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EQUIVALENT WIND SPEED MODEL FOR WIND TURBINES CONNECTED TO THE DISTRIBUTION GRID

BY

CORNEL-MARIAN IFTIME*

“Gheorghe Asachi” Technical University of Iaşi,
Faculty of Electrical Engineering, Energetics
and Applied Informatics

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Abstract. For many countries from entire world the problem related to the best integration of wind energy in their energetic system is an actual issue. The major cause of this problem is the continuous variability of wind speed value that is translated in to the variation of the main mechanical and electrical parameters of the wind turbine: aerodynamic torque, mechanical torque, voltage, frequency, active and reactive power, flicker and harmonics. Not only the inflow wind speed variation affects the stability of aerodynamic torque, even when wind speed is constant, the aerodynamic torque varies due to the influence of deterministic and stochastic factors. In a wind farm each wind turbine has his own particularly influence on the cumulate reaction that the whole system it has in point of common coupling to the grid. Considering that all turbines are of the same type and excepting the different degrees of wear, the particularly influence is related to the different wind speed conditions at each hub.

Key words: wind turbine; wind speed; equivalent model; shear exponent; tower shadow.

1. Introduction

Due to the large diversity of types of wind turbines used, optimal integration of wind farms on power systems involves, for each case, the

* *e-mail*: corneliftime@yahoo.com

development of detailed preliminary studies, allowing a more precise calculation of the influence upon system stability. Essential for these studies is to use more adequate models that could reproduce more accurately the real behavior of wind turbines in various operating regimes.

A complex and suitable model for wind energy conversion systems (WECS) can not be structured without an aerodynamic model that could take into account all the variables that influence the value of wind speed and aerodynamic torque on all section of the blade rotor namely

a) ***deterministic part*** – mean wind speed, v_H, tower shadow, $v_{\mathrm{eq}_{ts}}$, and $v_{\mathrm{eq}_{ws}}$ wind shear;

b) s*tochastic part* – turbulence intensity, I_v , and coherence of the wind, $\gamma_v(f, d)$.

In this paper, using Simulink platform from Matlab software was developed a model for the equivalent wind speed, W_{eq}, that acts on the rotor blade and produces the equivalent aerodynamic torque, T_{eq}, which drives the rotor shaft and transfer the power to the drive train.

2. Wind Speed and Influence on Generated Power

The energy available in the wind varies as the cube of the wind speed, so an understanding of the characteristics of the wind resource is critical to all aspects of wind energy exploitation, from the identification of suitable sites and predictions of the economic viability of wind farm projects till to the design of wind turbines themselves, and understanding their effect on electricity distribution networks and consumers.

From the point of view of wind energy, the most striking characteristic of the wind resource is its variability. The wind is highly variable, both geographically and temporally. Furthermore this variability persists over a very wide range of scales, both in space and time. The importance of this is amplified by the cubic relationship to available energy.

The mechanical power that the turbine extracts from the wind is given by relation

$$P_m = \frac{1}{2} rpR^2v^3C_p \, , \tag{1}$$

with: ρ – air density; R – radius of the rotor blade; C_p – power coefficient of the turbine.

Power coefficient of the turbine, $C_p = C_p(l, b)$, depends of the tip speed ratio of the wind turbine, $l = Rw / v$, and b – pitch angle of the blades.

The wind turbine torque on the shaft can be calculated using the relation

$$T_m = \frac{1}{2} rpR^3v^2C_T \, , \tag{2}$$

with: torque coefficient $C_T = C_p / l$.

3. General Wind Turbine Model

The huge diversity of currently used wind turbines types determining a geat variety of structures and technical configurations, leading to smaller or larger differences in terms of quantitative and qualitative parameters of the generated electricity.

Whichever variant of turbine is used, with fixed or variable speed, with or without pitch control system, with synchronous or asynchronous generators, with or without gear box, etc. all models include the following subsystems:

1. aerodynamic model;
2. drive train model;
3. electric model;
4. automatic adjusting and control system model.

The aerodynamic system is one of the most important systems, regarding the quality and stability of the output parameters of wind turbines. If all other variables involved in this complex system can be fully controlled and modified so that the output values to lie in the allowable limits, at least, in theory, only wind speed is the input parameter whose value can just be limited to a certain level.

