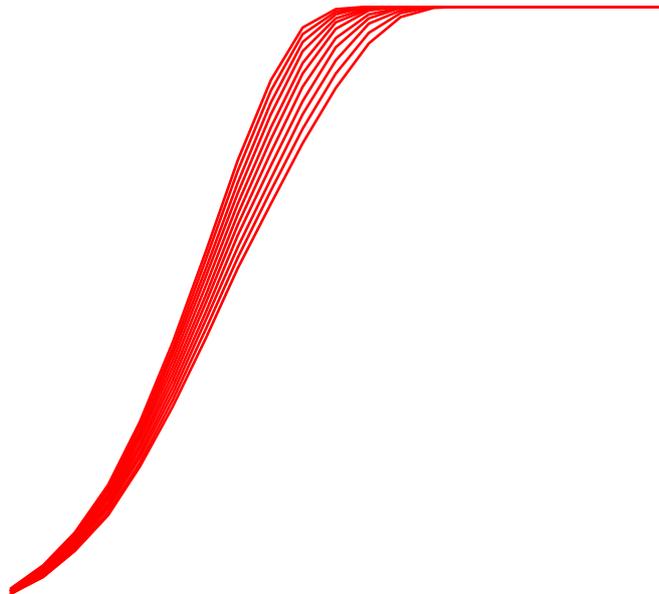


WindPRO / Energy

Power Curve Air Density Correction And Other Power Curve Options In WindPRO



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Front cover

The front cover shows a suite of air density corrected power curves.

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1 Air density correction of power curves

In wind energy prediction of annual energy production (AEP) the air density is accounted for by using power curves valid for the site specific annual mean air density. In WindPRO's wind turbine catalogue the default power curves available are valid at standard air density, but the user can also manually input air density specific power curves, if available. However, normally such power curves are not available in the preliminary project phases before an agreement has been made with a particular manufacturer. At later stages the chosen manufacturer might provide such site specific power curves. Thus, in the early project phases, air density correction of power curves valid at standard air density often is the only option. WindPRO has several options for this correction as described in this text.

1.1 Basic considerations

The power available in laminar wind is proportional to the air density (ρ) and the cube of the wind speed (u), as expressed in eq. 1. Rotor area is denoted by A , and available power by P .

$$P = \frac{1}{2} \rho A u^3 \quad (\text{eq. 1})$$

Thus, considering the power available in the wind energy resource it is simply proportional to ρ . Wind turbines do not extract 100% of the available resource due to limitations of efficiency (aerodynamic, electric etc.) and generator size. Having reached a certain power, the rated power, most modern wind turbines level their output at this constant level by pitching the blades. This pitch control affects the power output's dependency on the air density making it different from a simple proportionality to ρ .

2 IEC 61400-12 air density correction

The IEC 61400-12 is a standard for measurement of wind turbine power curves. This standard describes how to correct power curves measured at one site specific air density to the standard air density of 1.225 kg/m^3 . However, the method also works the other way around, i.e. to correct a power curve given at standard air density to higher or lower site specific air densities.

The principle of the method is simple and is a two step procedure. The power output at all wind speeds is assumed to have the ρu^3 dependence of eq. 1. Instead of scaling the power values at standard air density (P_{std}) by the ratio of site air density-to-standard air density (which would alter the rated power), **step 1** is scaling of the wind speeds of the standard power curve according to:

$$u_{\text{site}} = u_{\text{std}} (\rho_{\text{std}} / \rho_{\text{site}})^{1/3} \quad (\text{eq. 2})$$

The resulting corrected power curve ($u_{\text{site}}, P_{\text{std}}$) is, however, sampled at the new wind speed values, u_{site} . To obtain the air density corrected power curve at the original wind speeds (u_{std}), **step 2** is to interpolate the new corrected power values at the original wind speeds, i.e. ($u_{\text{std}}, P_{\text{site}}$), from the curve ($u_{\text{site}}, P_{\text{std}}$).

2.1 Limitations of the IEC 61400-12 correction

The assumption implicit in eq. 2 and thus the IEC correction is that the efficiency of the turbine is constant at all wind speeds, which we know from the C_p curve is not fulfilled. As a result the IEC correction does not perform well around rated power, where it does not correct the power values enough. The reason being that close to rated power the power output is not proportional to u^3 , but u at some lower exponent, which in principle equals zero above rated power, where output is constant.

The result is that using the IEC 61400-12 to correct from standard air density to lower densities, the predicted AEP will be overpredicted, possibly up 5%, for very low air densities. At densities higher than the standard air density the IEC correction results in a slight underprediction of AEP.

Therefore, the IEC 61400-12 correction should only be used for small air density corrections!

3 New WindPRO correction (improved IEC method)

Analyzing the shortcomings of the IEC 61400-12 air density correction as above it is not difficult to come up with an improved air density correction. From WindPRO 2.7 we therefore introduce an improved air density correction based on a simple adjustment of the IEC 61400-12 method. This improved method is (will be, as of writing) published and presented at the EWEC 2010 conference (Author: *Lasse Svenningsen*, Title: *Proposal of an improved power curve air-density correction*).

