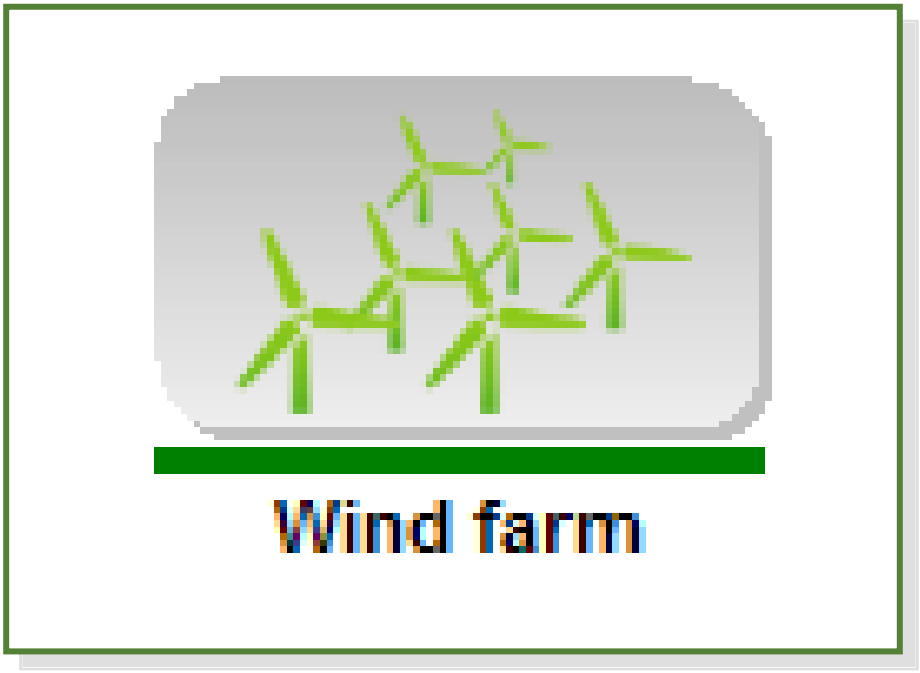
HOW TO GUIDE

Wind farms in energyPRO



Software for techno-economic analyses of energy projects

EMD
www.emd.dk

Preface

energyPRO is a Windows-based modeling software package for combined techno-economic analysis and optimisation of complex energy projects with a combined supply of electricity and thermal energy from multiple different energy producing units.

The unique programming in energyPRO optimises the operations of the plant including energy storage (heat, fuel, cold and electrical storages) against technical and financial parameters to provide a detailed specification for the provision of the defined energy demands, including heating, cooling and electricity use.
energyPRO also provides the user with a detailed financial plan in a standard format accepted by international banks and funding institutions. The software enables the user to calculate and produce a report for the emissions by the proposed project.
energyPRO is very user-friendly and is the most advanced and flexible software package for making a combined technical and economic analysis of multi-dimensional energy projects.
For further information concerning the applications of energyPRO please visit www.emd.dk.

Terms of application

EMD International A/S, November 2013

Content

1. Introduction

Adding a wind farm in energyPRO allows the user to make more complex analyses by adding fluctuating energy to an existing system. This 'How to Guide' provides descriptions on how to add a wind farm in energyPRO, different ways of calculation(s) and specification of the wind speed. All approaches towards calculating on a wind farm require that a time series holding wind speed is available and present in the "External conditions"-folder.

2. Adding a wind farm in energyPRO

A wind farm in energyPRO is very easily added. You can either do it as shown on Figure 1 or you can click on the blue plus in the editing window, choose "Energy conversion unit" and select "Wind farm".