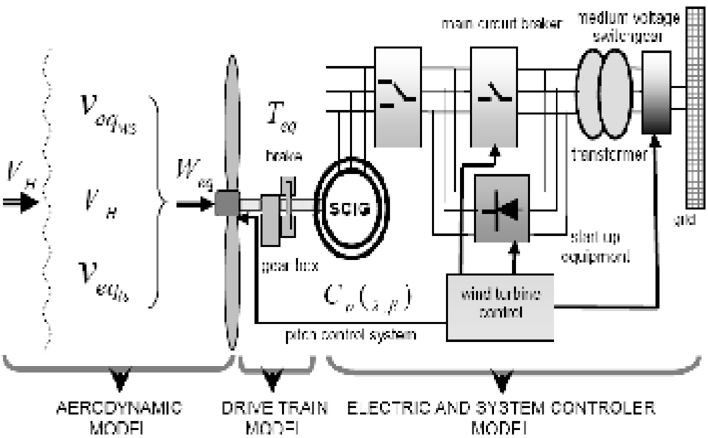

Fig.1 – Model of subsystem components for a WECS.

Another major difficulty is caused by the limited possibilities to forecast with precision the evolution of wind speed values for a certain period of time. It is therefore very important, that when wind speed is used for different calculations, to take into account all factors that have a greater or lesser influence on the variation of its value on the rotor shaft. For more detailed and precise calculations it is important to use the equivalent wind speed, parameter which includes the influence of all factors: techniques (design), weather and location.

4. Mathematical Equations for Equivalent Wind Speed Model

These equations are

$$T_{\mathrm{eq}}(t,q) = y_{\mathrm{eq}} W_{\mathrm{eq}}(t,q), \tag{3}$$

$$T_{\mathrm{eq}}(t,q) = 1 + \frac{2}{mV_H}\left[v_{\mathrm{eq}_{ws}} + v_{\mathrm{eq}_{ts}} + (1-m)V_H\right], \tag{4}$$

$$m = 1 + \frac{a(a-1)R^2}{8H^2}, \tag{5}$$

$$v_{\mathrm{eq}_{ws}} = V_H\left[\frac{a(a+1)}{8}\cdot\frac{R^2}{H^2} + \frac{a(a+1)(a-2)}{60}\cdot\frac{R^3}{H^3}\cos 3q\right], \tag{6}$$

$$v_{\mathrm{eq}_{ts}} = \frac{mV_H}{3R^2}\sum_{b=1}^{3}\left[\frac{a^2}{\sin^2 q_b}\ln\left(\frac{R^2\sin^2 q_b}{x^2}+1\right) - \frac{2a^2R^2}{R^2\sin^2 q_b + x^2}\right], \tag{7}$$

where: R is the radius of the rotor, H – the elevation of the hub, a – the tower radius, x – the longitudinal distance from blade to tower centre, θ_b – the azimuthal angle of blade b and α – the empirical wind shear exponent.

5. Simulations and Results

The model developed in Simulink platform want to show the influence of site characteristics and technical data of wind turbine on the equivalent wind speed acting on the rotor blades. Any small variation of wind speed exerts an important influence on power generation, because according to (1), the output power varies directly with wind speed cube.

In Table 1 are given the characteristic data of the cases selected for simulation.

Performed tests were aimed to establish for each parameter the degree of influence on wind speed variation. In Figs. 2,…,5 are shown the most significant results for two types of tests, cases 1,…,3 and 4,…,6. The first three cases correspond to small wind turbines, in range of tens of kW and the other three cases, to large wind turbines with installed capacity of 1.5,…,3 MW. For all cases was considered share exponent coefficient in the range of 1,…,1.5 and the wind turbine characteristics was different, depending on the height of rotor installation.

