behind the WPS.

To model the clutter caused by WPS on WR, the RCS of the visible part of the rotating blades of the WPS are calculated. The rotor blades are assumed to have the shape of elliptical cylinders. The model further assumes that the WPS face the radar. Dividing the RCS by the distance squared yields a value proportional to Z (radar reflectivity factor), which can be converted to rain rate. This value is then compared to the results from the data analysis. The model described above performs well when calibrated by a constant factor to compensate for the differences between what is modelled and measured.

5.2 Blocking

Finding the blocking caused by WPS is not trivial since WPS also gives rise to an increase in reflectivity, as shown above. To study the blocking problem, a stationary target was therefore considered, the air traffic control tower at Stockholm-Arlanda airport. This tower is located 0.9 km from the nearest WR. The angular width of the tower is smaller than the beam width of the radar lobe.

Blocking can be detected by comparing the measured precipitation of the blocked azimuth gate to those of the nearby gates with the implicit assumption that the precipitation is equal for these gates.

To find the blocking of the tower, precipitation over a period of more than three years, November 2007 to December 2010, were accumulated. The average precipitation per hour at 1.0° elevation is shown in Figure 8. The azimuth gates in which the tower is positioned are readily seen in the figure, showing a decrease in measured precipitation.

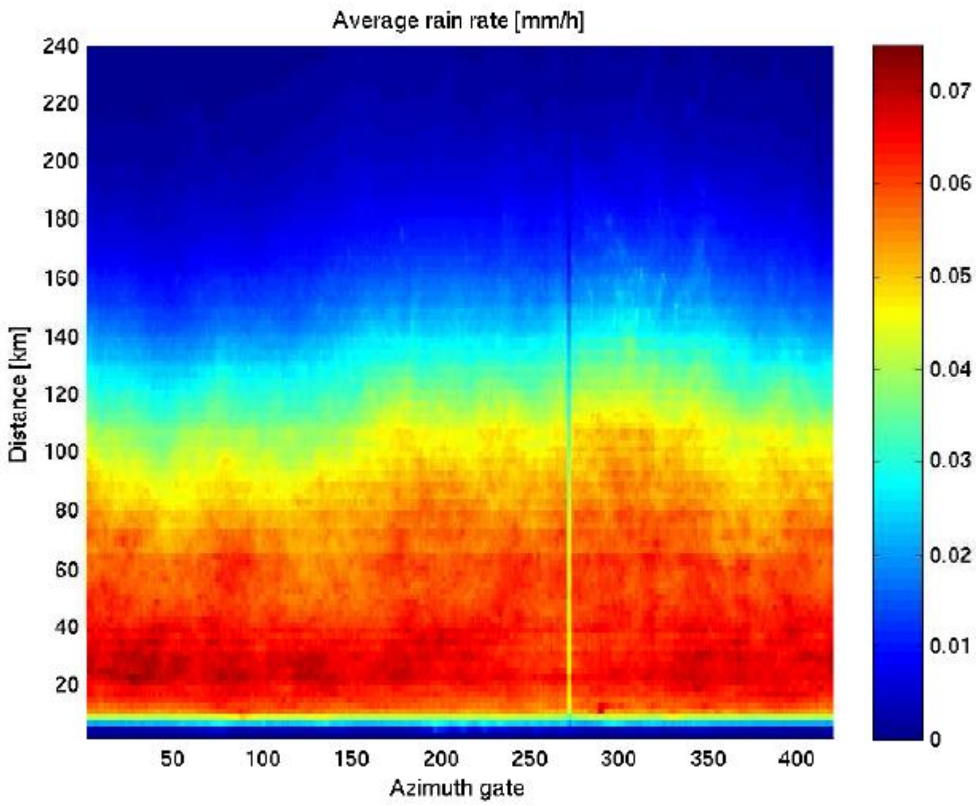

Figure 8: Average precipitation per hour at 1.0° elevation, as measured by the WR at Stockholm-Arlanda Airport. Note the decrease in precipitation near azimuth gate 270, due to a blocking tower.

