

Appendix

VINDRAD — Technical documentation

The VINDRAD programme is a numerical tool for evaluating the possible interference caused by wind power stations (WPS) to weather radars (WR). The interference investigated is limited to clutter and blockage. Figure 1 shows the layout of the VINDRAD programme.

Technical information

The scripts comprising the VINDRAD programme are written in Python Programming Language. The following files are part of the VINDRAD programme.

- *vindrad.py* Main programme file. Input and output are described below.
- *vindrad_maintenance.py* Maintenance programme. Should be run every time a new version of a WPS data base is received.
- *vindrad_functions.py* Various functions called by *vindrad.py* and *vindrad_maintenance.py*.
- *vindrad_helpers.py* General help functions called by *vindrad.py* and *vindrad_maintenance.py*.
- *vindrad_defines.py* Contains definitions and threshold values.
- *swerad.conf* Configuration of the Swedish weather radar network (SWERAD).

To run the VINDRAD programme Python 2.6.4 is required with the following packages installed

- numpy v1.4.0
- pyproj v.1.8.6

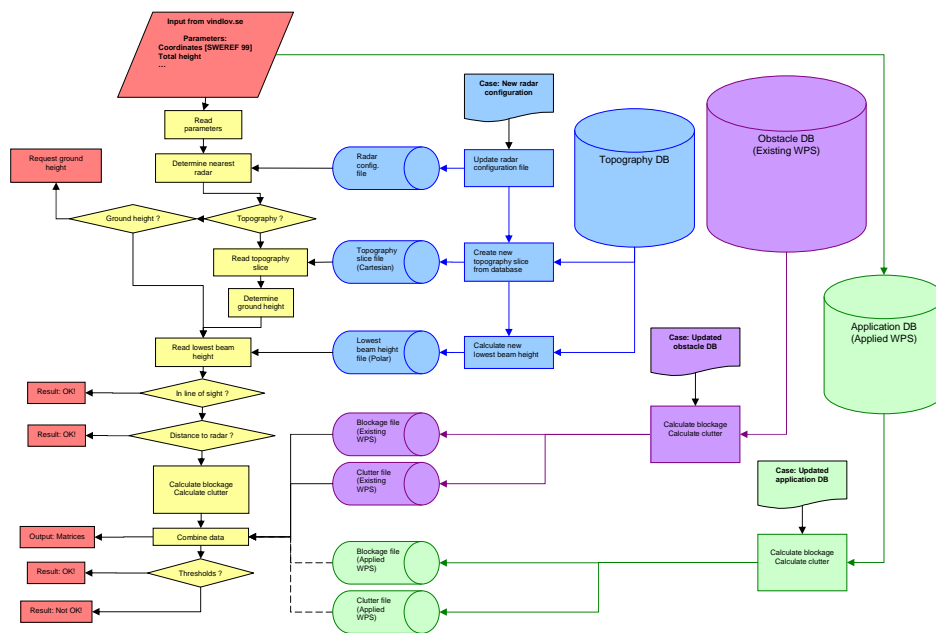


Figure 1: Layout of the VINDRAD programme. The topmost box represents the input to VINDRAD, objects coloured in red (to the left) are the outputs. The chain under the input box illustrates the process of VINDRAD. The process depends on various files (horizontal cylinders), which all are results from different cases. In the figure the required (Existing WPS and Topography) databases are shown, in addition to the chain coloured in green which refers to the processing of applied (not yet built) wind power stations including their database.

- gdal v1.7.3¹
- matplotlib v1.0.1 with toolkit basemap v1.0 (requires geos)¹
- geos v3.2.2¹

Certain data bases should be installed for the VINDRAD programme to function properly

- Topographical map (e.g. Lantmäteriet HDB 50).
- Obstacle data base (provided by the Swedish Air Navigation Services). Currently, SMHI is using a text file.
- Applications data base (containing WPS that have been applied for but not yet been built). Currently, SMHI is using a text file.

Input

The input to the VINDRAD programme is a set of coordinate vectors (given in SWEREF 99), specifying the location of any number of wind power stations (WPS) to be tested. The total height of each WPS must be supplied whereas specifying the turbine radius of each WPS is optional.

Output

The programme returns a vector with the results of the test. The result is binary, where 1 means the WPS is approved by the programme and 0 means the WPS causes an unacceptable level of interference to the weather radar (WR).