Table 1
Characteristics for Simulated Cases

Wind turbine parameters	Cases for simulations					
	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
R	6	10	12	30	40	60
H	27	35	40	70	80	120
α	1…1.5	1…1.5	1…1.5	1…1.5	1…1.5	1…1.5
a	0.7	0.8	0.8	1.6	1.75	2
x	1	1.2	1.2	1.8	2.2	3.8

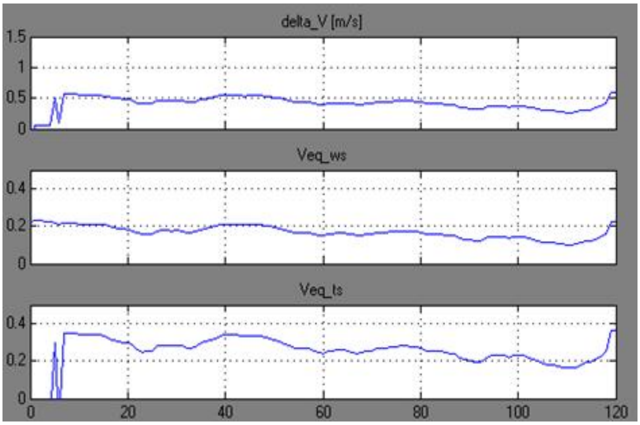

Fig. 2 – Characteristic curves for wind speed variation in cases 1,…,3.

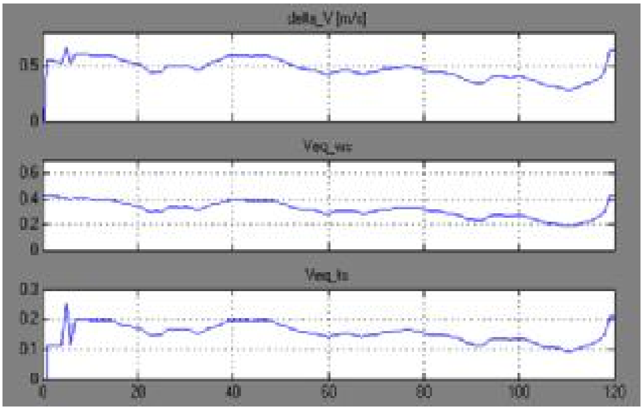

Fig. 3 – Characteristic curves for wind speed variation in cases 4,…,6.

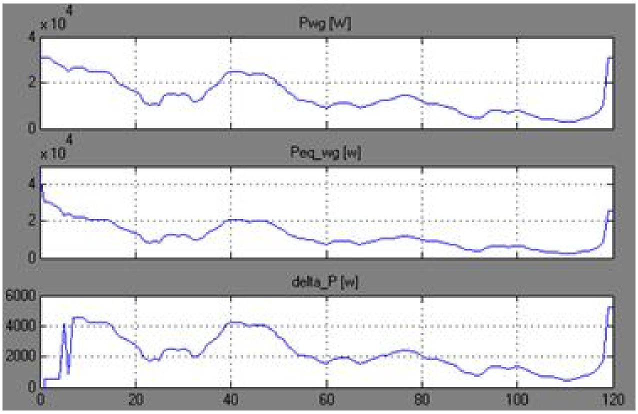

Fig. 4 – Characteristic curves for power variation in cases 1,…,3.

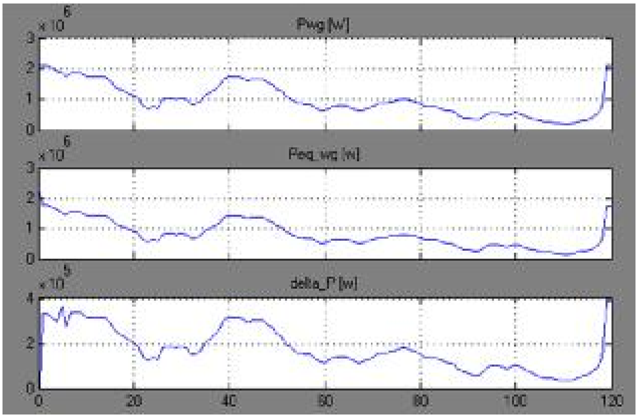

Fig. 5 – Characteristic curves for power variation in cases 4 ,…,6.