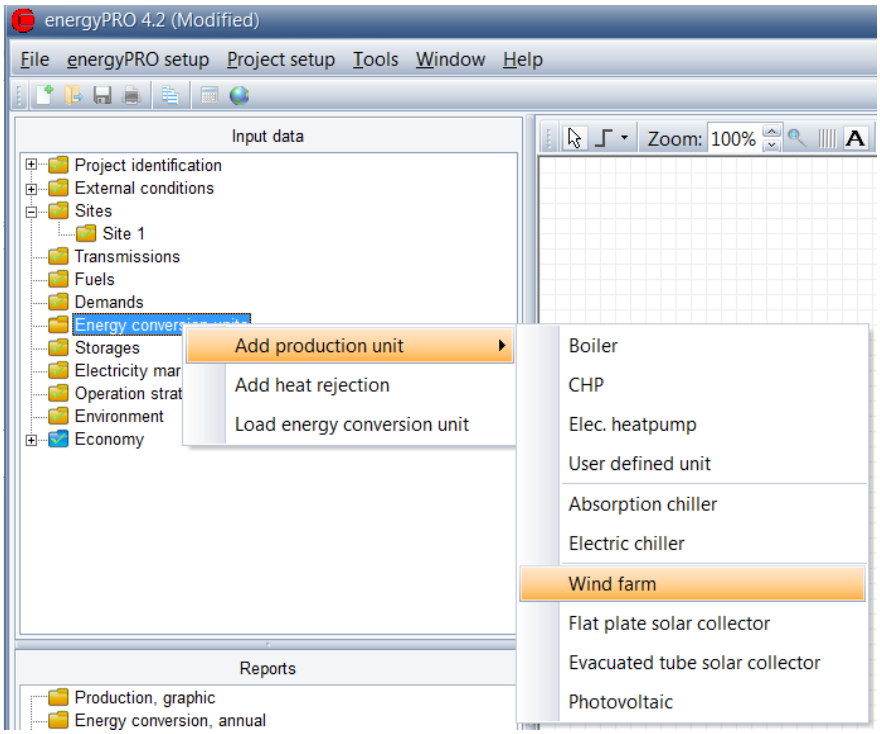


Figure 1. Select and specify the production unit - Wind farm

The new wind farm uses an external time series with measured wind speed and a wind farm power curve to calculate electric production from the wind farm. The time series with wind speed must be present in the "External conditions"-folder and the power curve must be specified in the wind farm editing window. After the time series for wind speed has been added, double-click on the wind farm logo in the editing window and a picture similar to the one on Figure 2 appears.