Using a window of 15 azimuth gates, centred at the azimuth of the tower, and normalising the precipitation to the average of the gates not affected by the presence of the tower reveals the blocking, see Figure 9. The blocking is seen to be near 25% for the gate immediately behind the tower.

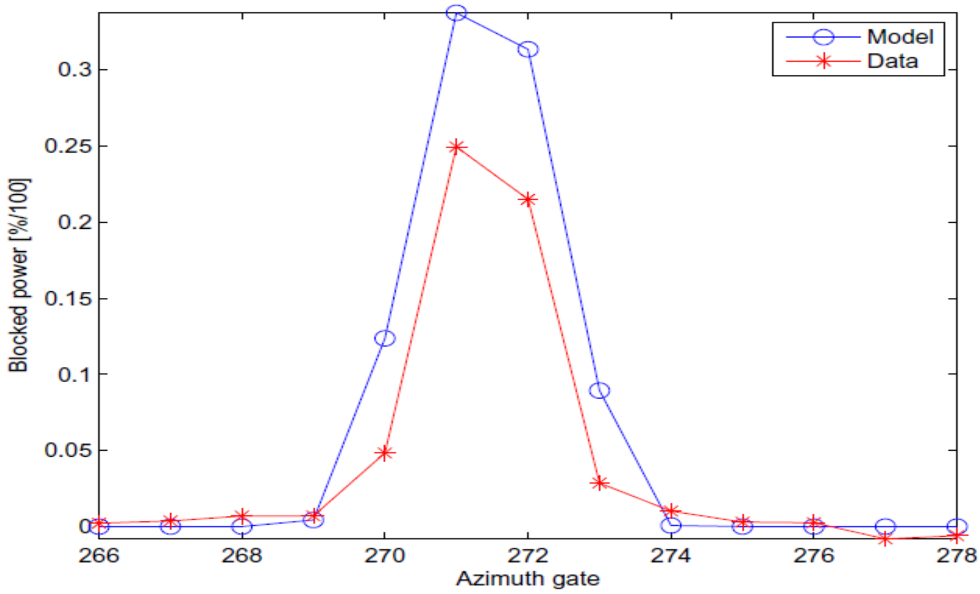

Figure 9: Power blocked by air traffic control tower at Stockholm-Arlanda airport. Elevation is 1.0°. Data and model.

5.3 Threshold values

Threshold values for the criteria used for clutter and blocking effects in the calculation model, to be used in the consultation and approval process, must be decided upon by SMHI and SAF. These values may have to be updated as more experience is gained in the future process.

6 Proposal for new guidelines

6.1 Guidelines and motivation

It is suggested that the present consultation and approval process is retained but the assessment of WPS interference to WR beyond 5 km separation distance is performed with the calculation tool presented in the Appendix. The calculation tool should be implemented in the WRAP Obsman software, used by FMV for WPS application assessments.

The present 20 km distance value (cf. sections 4.2 and 4.3) should be removed. The calculation model manages greater distances and the risk of interference from WPS at longer distances than 20 km should not be ignored. From an administrative point of view, a maximum distance for analysis in the calculation model should be introduced, in order to limit the number of projects to be analysed.

The developed calculation model will result in a more proper assessment of the interference to WR from WPS, based on verified calculation methods, avoiding unnecessary overprotection of WR while still maintaining a reliable national weather radar network.

The consultation and approval process may be further enhanced by the use of a pre-consultation tool for the WPS planners or operators. The supposedly web based tool should provide an opportunity for WPS planners to get a preliminary assessment of interference to

WR, thus avoiding any projected deployment that will be unacceptable from the weather radar perspective to be put forward in the consultation and approval process.

A final assessment by FMV of each WPS project is still necessary, in order to take all factors into consideration, e.g. other ongoing projects, classified objects or other information that cannot be registered in an unclassified database. It must also be remembered that WR interference is only one of several systems, functions or activities that must be considered in the overall total defence consultation and approval process.

If technological developments lead to significant changes of WPS design or WR functionalities, the present studies have to be revised and the guidelines may need to be updated in line with new calculation methods or rules for interference assessment.

