POWER OPTIMISATION CONTROL SYSTEM OF WIND TURBINES BY CHANGING THE PITCH ANGLE

Ilie CATANĂ[1], Carmen-Anca SAFTA[2], Valentin PANDURU[3]

Lucrarea prezintă o metodă de optimizare a funcţionării turbinelor eoliene, astfel încât puterea furnizată de acestea să fie maximă la diferite unghiuri de aşezare ale palelor rotorului. Sunt analizate structura şi performanţele unui servomecanism electrohidraulic folosit pentru controlul poziţiei palelor turbinei în condiţiile de optimizare mai sus menţionate, pentru diferite viteze ale vântului. Metoda prezentată este validată de simulările numerice, rezultatele putând fi comparate cu cele existente în literatura tehnică de specialitate.

The paper presents a method of power optimization of the wind turbines by changing the pitch angle. There are analysed the structure and the performance of a electro-mechanical servomechanism used to put on position the wind turbine blades so that a maxim out power could be obtained at a given wind speed. Numerical simulations validated the applied method, and the results obtained are comparable with the ones from technical literature.

Keywords: wind turbine, pitch angle, optimization, synchronic system, fuzzy controller

1. Introduction

In 1997 the Commission of the European Union published its *White Paper* calling for 12 percent of the gross energy demand of the European Union to be contributed from renewable 2010. Wind energy was identified as having a key role to play in the supply of renewable with an increase in installed wind turbine capacity. Also the problem of optimisation of the process wind energy conversion is current and needs new methods in using of the control system to result a maxim wind out power.

Wind turbine performance could be characterized by three basis parameters for power, torque and the load of the tower of wind turbine. The power size is important to know the energy which could be transformed by the rotor of wind turbine; the torque size is important to design the mechanical elements as the

[1] Prof., Automatic Control and Computers Faculty, University POLITEHNICA of Bucharest, Romania
[2] Assoc. Prof., Hydraulics, Hydraulic Machinery and Environmental Engineering Department, Power Engineering Faculty, University "Politehnica" of Bucharest, safta.carmenanca@gmail.com
[3] Assoc. Prof., Ecological University of Bucharest, Romania

wind rotor, gear box and brake. The tower of the wind turbine and foundation are designed to compression and against buckling and the axial loading is considered.

In the theory of the wind turbines are used some physical models to study the aerodynamics of a wind turbine: the actuator disc concept; rotor disc theory; vortex cylinder model of the actuator disc; rotor blade theory; breakdown of the momentum theory. In all physical models the problem is to maximize the extracting kinetic energy from the wind. The actuator disc theory known as Betz's theory has some limitations but is still used in modelling a wind turbine operating.

2. Mathematical modelling of a wind turbine operating

Betz's theory used the hypothesis of an ideal fluid and a constant pressure in the stream-tube, as in Fig. 1.

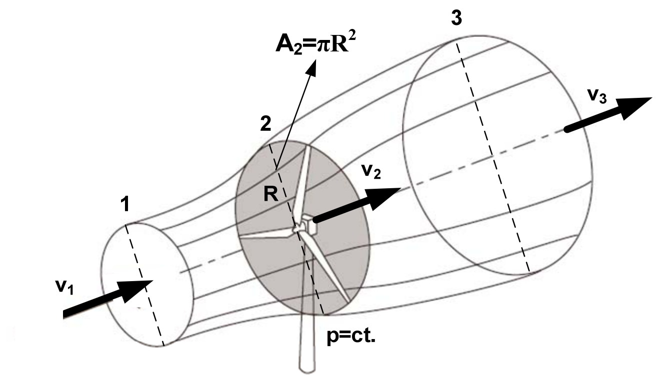

Fig. 1. Stream-tube for the Betz's wind turbine physical model

Betz's model is described by the equations:

$$P = \rho \cdot Q\left(\frac{v_1^2}{2} - \frac{v_3^2}{2}\right); \quad F = \rho \cdot Q(v_1 - v_3); \quad \rho = ct. \text{ and } p = ct. \tag{1}$$

It will be considered the hypothesis of a linear variation of the wind speed in the stream-tube and will write:

$$v_2 = (v_1 + v_3)/2\,. \tag{2}$$

If it will be used the notion of flow induction factor, *a*, as:

$$a = v_2/v_1\,, \tag{3}$$

then Betz's equations will be:

$$P = P_0 \cdot C_p\,, \tag{4}$$

where C_p is the power coefficient:

$$C_p = 4 \cdot a^3 \cdot (1-a), \tag{5}$$

and P_0 is the maximum wind power with v_1 wind speed:

$$P_0 = \rho \cdot A \cdot v_1^3/2\,. \tag{6}$$

The maximum value of the power coefficient C_p is obtained by the derivation of (5):

$$a_{opt} = 16/27 = 0.593 \tag{7}$$

The power coefficient evolution described by (5) is plotted in Fig. 2 using LabVIEW [8]: 59.3% from the kinetic energy is the maximum value that could be extracted from the wind, in the conditions where the output axial speed is one third from the input speed: $v_3 = v_1/3$.