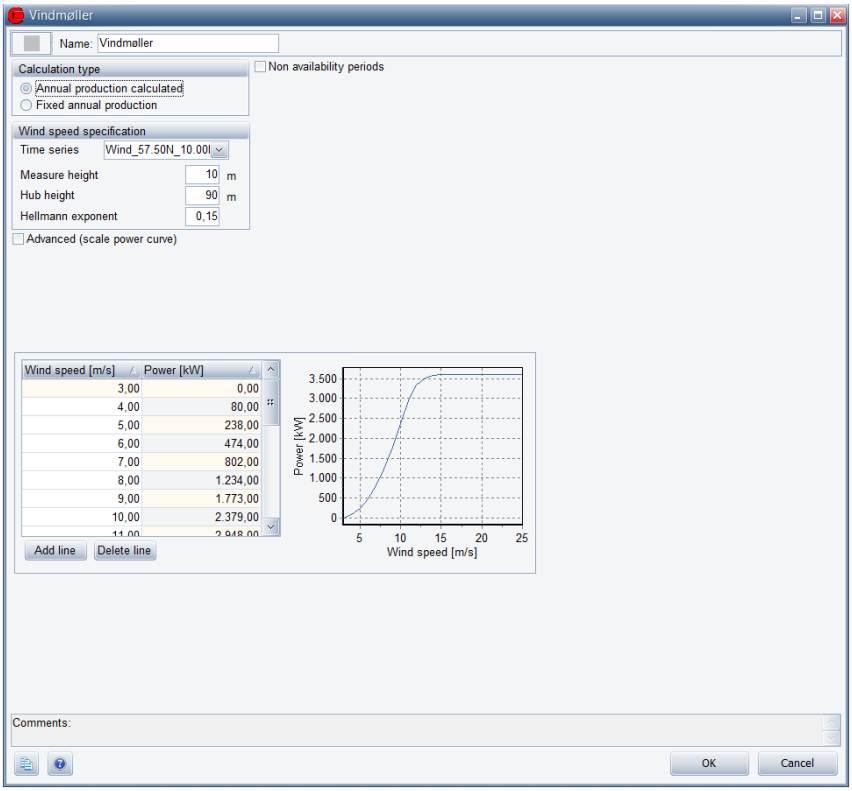


Figure 2. Characterise the wind farm

Here you can select the right time series, further specify the wind speed characteristics and choose the calculation type.

3. Wind speed specification

To set up the wind speed specifications you do this in the window shown on Figure 2 in the box shown on Figure 3.

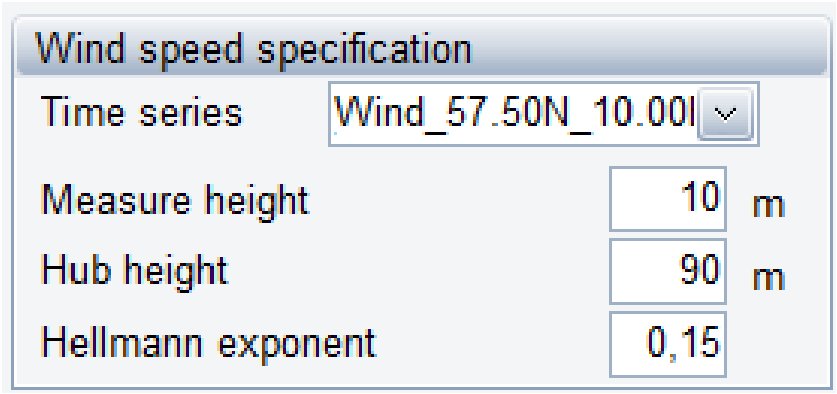


Figure 3. Wind speed specification

The wind speed at hub height is defined through the following parameters, which is used for converting the wind speed in measure height to wind speed at hub height.

1. A time series holding the wind speed
2. The measure height of the time series
3. The hub height of the turbines
4. The Hellmann exponent

Ad 1) The time series must be established in “External conditions” prior to the specification.

The Hellmann exponent is a value used in the calculation of the hub height and varies depending on the coastal location, shape of terrain and stability of the air.

4. Specification of power curve

The power curve consists of a data set of values containing the wind speed and the corresponding power output from the turbines. In the calculation, the power output is assumed linear between two data elements. The power curve is specified through a data table and shown on a corresponding graph such as the one seen on Figure 4.

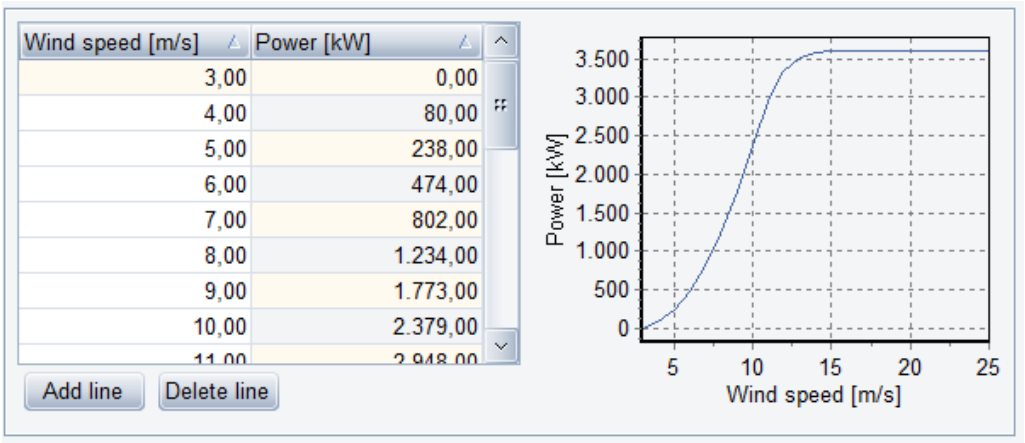


Figure 4. The power curve of the wind farm

The functionalities of the table are comparable to the other energyPRO tables. This includes unlimited number of values, “add line” and “delete line”-buttons. Data is added by typing data into the table or by pasting via the clipboard. It is possible to copy a calculated wind farm curve from WindPRO® via the clipboard to the wind farm power curve in energyPRO as shown on Figure 5.