6. Conclusions

The developed equivalent wind speed model presented in Fig. 6 can be applied to any type of site and wind turbine. Influence of wind shear factor varies depending on site location and can not be correlated with other parameters. On the other hand, the influence of tower shadow factor depends directly on the manufacturer's design parameters and in some specific limits can be adjusted. For all considered cases the most important feature is the amount of energy "delta_P". In technical-economic analysis of a wind project is very important to calculate precisely the total energy injected into the common grid connection point. This equivalent wind speed model allows a more precise calculation of production that is expected to be delivered in the grid.

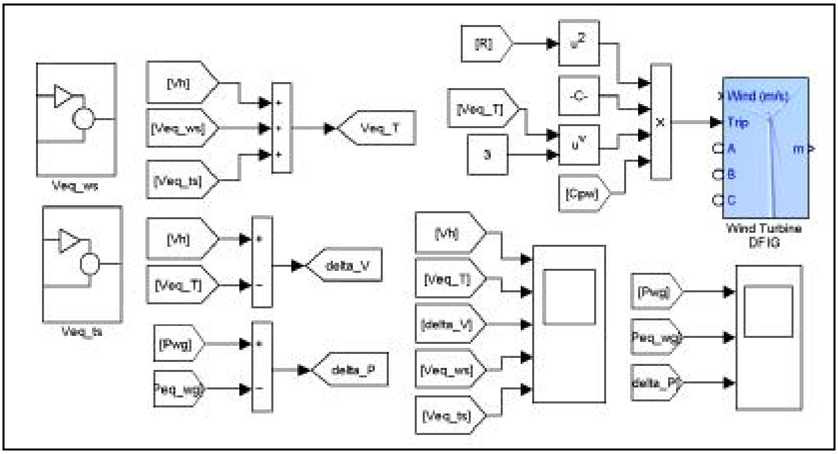

Fig. 6 – General structure of equivalent wind speed model.

REFERENCES

Bollen M., Jin Z., Samuelsson O., Bjornstedt J., Ludvika A. B., *Performance Indicators for Microgrids During Grid-Connected and Island Operation.* Proc. of the Internat. Conf. Power Tech., Bucharest, Romania, June 2009.

Dale S., Dolan P., Lehn P., *Real-Time Wind Turbine Emulator Suitable for Power Quality and Dynamic Control Studies.* Proc. of the Internat. Conf. on Power Syst. Trans., IPST'05, Montreal, Canada, June 2005.

Ramirez-Elizondo L. M., Lojowska A., Paap G. C., *Design of Energy Management System to be Implemented at Denlab.* Proc. of the 6-th Internat. Conf. Electr. Power Engng., Iaşi, Romania, Oct. 2010.

Ramirez-Elizondo L. M., Paap G. C., Woudstra N., *The Application of a Fuel Cell - Electrolyzer Arrangement as a Power Balancing Set-Up in Autonomous Renewable Energy Systems.* Proc. of the 40th IEEE North Amer. Power Symp., Calgary, Canada, 2008.

Rosas P., *Dynamic Influences of Wind Power on the Power System.* Ph. D. Diss., Techn. Univ. of Denmark, 2003.

Van Voorden A. M., Paap G. C., Van der Sluis L., *The Set-Up of a Renewable Energy Laboratory*. Proc. of the Internat. Conf. IEEE Young Res. Conf., Leuven, Belgium, May 2002.

MODEL ECHIVALENT AL VITEZEI VÂNTULUI PENTRU TURBINELE EOLIENE CONECTATE LA REŢEAUA DE DISTRIBUŢIE

(Rezumat)

În vederea realizării unui model adecvat pentru orice tip de sistem de conversie a energiei eoliene este esenţial să se utilizeze un model cât mai precis pentru sub-

sistemul aerodinamic. Modelul pentru acest subsistem trebuie să ia în calcul principalele variabile care influenţează amplitudinea şi frecvenţa de variaţie a vitezei vântului în dreptul rotorului. Modelul realizat şi testat în lucrarea de faţă studiază influenţa a doi factori principali: „tower shadow” şi „wind shear exponent”. Se studiază atât influenţa asupra vitezei reale a vântului din raza de acţiune a palelor cât şi asupra cantităţii de energie generată.