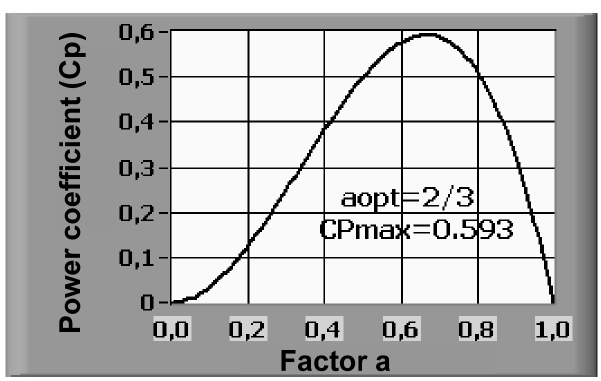

Fig. 2. Power coefficient versus flow induction factor

From the continuity equation in hypothesis of Betz's theory results:

$$Q = v_1 \cdot A_1 = v_2 \cdot A_2 = v_3 \cdot A_3 , \tag{8}$$

so, if the stream-tube is associated with the wind turbine, the wind turbine must have the shape of a diffuser in which the output area is three times bigger than the input area. This condition could be accepted in practises and this is the limit of Betz's theory. The conversion process of wind energy in a wind turbine could be described better if will be introduced the *tip speed ratio* defined as the ratio of the tangential speed (ωR) and the wind speed:

$$\lambda = \omega R / v_1 . \tag{9}$$

A wind turbine could operate when the tip speed ratio is changing in large limits but a maximum power coefficient, C_p, could be obtained only for an optimal value of λ (tip speed ratio). It results that the maximum efficiency in the wind energy conversion and the rotational speed of the rotor wind turbine must be correlated with the wind speed.

3. Method of an optimal control of wind turbine with variable speed

Wind turbines having the control of pitch angle will have the power coefficient described by a function that depends on pitch angle and tip speed ratio:

$$C_p(\lambda, \beta) = C_1 \cdot \left(C_2 \lambda_i - C_3 \beta - C_4 \right) \cdot e^{-C_5 \lambda_i} + C_6 \cdot \lambda , \tag{10}$$

where:

$$\lambda_i = \frac{1}{\lambda + 0.08 \cdot \beta} - \frac{0.035}{\beta^3 + 1} . \tag{11}$$

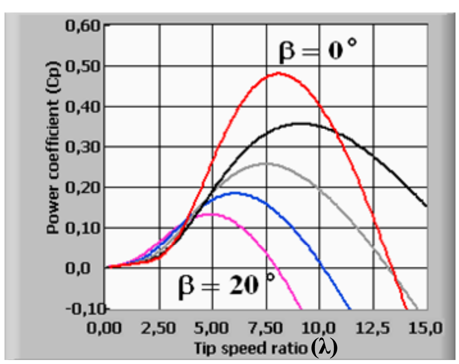

Fig. 3. Power coefficient C_p variations

Reference [1] indicates the following values: C_1=0.5175, C_2=116, C_3=0.4, C_5=5, C_6=21. If the pitch angle β varies from 0º to 20º, the power coefficient C_p has the evolution from Figure 3. The results from Figure 3 used numerical computations of (10) and (11) performed in LabVIEW [8].

4. Application of the control method

To apply the pitch control method to a wind turbine is necessary to know the function between the output power and rotational speed having the wind speed as the parameter. These mechanical characteristics were represented in a program elaborated in MATLAB [9], presented in Table 1.

