PARALLEL OPERATING OF WIND TURBINES BY USING ELECTROHYDRAULIC TRANSMISSIONS

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The paper deals with the problem of how could be the wind turbines more then 750 kW operating in parallel by using electro hydraulic transmissions to synchronized and to have a performance dynamical behavior of the wind turbine.

It was used the numerical simulation technique to see the control system behavior for different values of the reference and some others perturbed parameters. It was proved the opportunity of the electro hydraulic transmission as a synchronize system.

Keywords: wind turbine, hydrostatic transmission, synchronic system, controller, numerical simulation

1. Introduction

Statistics releases by the European Wind Energy Association (EWEA) show that 43% of all new electricity generating capacity built in the European Union in 2008 was wind energy, exceeding all other technologies, Figure 1, [7].

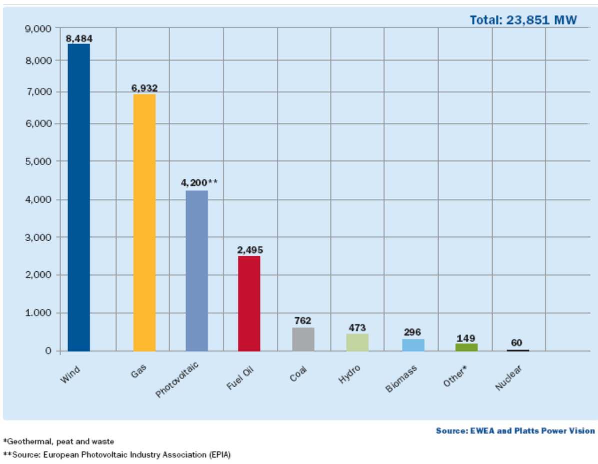

Figure 1. New power capacity installed in EU in 2008, [7].

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To transform the wind potential into electrical energy means to use wind turbines which are working individual or in parallel within of the energetic system. Exceeds of wind energy goes to a rapid development of the wind turbine industry for all kind of energy power. The important goal in the design of mechanical and electrical equipment which are used in the wind turbines is the less cost price comparative with others renewable energy equipment.

Not only an optimal design could be achieved but also the best efficiency of the electrical conversion by using performing equipment in the controlling of the wind turbine for variable speeds of the wind in the place where the wind turbine is located.

How could be control the synchronic generator to keep a constant frequency of the electricity delivered to the customs for the individual wind turbines by using as speed rotation multiplication an electro hydraulic transmission is about in this paper.

2. Aerodynamic elements of wind turbines

A wind turbine extract the cinetic energy from the wind to transform it in electrical energy by passing through mechanical energy. The wind turbines clasiffication criteria is doing by the turbine's ax position, working way, turbine's tip speed ratio, the position of the hub versus wind direction, the wind turbine power, the number of blades, [3]. All modern electricity-generating wind turbines use the lift force derived from the blades to driven the rotor. There are considered the horizontal-axis wind turbines where the torque is produced by the aerodynamical axial force, respectively wind turbines with instaled power more then 750 kW.

A wind turbine is characterized by two parameters which are defined independentlly by the constructive elements of the wind turbine: the tip speed ratio, λ_E, and the solidity factor, σ. Tip speed ratio is the ratio of the tangential speed (ωR) and the wind speed, $\lambda_E = \frac{\omega \cdot R}{V_\infty} = \frac{\pi \cdot n_t \cdot R}{30 \cdot V_\infty}$, where n_t is the rotational speed of the turbine shaft, R turbine's radius, V_∞ wind speed. The solidity factor is the ratio of blade area (S_{tp}) and rotor swept area (S_b): $\sigma = S_{tp}/S_b$. There are known some relations between the tip speed ratio and the rotor solidity factor, or between the tip speed ratio and the power coefficient C_p, for different types of wind turbines. For $\lambda_E > 4$ the rotor solidity has less values and the area of the rotor blades is less, Figure 2. The power coefficient is defined as $C_p = \frac{P}{\frac{1}{2} \cdot \rho \cdot \left(\frac{\pi \cdot D^2}{4} \right) \cdot V_\infty^3}$, with P the out-power at the wind turbine's shaft, ρ

air density and D ($D = 2R$) the rotor diameter. The power coefficient is variable with the tip speed ratio and the constructive type of wind turbine, Figure 3.

