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Optimization of the Wind Systems, Based on the Maximum Wind Energy

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Abstract. The paper presents a optimization criteria for wind systems based on the maximum wind energy. The wind turbine (WT) and the synchronous generator with permanent magnets (SGPM) are modeled through an set of non-linear equation and the speed / mechanical angular reference speed ωref, at different wind speed, will be imposed to be that corresponding to the maximum speed of wind. The effectiveness of the proposed method is evaluated at the electric charge of the SGPM, that is represented by a converter (rectifier / inverter), connected to the electric grid

Keywords: mathematic models WT + SGPM, variable wind speed, estimation of the reference speed, maximum power

1. Introduction

The wind systems became techno – economic profitable, at wind speeds higher than 4 m/s. [1], [9]. As the wind speed is significant variable in time, the speed regulation has to be controlled: $n^* = \omega^* / 2\pi$ at the SGPM, so that the captured wind energy has to be maxim [5], [6], [11].

Next is analyzed the condition in that the mechanical power injected in the system, has to be maxim, in the condition in that the wind speed varies, figure 1.

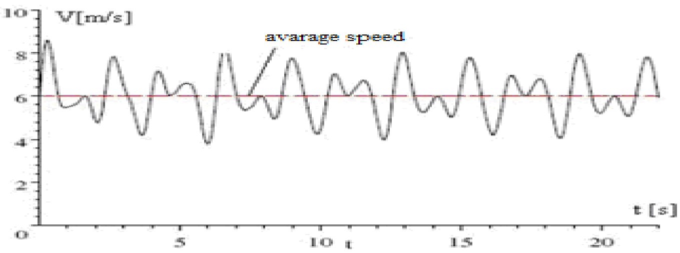

Fig. 1: Wind speed variation in time.

The mathematic model of the chosen wind speed example:

$$v(t) = 6 + \sin(3t) + \sin(5t) + 0.5e^{-0.1t}\sin(6t) \quad (1)$$

Due the rapid and significant variation of the wind speed and the tendency to function closer to the maximum possible power that the WT can give, the system (WT + SGMP) is a sensible time varied power source [7], which is considered disruptive for the power system if the SGMP debits in the given power and frequency system.

In an autonomous operation, the power fluctuations modify significantly the voltage and the frequency of the power system, and to keep them in their rated values, a rapid voltage adjustment, on the excitation of the

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synchronous generator, that has to be a DC and not a PM (permanent magnet) excitation, will be necessary [8].

The wind speed in the techno – economic exploitable field is $v = 4 \div 25$ [m/s], with the best results in the range $v = 12 \div 15$ [m/s] [9]. Because of the very large inertial moment J of the WT, the speed change on the SGMP is slow and therefore it can not track in time the rapid variation of wind speed as it would be required to work at the maximum power point. For this reason it is not possible to operate at the maximum power in the hall area [2].

The design of the control system, at variable wind speed, can consider only the dependence speed / mechanical angular velocity ω_{ref}, to the average speed, v_{med}, as below, figure 2:

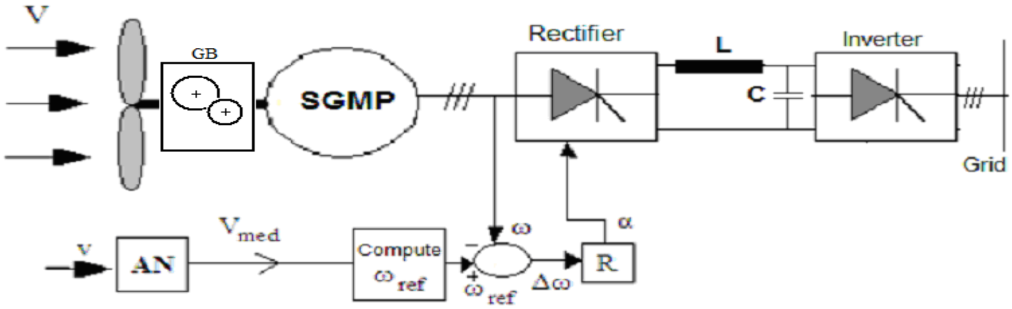

Fig.2 :Optimal control systems at maximum wind speed.

