

# PERFORMANCE CHECK

## Wind Farm and wind model performance verification



### Function

The Performance Check module is used for analysis of the actual production of turbines and wind farms. Main purpose is to check if the turbines produce as expected and if not which production to expect with the knowledge gained after a period of operation. In addition, the module is a unique tool to test if calculation models and model input work properly or if the turbines perform according to their power curves.

### Calculation Method

Two different approaches are available:

#### 1) Wind index - Production prognoses

Based on monthly wind energy indexes and monthly production data, the expected long-term wind-index-corrected production (WCP) is calculated. Additionally, a rough evaluation of lost production can be performed.

#### 2) Wind speed - Performance check

Based on measured wind near or on turbines a time-varying PARK calculation is performed. With detailed production data (e.g. 10-min. or hourly), the analysis of calculated vs. actual summarized by direction, season, day/night, temperature, etc. provides both a model calibration/check and a detailed loss/poor performance check. Power curve validation is also an option having the right measurement setup.

### Description

#### 1) Wind index - Production prognoses

The wind index correction concept has been used in Denmark since 1979. The wind energy index is simply based on measuring the available wind energy on a monthly basis taking the production from a large number of operating turbines, and then relating this to the long-term average production.

Official wind energy indexes are not available in every country. Therefore a comprehensive tool is included which can calculate an index for a region or country based on wind data, e.g. the free MERRA data set.

Having the wind index and imported monthly production data, a graphic tool helps the user to analyze the data and do the correct filtering. The result will be the wind energy index corrected production (WCP). Further included are additional features such as loss estimator and uncertainty evaluator.

#### 2) Wind speed – Performance check

The wind speed- AND direction-based tool is a far more comprehensive tool for very detailed analyses of the performance. This tool does not only include the turbine performance, but also the calculation model and model setup performance. The basic concept is to run the calculation model, based on the measured wind using the same time steps as the available production data, and then compare actual and calculated production by aggregating directional sector, day/night, season, etc. A very important part of this tool is the filtering process – turbines are occasionally out of operation, which often makes it very difficult to test the performance. Having detailed calculated production to compare with the actual one in time steps, it is possible to isolate “normal operation” data and then use these for model calibration. When the model setup can reproduce “normal operation” in the time steps, it is possible to identify losses during non-operational hours and/or poor performing periods. The Wind speed performance check tool can really be an eye opener for finding both calculation model problems and turbine performance problems. An early identification of problems can result in improved revenues and prevention of previous mistakes to be repeated in future.

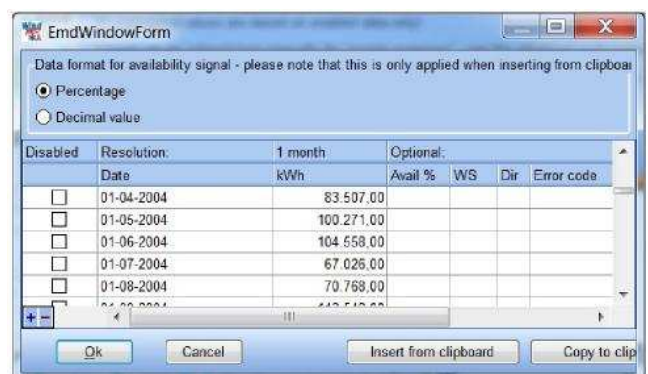
### Necessary input data / Data Import

The basis of this module is the Existing WTG Object. The structure of this object is expanded with a data structure containing time series of production and optionally also availability, wind speed and direction (nacelle). Also other data like pitch angle, rpm etc. can be added. The data can be copied directly from clipboard into the Existing WTG Object form.

If the data amount is excessive, an advanced importer is available for loading them from files into the WTG objects. The import process is much like the Meteo Object and can handle numerous and complex data structures.

The wind energy indexes for Denmark are available in a built-in database, but users can also create and maintain their own wind index databases.

Wind data have to be available in a Meteo Object, and can be used 1) to create a wind energy index or 2) to run a time-varying PARK calculation.