6.2 Calculation Tool (Appended)

A technical documentation of the interference model developed by SMHI is presented in the Appendix. The actual calculation model will be delivered to the Swedish Energy Agency by SMHI as scripts written in Python open source programming language for implementation in a web based application in VINDLOV.SE and in computer based decision support systems, e.g. WRAP Obsman.

An article with a detailed description of the scientific part of the VINDRAD project will be published in a scientific journal by SMHI.

6.3 Further studies

Anomalous propagation is a common phenomenon in Sweden as many WR are located close to the sea. This means that the magnitude of clutter, beam blocking and erroneous Doppler winds could occasionally be even higher. This has not yet been analysed in the project. Anomalous propagation conditions could be identified using refractivity profiles derived from radiosondes or NWP models.

The RCS depends on the physical size of the target as well as on its shape and material. The calculation model developed by SMHI only allows for adjusting the physical size. The shapes of all WPS-parts are generic, blades are modelled as elliptical cylinders and towers are modelled as cylinders. There are, however, studies indicating that the shape and material of WPS may have a large impact on the RCS[13][14]. If the shape and materials aspect should be taken into account the calculation model must be developed further.

The studies of the impact of WPS on Doppler wind measurements (section 3.4.3) should be completed, in order to achieve a calculation model including all the three factors that may have an influence on WR products, i.e. clutter, beam blocking and Doppler winds.

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[13] Appleton, S., Stealthy wind turbines - addressing the radar issue. BWEA28 conf. Glasgow, October 2006
[14] Poupart, G. J., Wind farms impact on radar aviation interests - Final report. Technical report, QinetiQ, September 2003

There are at least two possible ways to explore when trying to reduce the impact on WR from WPS. One way is to use “gap fillers”, i.e. extra weather radars to compensate for the loss in coverage due to WPS. The other way is to reduce the radar cross section (RCS) of the WPS, primarily on the rotating blades, when clutter is the predominant reason for disturbances.

The RCS can be reduced by using “stealth technology”, for instance with radar-absorbing materials and coatings. A method has been demonstrated in the UK[15], where material incorporated into the composite manufacture of the blade itself showed a decrease of the RCS.

[15] QinetiQ 22 Oct 2009, http://www.qinetiq.com and http://news.bbc.co.uk/2/hi/8320622.stm

7 References

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[Ref 3] *Rapport av fas 1av Energimyndighetens uppdrag till SMHI ang VINDRAD*
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[Ref 7] *Impact of Wind Turbines on Weather Radars*
OPERA deliverable OPERA WD_2006_18 (www.knmi.nl/opera)

8 List of acronyms

BALTEX	WMO World Climate Research Programme, Baltic Sea Experiment
BALTRAD	An advanced weather radar network for the Baltic Sea region. An EU financed project
Doppler	Doppler effect is the change in frequency of a wave for an observer moving relative to the source of the wave (Christian Doppler, 1842)
EUMETNET	A network of 26 European National Meteorological Services
FMV	Swedish Defence Materiel Administration (Försvarets materielverk)
FRA	National Defence Radio Establishment, is the Swedish national authority for signals intelligence (Försvarets radioanstalt)
ITU	International Telecommunications Union, a United Nations specialized agency
NORDRAD	The Nordic Weather Radar Network
NWP	Numerical weather prediction
Obsman	See WRAP Obsman
OPERA	Operational Programme for the Exchange of weather RAdar information
RCS	Radar Cross Section
SAF	Swedish Armed Forces (Försvarsmakten)
SMHI	Swedish Meteorological and Hydrological Institute
SWERAD	The Swedish Weather Radar Network
VINDLOV.SE	www.vindlov.se is a website for WPS consultation and approval process issues
WMO	World Meteorological Organization, a United Nations specialized agency
WPS	Wind Power Station (Wind Turbine)
WR	Weather Radar
WRAP Obsman	Obstruction Manager, a tool in the WRAP spectrum management system for management of obstacles, including Wind Power Stations
Z	Radar reflectivity factor