Blockage

Blockage is determined by dividing the power intercepted by the WPS by the total power of the radar lobe.

$$B = \frac{P_{\text{WPS}}}{P_{\text{tot}}} \quad (1)$$

The beamwidth of the radar lobe is defined as the full width at half maximum. Assuming a Gaussian beamshape the total power of the radar lobe is given by

$$P_{\text{tot}} = p_0 \frac{\pi R^2}{2 \log 2} \quad (2)$$

where p_0 is the power flux at the centre of the lobe and R is the radius of lobe with the beamwidth defined above.

¹SMHI's setup

The power intercepted by the WPS is calculated by dividing the WPS in small areas A_i and then summing the areas multiplied by the power flux p_i at their respective location

$$P_{\text{WPS}} = \sum_i A_i p_i \quad (3)$$

Behind the WPS the blockage diminishes due to diffraction. The radar shadow behind the WPS is calculated as [Poupart, 2003]

$$B(d) = \begin{cases} B_0 \left[\frac{W}{\sqrt{\frac{\lambda D d}{D+d}}} \right]^4 & \text{for } W < \sqrt{\lambda D d / (D+d)} \\ B_0 & \text{for } W \geq \sqrt{\lambda D d / (D+d)} \end{cases} \quad (4)$$

where B_0 is the blockage at the WPS, W is the width of the rotor blade, D is the distance from the WR to the WPS, d is the distance behind the WPS, and λ is the wavelength of the radar wave.

Clutter

Clutter is calculated as the amount of extra rain rate caused by the WPS. In the calculations the WPS is assumed to face the WR and its blades are modelled as elliptical cylinders. The rain rate is given by

$$RR = \left(\frac{C_1 \sigma}{200 D^2} \right)^{2/3} \quad (5)$$

where C_1 is an empirically determined constant, σ is the radar cross section of the visible part of the WPS, and D is the distance from the WR to the WPS.

The radar cross section is calculated for the visible part of the rotating blades according to [Ousbäck, 1999]

$$\sigma = \frac{k L^2 a^2 b^2 |\cos \theta|}{(a^2 \cos^2 \phi + b^2 \sin^2 \phi)^{3/2}} \left[\frac{\sin(k L \sin \theta)}{k L \sin \theta} \right]^2 \quad (6)$$

where k is the wave number of the transmitted radar wave, L is the length of the blade (L is divided into parts if the far field approximation, $L \leq \sqrt{D \lambda} / 2$, is not fulfilled). Angles θ and ϕ are angles of incidence as defined in Ousbäck [1999]. The major- and minor semiaxes, a and b , of the rotor blades are given by

$$a = 0.035 R_{\text{WPS}} \quad (7)$$

$$b = 0.25 a \quad (8)$$

where R_{WPS} is the radius of the WPS turbine.

The different parts of the radar cross section are summed by

$$\sigma = \left[\sum_i \sqrt{\frac{\sigma_i p_i}{p_0}} e^{ikD_i} \right]^2 \quad (9)$$

For every WPS the factor σ/D^2 is saved together with the number of WPS in that particular radar cell. The tail of clutter behind a WPS is then calculated as

$$RR(d) = RR_0 \exp\left(-\frac{C_2 d}{N}\right) \quad (10)$$

where RR_0 is the total amount of rain rate from a radar cell containing WPS, C_2 is an empirically determined constant, d is the distance behind the WPS, and N is the number of WPS in the radar cell considered.

Decision

To decide whether a WPS in the WR line-of-sight can be accepted or not the clutter and blockage caused by the WPS are added to the total clutter and blockage caused by all existing WPS near the same WR. The total values at the location of the WPS and in all radar cells behind the WPS having the same bearing are compared to the predetermined tolerance levels for clutter and blockage. If neither threshold is exceeded the interference due to the WPS is considered acceptable and the WPS is approved by the programme.

End notes

The programme has been tested under Linux (Fedora 10) using Python 2.6.4.

References

- J.-O. Ousbäck. Försvaret och vindkraften. Huvudstudie radar. Technical Report 99-2936/L, Försvarets forskningsanstalt (FOA), September 1999.
- G. J. Poupart. Wind farms impact on radar aviation interests—Final report. Technical Report FES W/14/00614/00/REP, DTI PUB URN 03/1294, QinetiQ, September 2003.