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WindPRO version 2.9.250 Jul 2013

|                              |  |   |
|------------------------------|--|---|
| Project:<br><b>Kragelund</b> | Description:<br>Example of a report from the performance check module. | Printed/Page:<br>13-08-2013 13:38 / 1   |
|                              |  | Licensed user:<br><b>EMD International A/S</b><br>Niels Jernes Vej 10<br>DK-9220 Aalborg Ø<br>+45 9635 4444<br>Karina Bredelle<br>Calculated:<br>13-08-2013 13:38 |

### Performance Check - Wind index - production prognosis

WTG: 4: 57071500000013478: 660 kW VESTAS - Volstrup

#### Calculation of wind index corrected production (WCP) for:

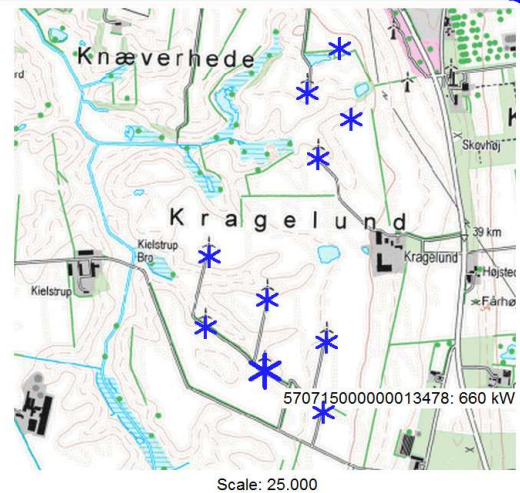
Turbine: VESTAS V47 660-200 47.0 IO!  
 ID: 4: 57071500000013478: 660 kW VESTAS - Volstrup  
 WTG properties: 660 kW, Rotor: 47,0 m, Hub: 45,0 m  
 Coordinates: UTM ED50 Zone: 32 East: 589.008 North: 6.352.170

#### Assumptions:

Wind index source: DK Wind Index  
 Region: 3  
 Wind index reference period: Undefined To: Undefined  
 Wind index data: January-1979 To: May-2013  
 Production data: January-2002 To: November-2012  
 Wind index in concurrent period: 92,9%  
 Wind index calculation method: Sum Prod./Sum Index

#### Filter settings:

Minimum availability: <Not selected>  
 Min. WCP of average: 80,0%  
 Data from: <Not selected> To: <Not selected>  
 Total months (years): 131 (10,9)  
 Filtered months (years): 2 (0,2)  
 Used months (years): 129 (10,8) Percent: 98,5 %

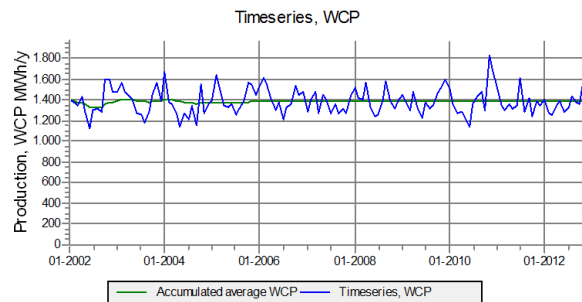
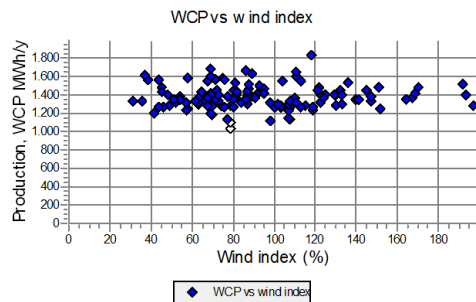
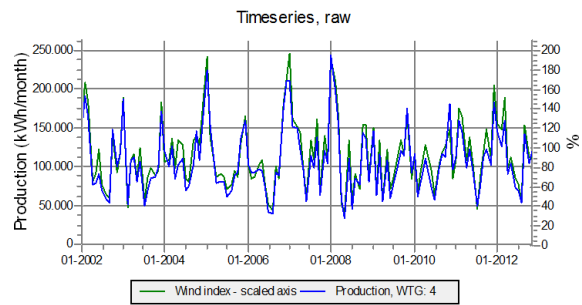
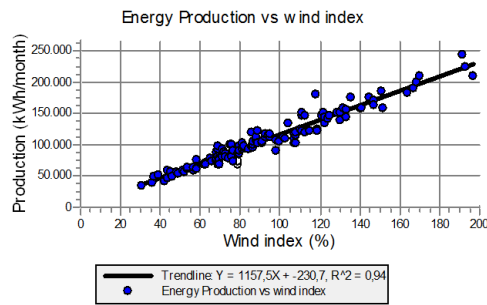