Table 1

MATLAB program called mechanical_characteristics.m

```
% mechanical_characteristics.m

% numerical simulations of the power coefficient of the wind turbine as a function of the tip
% speed rate and the pitch angle.

clear;
c1=0.5176; c2=116; c3=0.4; c4=5; c5=21; c6=0.0068; r0=1.29; D=40; A=pi*D^2/4;
L=0.01:0.1:15;
b=0;
V=[8,10,12,14,16,18,20];

for k=1:length(V)
   for p=1:length(L);
      AI(p)=1/(L(p))-0.035;
      CP(p)=c1*(c2*AI(p)-c4)*exp(-c5*AI(p))+c6*L(p);
      P(k,p)=(V(k)^3)*CP(p)*r0*A/2;
      n(k,p)=(60/(pi*D))*AI(p)*V(k);
   end;
hold on;
end;

M=max(P(6,:)); m=max(M); P=P/m; n1=length(L); n2=length(V);

for j=1:n1;
   P(:,n1-j+1)=P(:,j);
end;

PR=P;
for q=1:n2;
   plot(n(q,:), PR(q,:)); hold on
end;

grid; axis([0.1,1.45,-0.1,1.4]);
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Numerical simulation results are graphically represented in Figure 4. It could be observed that for any wind speed value the characteristic curve power-rotational speed has a maximum value.

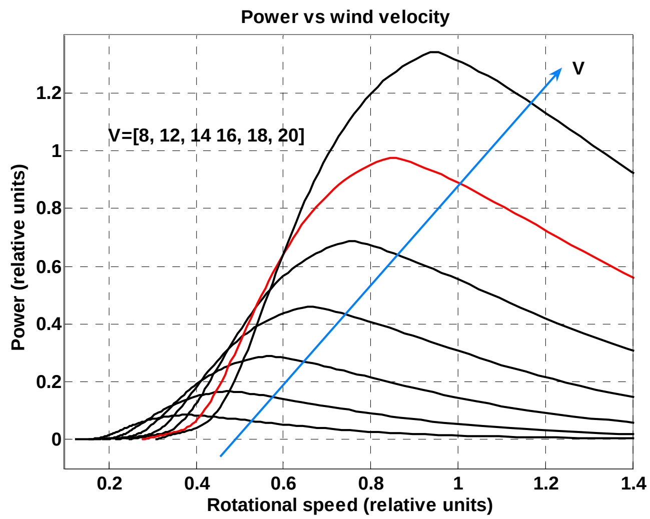

Fig. 4. Wind turbine output power vs rotational speed, with wind speed as parameter

5. Diagram of the optimum control of wind turbines with variable speed

To have an optimum control of the wind turbines with variable speed it is proposed a control method having the block diagram represented in Fig. 5.

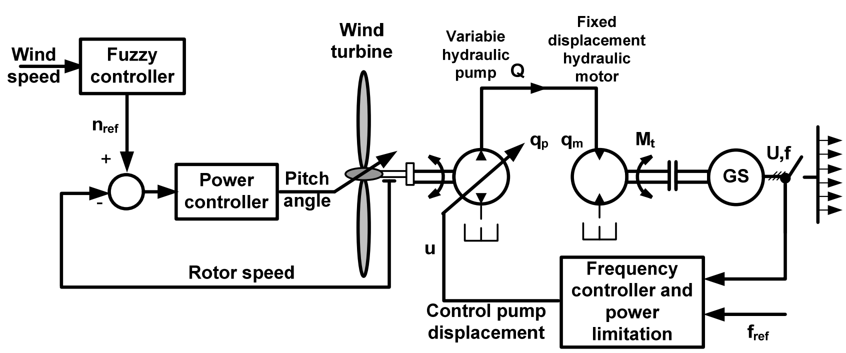

Fig. 5. Diagram of output power control method of a wind turbine

In the electro-mechanical chain of the conversion of wind energy in electrical energy is used a compact hydraulic transmission with a variable hydrostatic pump. Frequency variation and generator's power are monitored using a frequency controller and a power limitation to keep in constant limits the frequency and the output power. The controller will command the hydrostatic pump displacement. Rotational speed of the shaft generator and the wind speed are continuously measured. In function of the wind speed, the fuzzy controller will follow a "*P-n*" characteristic or another to obtain a maximum output power in any condition of the wind speed by changing the pitch angle, Figure 6.

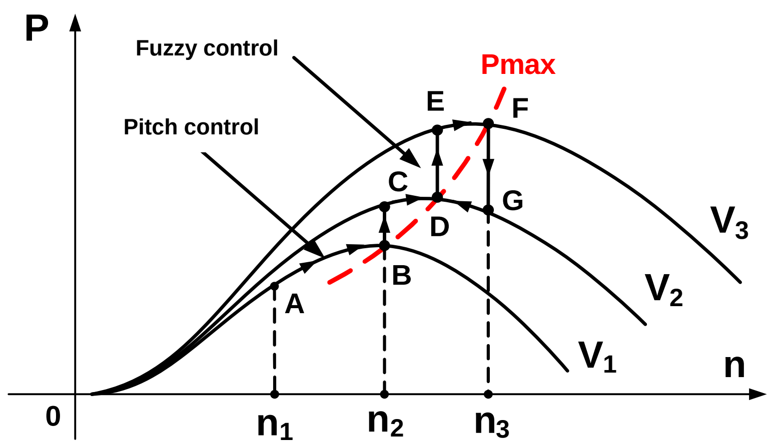

Fig. 6. Graphical representation of the control method

6. Conclusions

It was proposed a control method of the wind turbine, which could operate at maximum output power in any condition of the wind speed, by changing the pitch angle. A frequency controller, a fuzzy controller and an electro hydraulic transmission are used to apply the method.

The method proposed has the advantage to extract the maximum power from the wind kinetic energy having the load parameters constant. The method could be applied to the existing wind turbines. The fuzzy controller could be implemented as software using a dedicated programme and hardware, too, by using fuzzy microprocessors.

The efficiency of the method was numerical tested on a real wind turbine. The method could be applied in situ.

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