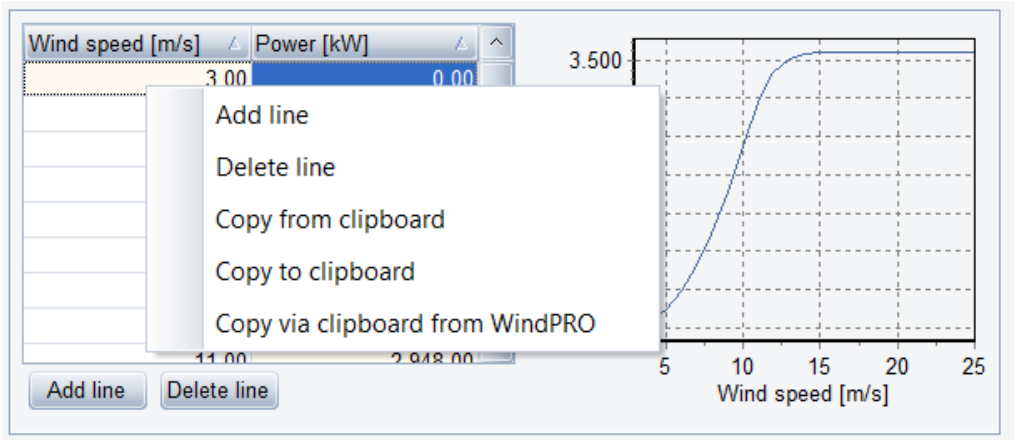


Figure 5. The power curve. Values can be copied via clipboard, including wind farm power curve calculated in WindPRO

5. Calculation type

When calculating on wind farms in energyPRO there are two main approaches of doing so The calculation type can be chosen in the window from Figure 2 and gives the two possibilities shown on Figure 6.

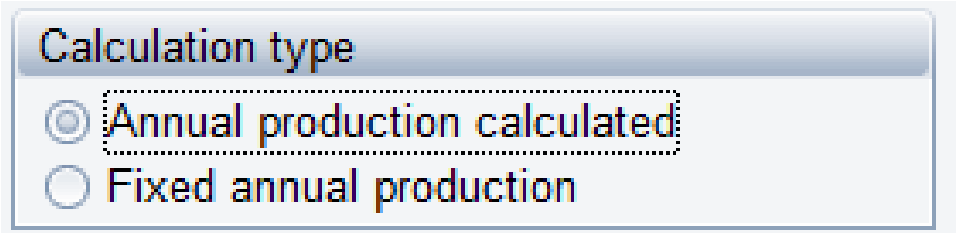


Figure 6. Select Calculation type

Annual production calculated. In this case the productions from the wind farm is calculated based on the wind speed specification and power curve of the wind farm. As an advanced setting, there are options to scale the power curve to another level and thereby the production.

Fixed annual production. This option serves to distribute a desired annual production given a specified wind farm power curve. All wind speeds specified through "Wind speed specification" (see next section) are scaled by the modification factor that makes agreement between the annual production, the power curve and the wind speeds. This factor is found through iterations.

5.1 Annual production calculated

The two ways of calculating on the wind farm have in the following been emphasized more deeply with the purpose of detailing the different options within each way of calculation.

5.1.1 Annual production calculated, not advanced

Figure 7 shows the content of the wind farm editing-window if "Annual production calculated" is selected.