The “New WindPRO” method uses the two step approach identical to that of the IEC 61400-12 method. However, with the simple but important difference that the exponent in eq. 2 is not constant at $1/3$ for all wind speeds. Instead, the exponent is made a function of wind speed. For wind speeds lower than 7-8m/s the exponent is $1/3$ as for the IEC method. Between 7-8m/s and 12-13m/s, the exponent is smoothly stepped from $1/3$ up to $2/3$. Above 12-13m/s the exponent is constant at $2/3$. Otherwise, steps 1 and 2 are performed identically to the IEC 61400-12 method.

The exact values of the exponent and where the smooth transitions sets in has been calibrated against a large pool of density specific power curves provided by most of the large manufacturers. In the actual WindPRO implementation the exponents are not exactly $1/3$ and $2/3$, due to the calibration, but close.

The calibration against many density specific power curves indicates that errors on AEP are generally less than $\pm 1\%$, even for very large corrections. This should be compared with the IEC 61400-12 correction with overpredictions of up to $+5\%$. Figure 1 illustrates air density correction of a power curve at standard air density to a very low air density using the IEC 61400-12 and the new WindPRO method. Also shown is the “true” density specific power curve provided by the manufacturer. For clarity the case shown is an extreme example. In most cases the difference is not quite as large, and the new WindPRO method might perform slightly poorer.

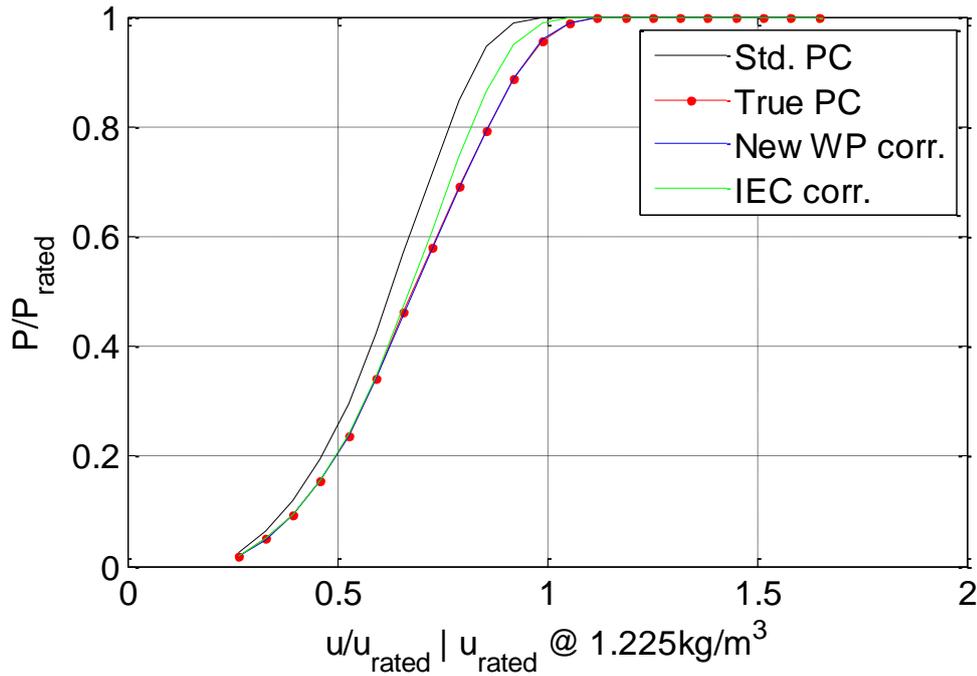


Figure 1: A good case illustrating the difference between the New WindPRO correction and the IEC 61400-12 correction. The black power curve (PC) is the standard PC at 1.225kg/m³, to which the corrections are applied. The red PC is the “true” air density specific power curve at 1.0kg/m³ calculated by the manufacturer using a full aero-elastic model of the turbine. The green PC is the standard PC corrected using the IEC61400-12 method and the blue curve is corrected using the new WindPRO method.

Notice: that power and wind speeds have been normalized for reasons of confidentiality, to mask the manufacturer providing the air density specific PC. The PCs shown are for a frequently sold >2MW model from a major manufacturer.

4 Old WindPRO correction

The original WindPRO air density correction is based on the simple scaling of power values according to the ratio of site-to-standard density ratio, typically used for stall regulated wind turbines. This scaling approach would change the level of the rated power if applied at all wind speeds. To avoid this, an empirical solution is made, such that the scaling stops shortly before the scaled rated power is reached, and instead a smooth empirical transition to the real rated power is made.

The drawback of this approach is that for large corrections (usually to low air densities) the empirical transition from the steep part of the power curve to the rated power is not smooth enough and the shape does not accurately mimic the behaviour of pitch regulated wind turbines. Overprediction of AEP as for the IEC u method can be the result for large corrections to low air densities.

5 No correction of power curve

From WindPRO 2.7 it is also possible to choose the option “No correction”, making the assumption that the power curves chosen represent the onsite air density. This is often the case at the very late stages of a project where an agreement has been made with a turbine manufacturer providing the site specific power curves.

6 Handling of negative power curve values

Typically, measured power curves will contain negative values at the lowest wind speeds just before cut-in. These negative values represent energy consumption due to start up of the turbine, running the generator as a motor, drawing power from the grid. This consumption will always be calculated, however, there are two options, allowing the choice whether the consumption should be subtracted from the result in the main report or not. In both cases the consumption is shown in the main report page in a separate column.