#### Results:

|                                    | MWh/y | MWh/MW/y              | Cap. factor |
|------------------------------------|-------|-----------------------|-------------|
| Calculated WCP at 100,0 % avail *) | 1386  | 2100                  | 24,0 %      |
| Calculated WCP at 100,0 % avail #) | 1386  | 2100                  | 24,0 %      |
| Correlation (R <sup>2</sup> )      | 0,94  | Grid loss subtracted: | Unknown     |

\*) Manual input by user

#) Decided presentation value (e.g. 100% or estimated future avail.)



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Project: **Kragelund** Description: Example of a report from the performance check module.

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### Performance Check - Losses

WTG: 4: 57071500000013478: 660 kW VESTAS - Volstrup

#### Assumptions for the loss table

Loss estimate does NOT include grid losses, but these might already be subtracted in the measured production data and thereby also in the index production. Loss estimate can be negative for some periods due to lack of precision in wind index. Basis for this report is that LOSS = INDEX production - ACTUAL production. Index production is calculated by multiplying the wind index with the WCP @ 100% availability, based on the period 01-2002 - 11-2012. (See previous page for WCP calculation details, like filters).

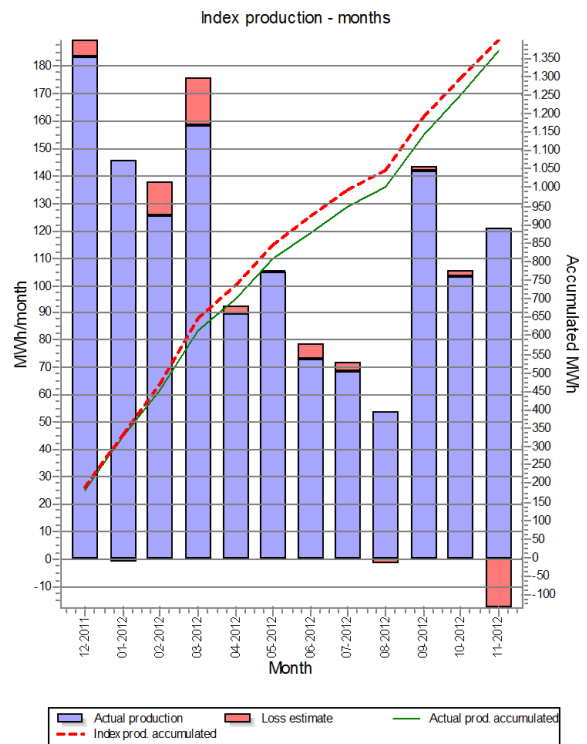
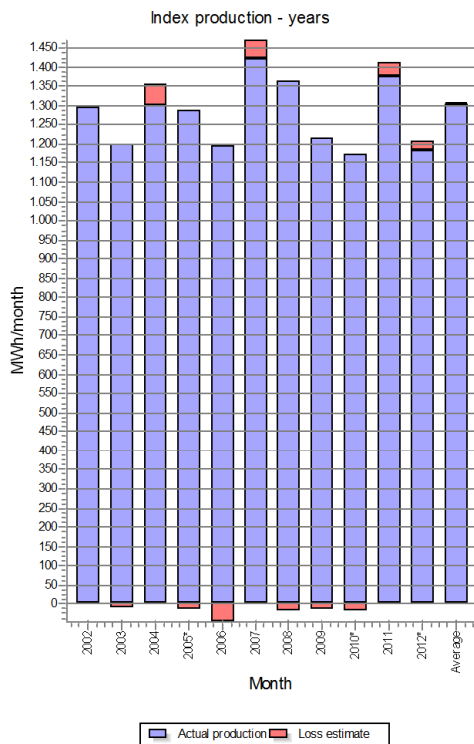
#### Loss calculation:

| Start             | Year    | 2002   | 2003   | 2004   | 2005*  | 2006   | 2007    | 2008   | 2009   | 2010*  | 2011    | 2012*  | Average | All    |
|-------------------|---------|--------|--------|--------|--------|--------|---------|--------|--------|--------|---------|--------|---------|--------|
| Actual production | MWh     | 1294   | 1200   | 1299   | 1289   | 1196   | 1423    | 1364   | 1217   | 1173   | 1376    | 1185   | 1304    | 14015  |
| Wind energy index | Percent | 93,8 % | 85,8 % | 97,7 % | 91,8 % | 82,9 % | 106,1 % | 97,2 % | 86,8 % | 83,3 % | 101,7 % | 95,1 % | 92,9 %  | 92,9 % |
| Index production  | MWh     | 1301   | 1190   | 1354   | 1273   | 1149   | 1470    | 1347   | 1202   | 1154   | 1409    | 1208   | 1308    | 14057  |
| Loss estimate     | MWh     | 6      | -10    | 54     | -16    | -46    | 47      | -18    | -14    | -19    | 33      | 23     | 4       | 41     |
| Loss estimate     | Percent | 0,5 %  | -0,8 % | 4,0 %  | -1,2 % | -4,0 % | 3,2 %   | -1,3 % | -1,2 % | -1,6 % | 2,4 %   | 1,9 %  | 0,3 %   | 0,3 %  |

\*) Incomplete data

#### Loss calculation: (Recent 12 months)

| Start             | Month   | 12-2011 | 01-2012 | 02-2012 | 03-2012 | 04-2012 | 05-2012 | 06-2012 | 07-2012 | 08-2012 | 09-2012 | 10-2012 | 11-2012 | Recent Y |
|-------------------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|----------|
| Actual production | MWh     | 183     | 146     | 125     | 158     | 90      | 105     | 73      | 68      | 54      | 142     | 103     | 121     | 1368     |
| Wind energy index | Percent | 164,0 % | 125,0 % | 119,0 % | 152,0 % | 80,0 %  | 91,0 %  | 68,0 %  | 62,0 %  | 45,0 %  | 124,0 % | 91,0 %  | 89,0 %  | 100,8 %  |
| Index production  | MWh     | 189     | 144     | 137     | 176     | 92      | 105     | 79      | 72      | 52      | 143     | 105     | 103     | 1398     |
| Loss estimate     | MWh     | 6       | -1      | 12      | 17      | 3       | 0       | 6       | 3       | -2      | 2       | 2       | -18     | 30       |
| Loss estimate     | Percent | 3,3 %   | -0,8 %  | 8,8 %   | 9,7 %   | 2,8 %   | 0,3 %   | 7,0 %   | 4,5 %   | -3,5 %  | 1,2 %   | 1,7 %   | -17,3 % | 2,1 %    |



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Project: **Kragelund** Description: Example of a report from the performance check module.

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### Performance Check - Prognosis

WTG: 4: 57071500000013478: 660 kW VESTAS - Volstrup

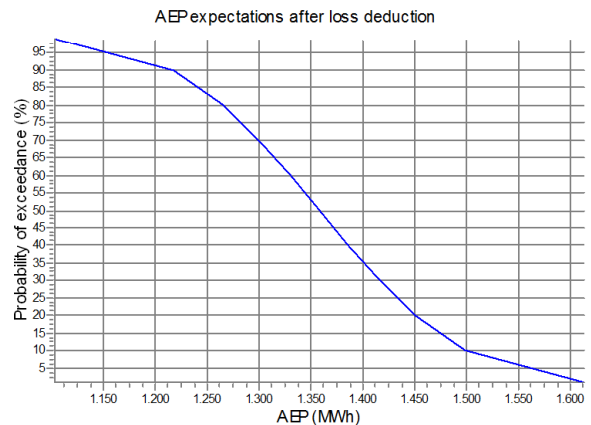
#### Assumptions for prognosis tables:

The historical variations of the wind energy index is used to give monthly expectations.

The future index level is difficult to predict – will it be similar to the average of the past one, 10 or 30 years? Therefore this is the most critical assumption in the prognosis. From this and historical variations month by month, the statistical figures of probability of exceedance are given for chosen exceedance levels, where e.g. P75 displays the values which will be expected with at least 75% certainty.