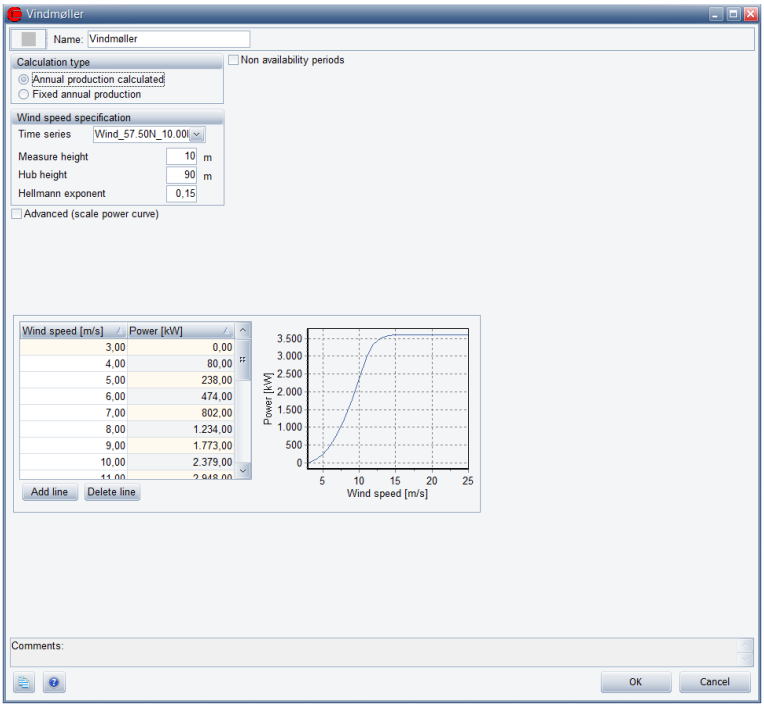


Figure 7. Wind farm, "Annual production calculated", not advanced

This option has to some degree already been described and will therefore not be touched further upon. However, the "Annual production, calculated" also opens an advanced option which in the following has been described further.

5.1.2 Annual production calculated, advanced (scale power curve)

By enabling the advanced option the power curve changes and looks to some extent as the one on Figure 8. Notice that the power curve now has a new resulting power curve both in the table presentation and in the graphic representation. There are two variants. It is possible to scale the power curve using a percentage or a new maximum power curve value, see Figure 9.

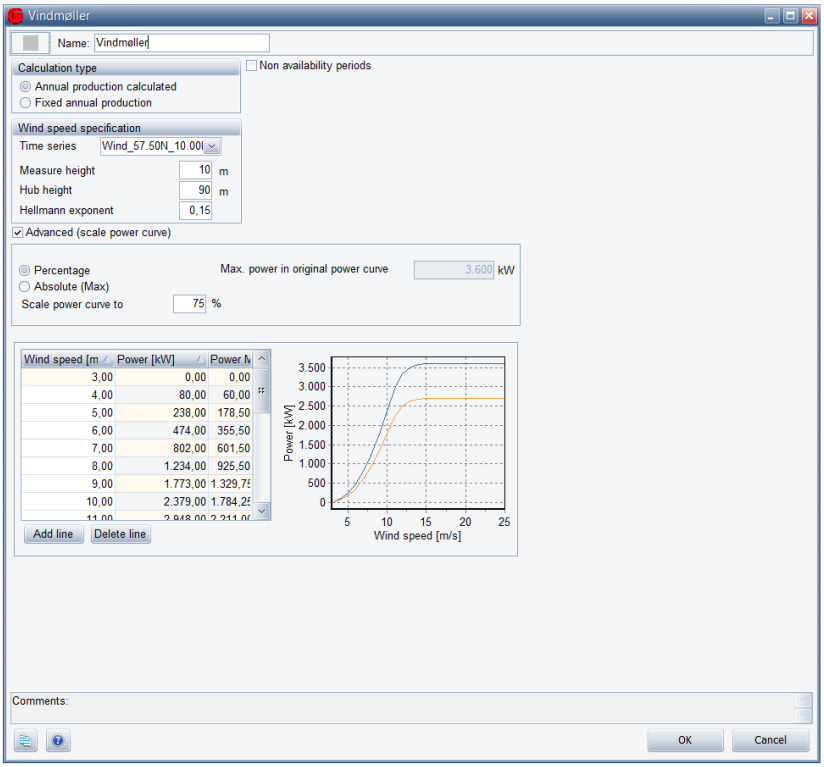


Figure 8. Wind farm, "Annual production calculated", power curve scaled with percentage