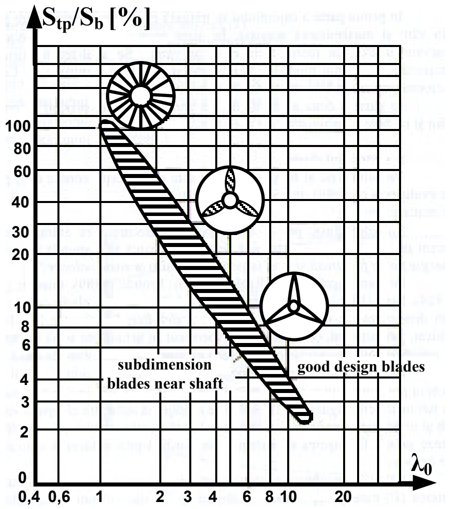

Figure 2. The influence of tip speed ratio above rotor solidity for horizontal-axis wind turbines.

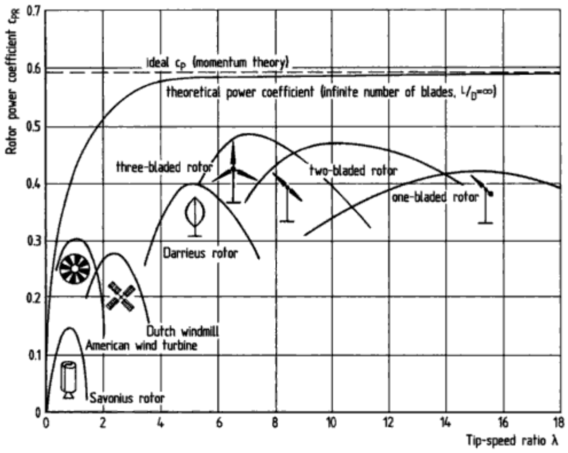

Figure 3. The influence of tip speed ratio above the wind turbine type and the power coefficient.

3. Parametrical modelling of wind turbines controled by electro hydraulic transmission

There are some advantages by using the electro hydraulic transmission to control the wind turbine comparing with electromechanical solutions such as: a more power-weight ratio; best energetic efficiency; better dynamical behaviour; best flexibility as power and torque variator used technical solution of control. Such of an electro hydraulic control system is shown in Figure 4.

To synchronize the generator with the grid-off energetically system in the case of working in test of the wind turbine or in the case of a constant frequency in individual working wind turbine is considered:

$$f = \frac{p_g \cdot n_g}{60} \tag{1}$$

where p_g is the number of poles pairs of the synchronic generator, and n_g is the rotational speed of the electrical generator which is equal with the coupled hydraulic motor. If the internal pump and hydraulic motor leakage flow are neglected the power conservation law will be finally:

$$n_g = n_t \frac{q_p}{q_m}. \qquad (2)$$

It will result that the constant rotational speed of the electrical generator could be done by changing the specific rate flow q_m of the hydrostatic pump independently of the wind speed *V* which will modifying the rotational speed of the wind turbine n_t. In the case of no internal flow rate in the hydrostatic pump and motor but having an incompressible hydraulic fluid the continuity equation is:

$$q_p n_t = q_m n_g + \alpha_H \Delta P \qquad (3)$$

where α_H is the total pressure losses coefficient.

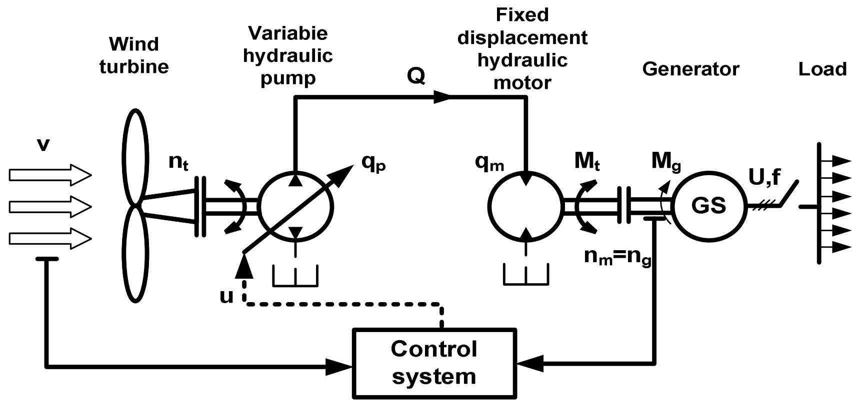

Figure 4 Electro hydraulic control system of a wind turbine

The pressure on the hydraulic motor will done a torque applied to the electrical generator (M_g) as in the equation:

$$q_m \Delta P = J \frac{dn_g}{dt} + M_g \qquad (4)$$

To control the displacement of the hydrostatic pump it is used a positional hydraulic servomechanism which is command by the control system. The above equations will done the expression of the rotational speed of the synchronous generator as a function of the two inputs:

$$n_g(s) = H_1(s) \cdot u_p(s) + H_2(s) \cdot M_g(s) \qquad (5)$$

where

$$H_1(s) = \frac{n_g(s)}{u_p(s)} = \frac{K_A}{1 + s \cdot T_A} \qquad (6)$$

$$H_2(s)=\frac{n_g(s)}{M_g(s)}=-\frac{K_V}{1+s\cdot T_A} \tag{7}$$

$$K_A=\frac{K_p\cdot n_t}{q_m};\quad K_V=\frac{\alpha_H}{q_m^2};\quad T_A=\frac{\alpha_H\cdot J}{q_m^2} \tag{8}$$

4. Control law synthesis

The controller is working so that the disturbances could be eliminated. The wind speed variations are considered as important disturbances because they are changing the rotational speed of the hydrostatic pump and the resistant torque of the electrical generator. The dynamical behavior of the hydro mechanic servomechanism which command the hydrostatic pump, could not be avoid and the control system has the configuration, Figure 5:

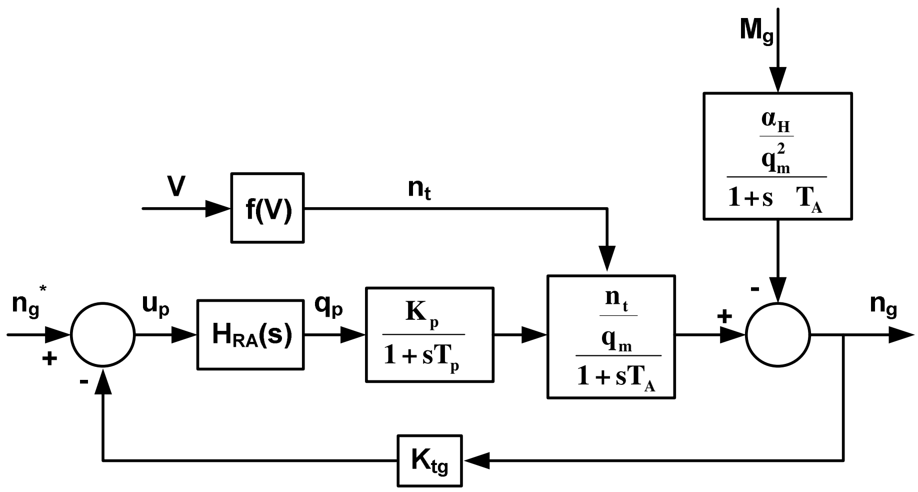

Figure 5 Wind turbine control system diagram

The wind turbine control system is a system with time variable parameters because of the parametrical multiplicative disturbances. Because the wind turbine is working as an autonomous wind turbine, a proportional-integral (PI) controller is used having the transfer function as:

$$H_{RA}(s)=\frac{n_p(s)}{\varepsilon_n(s)}=K_R\left(1+\frac{1}{s\cdot T_i}\right) \tag{9}$$

To optimize the controller parameters numerical simulation are made.