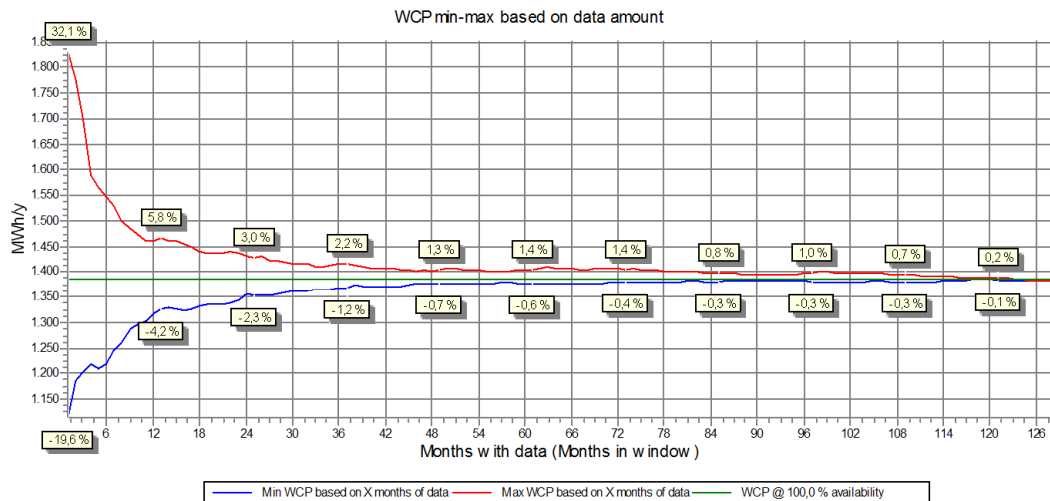
#### Data assumptions:

Prognosis for year: 2014  
 Years of monthly index variation used for prognosis: 2003 to 2012  
 Average index: 93,0 %  
 Scale to index (guess for 2014): 100,0 %  
 Assumed loss: 2,0 %  
 WCP @ 100 % availability: 1386,0 MWh/y  
 Assumed availability in filtered data: 100,0 %



The graph to the right shows the expectations based on historical index variations and the assumptions given in the table above.

|                          | Jan     | Feb     | Mar     | Apr    | May    | Jun    | Jul    | Aug    | Sep     | Oct    | Nov     | Dec     | Year    |
|--------------------------|---------|---------|---------|--------|--------|--------|--------|--------|---------|--------|---------|---------|---------|
| Assumed index            | 142,8 % | 104,6 % | 115,2 % | 86,0 % | 89,0 % | 83,9 % | 62,9 % | 72,7 % | 102,6 % | 97,9 % | 117,9 % | 124,6 % | 100,0 % |
| Index prod. (MWh)        | 164,9   | 120,8   | 133,1   | 99,3   | 102,8  | 96,9   | 72,7   | 84,0   | 118,5   | 113,1  | 136,2   | 143,9   | 1386,0  |
| Assumed loss (MWh)       | 3,3     | 2,4     | 2,7     | 2,0    | 2,1    | 1,9    | 1,5    | 1,7    | 2,4     | 2,3    | 2,7     | 2,9     | 27,7    |
| P50 Prognosis (MWh)      | 161,6   | 118,4   | 130,4   | 97,3   | 100,7  | 95,0   | 71,2   | 82,3   | 116,2   | 110,8  | 133,5   | 141,0   | 1358,3  |
| Standard deviation index | 47,4 %  | 43,2 %  | 27,9 %  | 22,6 % | 22,9 % | 20,4 % | 20,6 % | 16,4 % | 22,4 %  | 23,3 % | 21,8 %  | 40,1 %  | 8,1 %   |
| P75 prognosis            | 109,9   | 83,9    | 105,9   | 82,5   | 85,1   | 81,9   | 61,3   | 73,2   | 98,6    | 93,4   | 113,9   | 102,8   | 1284,5  |
| P90 prognosis            | 63,4    | 52,9    | 83,8    | 69,1   | 71,1   | 70,2   | 52,4   | 65,0   | 82,8    | 77,8   | 96,2    | 68,4    | 1217,9  |



Based on the historical data with filters applied (taking out outliers and/or months with poor availability), the min and max WCP is found within a window of X months dragged through the entire time series and the values are plotted versus months in window. This gives the possible index based prognosis error looking at a shorter time window.

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