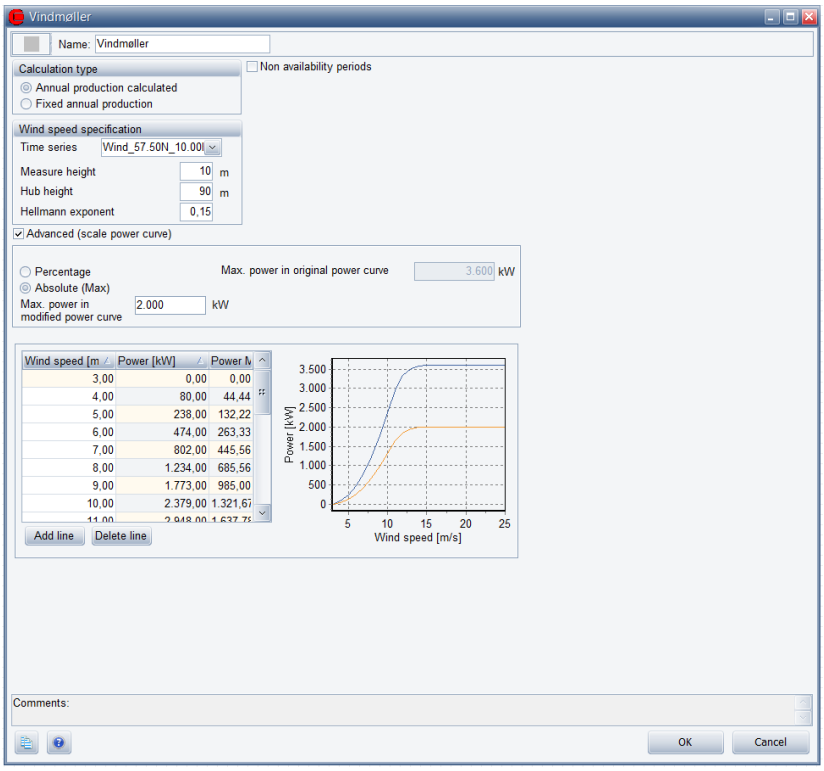


Figure 9. Wind farm, "Annual production calculated", power curve scaled with maximum power curve value

5.2 Fixed Annual production

If “Fixed annual production” is selected then the Annual production and the wind farm power curve is specified (e.g. calculated in WindPRO) as can be seen on Figure 10. Given the power curve and a stated annual production all wind speed values are scaled by a factor. This factor is calculated, and is used when calculating the production at any time. See the description in section 6.