5. Numerical simulations

The numerical model and the results of the numerical simulations are in Figure 6 and Figure 7.

```
% wind_turbine.m
% control the frequency of a synchronous
% generator by using an electro hydraulic transmission

clear;
qp=28; qm=4; Kp=2.8; Km=2.8; Tp=0.6; Tm=0.6;
TA=1.6; Ktg=1/150; ah=2.8; KR=10.8; Ti=1.2;
nto=[10,15,20,22,25,30];
    for i=1:length(nto)
        num1=[KR*Ti,KR]; den1=[Ti,0];
        num2=[Kp]; den2=[Tp,1];
        num3=[(1/qm)*nto(i)]; den3=[TA,1];
        num4=[Ktg]; den4=[1];
        numb=conv(num1,conv(num2,num3));
        denb=conv(den1,conv(den2,den3));
  [numo,deno]=feedback(numb,denb,num4,den4);
    t=0:0.001:20;
    [y,x,t]=step(numo,deno,t);
    z=10*y;
        plot(t,z); xlabel('t (secunde)');
        ylabel('n(rot/min)');
        hold on;
        end; grid;
        title('Step responses for different wind speeds');
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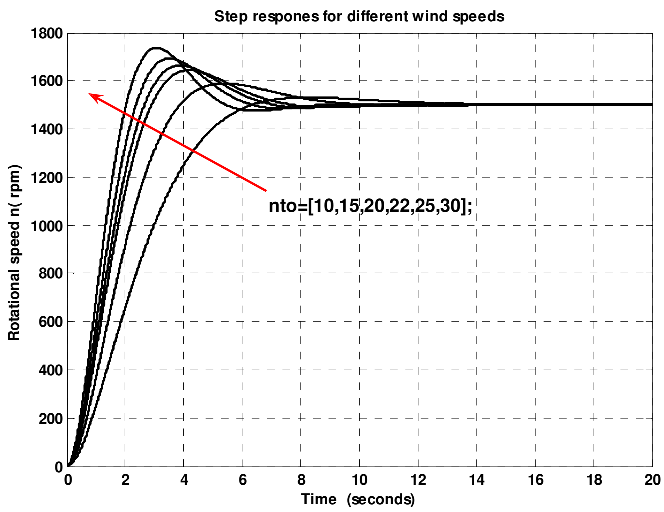

Figure 6. Step responses for different wind speeds.

The constants used in the numerical model are: q_p, hydrostatic pump's specific flow rate; q_m, hydrostatic motor's specific flow rate; K_P and K_m, transfer factors; T_p, T_m and T_A time constants; n_{go}, reference rotational speed; M_g, torque generator; K_{tg}, transducer's transfer factor; a_h, total pressure losses coefficient; K_R, PI controller's amplification factor; T_i, PI controller time constant; lambda (λ), tip speed ratio; R, wind turbine radius.

```
% wind_turbine_1.m
% control the frequency of a synchronous
% generator by using an electro hydraulic transmission
% respons of the system to perturbation (load variation)

clear;
qp=28; qm=4; Kp=2.8; Km=2.8; Tp=0.6; Tm=0.6; TA=1.6;
ngo=1500; MG=[1,2]; Ktg=1/150; ah=2.8; KR=2.8; Ti=1.2;
nto=[10,15,20,25,30];
for i=1:length(MG)
numv=-MG(i)*[ah*Ti*Tp/(qm*qm),ah*Ti/(qm*qm),0];
KKR= KR*Ktg*Kp*nto/qm;
denv=[TA*Ti*Tp,(TA+Tp)*Ti,Ti+KR*Ktg*Ti*Kp*nto/qm,KKR];
t=0:0.001:15;
[y,x,t]=step(numv,denv,t);
z=ngo+y;
plot(t,z);
xlabel('t (secunde)');
ylabel('n(rot/min)');
hold on;
end;
title('Step response for different loads'); grid;
```

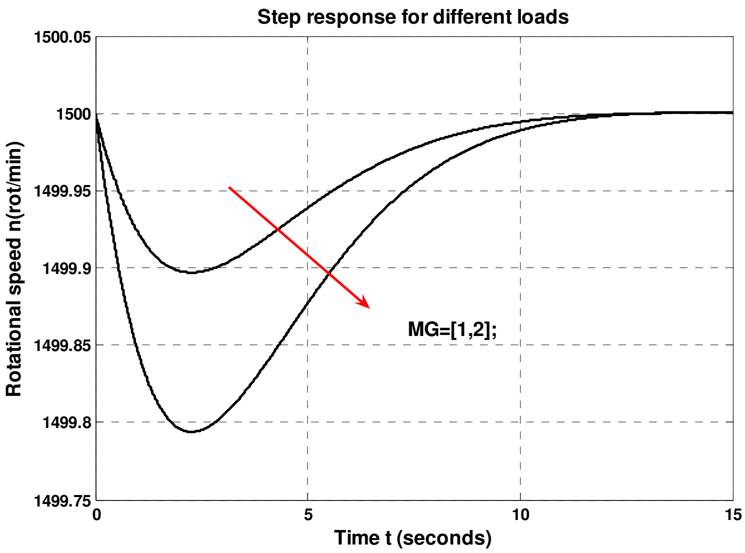

Figure 7. Step responses to different loads

6. Conclusions

The electro hydraulic transmissions are used in coupling the wind turbines, with the installed power more than 750 kW, with the synchronous generators at the electrical network because of the advantage of the frequency control for any values of the wind speeds.

The numerical simulations are used to demonstrate the opportunity of this technical method and the system performance, too, when the wind speed and the load is changing. A better efficiency, a less volume size and a better speed response are some of the advantage of using the electro hydraulic method comparing with the electro mechanical one. The control could be done to the hydrostatic motor to have a supplementary control in the power output limitation and to protect the wind turbine against the sever perturbation.

Acknowledgements

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