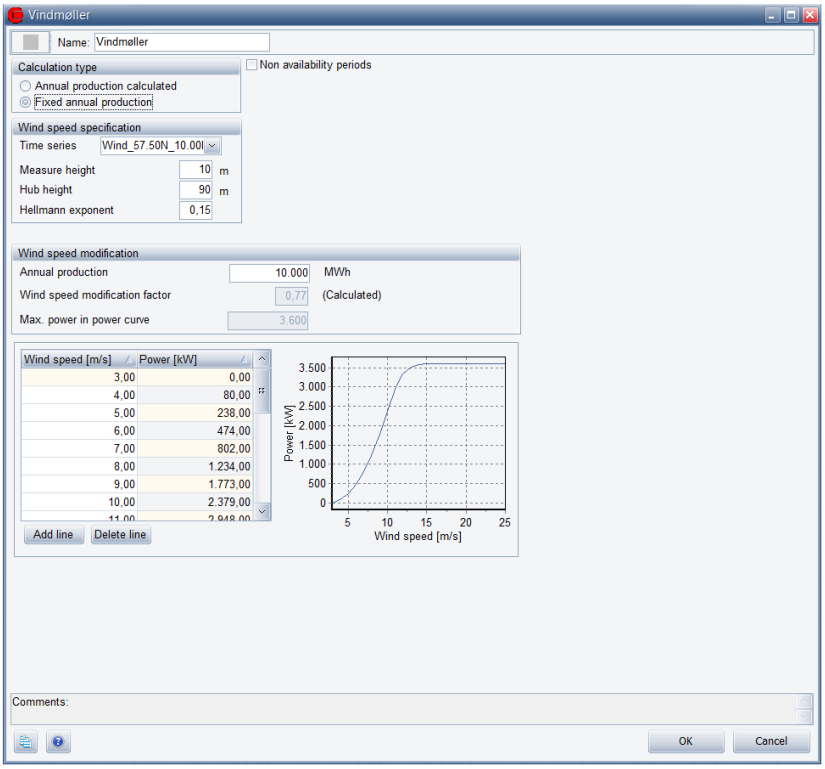


Figure 10. Fixed annual production (Scaling wind speed)

6. Method of wind farm calculation in energyPRO

The wind farm model in energyPRO covers the following cases.

1. Annual production calculated
    a. Power curve used directly
    b. Power curve is scaled to another level
2. Fixed annual production (wind speed is scaled)

The mathematical documentation and the symbols behind these calculations are in the following presented.

6.1 Definitions

$WS_m(t)$	= Wind speed measured (m/s) at time t
$WS_C(t)$	= Wind speed calculated (m/s) at time t
H_m	= Height of measurements (m)
H_h	= Hub Height (m)
α	= Hellmann coefficient
m_f	= Wind speed modification factor

$PC(WS_c(t)$ = The power from the power curve based on the calculated wind speed at hub height and linear interpolation on power curve.

P_{MaxPC} = Max power value found in power curve

P_{Max} = Max Power stated

$P(t)$ = Production at time t

$P_{annualDesired}$ = Annual production desired (MWh)

$P_{annualCalc}$ = Annual production calculated (MWh)

6.2 Mathematical documentation

The mathematical expressions behind the wind speed at hub height, production and wind modification factor has in the following been clarified.

6.2.1 Wind speed at hub height

Calculated wind speed at hub height in case 1a and 1b presented further below.

(1) $$WS_c(t) = WS_m(t) * \left(\frac{H_h}{H_m}\right)^{\alpha}$$

Calculated wind speed at hub height in case 2.

(2) $$WS_c(t) = WS_m(t) * \left(\frac{H_h}{H_m}\right)^{\alpha} * m_f \,,$$

where the modification factor is found through iterations

6.2.2 Calculation of production at time t

(3) $$P(t) = PC(WS_C(t))$$ (Case 1a)

(4) $$P(t) = PC(WS_C(t)) * P_{\max} / P_{\max PC}$$ (Case 1b)

(5) $$P(t) = PC(WS_C(t))$$ (Case 2)

where $PC(WS_C(t))$ returns the power from the power curve based on the calculated wind speed at hub height and linear interpolation on power curve.

6.2.3 Calculation of wind modification factor

(6) $P_{annualCalc} = \sum_{t=0}^{t=H_{Year}} PC(WS_C(t)) * \Delta T$, where $WS_c(t) = WS_m(t) * \left(\frac{H_h}{H_m}\right)^{\alpha} * m_f$

Start guess $m_{f=1}$

In each iteration the annual production is calculated (6) and compared to the desired value

If $P_{annualCalc} > P_{annualDesired}$ then decrease m_f

If $P_{annualCalc} < P_{annualDesired}$ then increase m_f

This is repeated until

$$P_{annualCalc} \cong P_{annualDesired}$$

meaning that m_f is found.

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