AN – anemometer measures that wind speed to obtain the average value in a T time period and, so that the reference speed can be computed $n_{ref}=\omega_{ref}/2\pi$. The speed measured at the SGPM, transmitted from the WT through the gear box (GB), obtain $\omega = 2\pi n$ and the difference $\Delta\omega = \omega_{ref} - \omega$, is the controller R input size, that, at his output, through α, the ignition angle of the phased thyristor rectifier, change the load of the generator SGMP, on the grid connected converter (rectifier and inverter) [7].

2. Turbines and generator models

The maximum power P that a wind turbine can develop at the wind speed v, depends approximately quadratic to the angular rotor speed ω (or Ω), as shown in figure 3. [4]

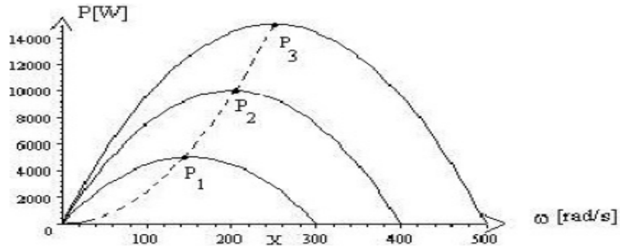

Fig. 3: Power variation with angular speed.

The control strategy for any wind power system that produce electric energy, requires to functions in the point Pk, corresponding to the maximum power [13].

The maximum that can be developed from the WT depends on cubed power of the wind speed:

$$P_{\max} = K_p V^3 = M_{TV} \cdot \omega \tag{2}$$

Given a linear mechanical characteristic, in the operation of the wind turbine [3], the dependence of the torque to the wind speed can be written as:

$$M_{TV} = aV^b \omega + cV^d \tag{3}$$

Analyzing the mechanical characteristics of the wind turbine WT, figure 4, experimentally obtained, the coefficients a and c of the wind turbine, are determined.

Writing this relationship: $M_{WT}=aV^b\omega+cV^d$ for two wind speeds, $v_1 = 5$[m/s] and $v_2 = 4$[m/s] in four functioning points $A_1(2,28)$ $A_2(9,0)$ for $v_1 = 5$[m/s] and $B_1(1,21)$, $B_2(7,0)$ for $v_2 = 4$[m/s], follows the next base form:

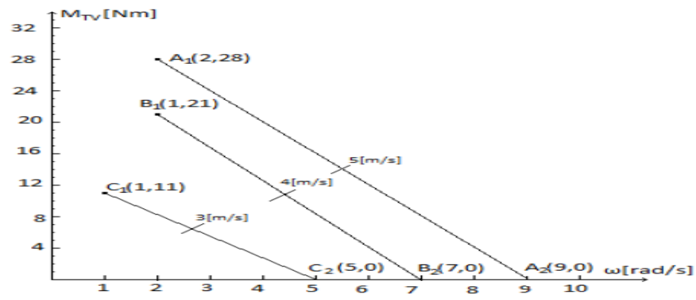

Fig. 4: Experimental mechanical characteristics of the WT.

$$M_{WT} = -1.526V^{0.598}\omega + 2.243V^{1,724} \tag{4}$$

A simplified form for the mechanical characteristic, such below, will be adopted:

$$M_{WT} = -1.5V^{0.6}\omega + 2.25V^{1,8} \tag{5}$$

The torque reduction M_{WT} at the generator shaft, at one transmission ratio, for example: 314 / 20, is done through the following transformations: $\omega_{WT} \rightarrow \omega_G(20/314)$ and M_{WT} at the generator shaft has to be multiplied with 20 / 314.

The expression of the torque developed by the wind turbine, reduce to the generator shaft, is:

$$M_{WT} = \left(-9.55\cdot 10^{-2}V^{0.6}\omega_G + 2.25V^{1,8}\right)\frac{20}{314} \tag{6}$$

In dynamic regime, the synchronous generator (SG), with DC excitation, is characterized in the orthogonal model, through the equations [6], [11]:

$$-U\sqrt{3}\sin\theta = R_d I_d + L_d\frac{dI_d}{dt} - \omega L_q I_q + M_E\frac{dI_E}{dt} + M_D\frac{dI_d}{dt} - \omega M_Q I_Q$$

$$U\sqrt{3}\cos\theta = \omega L_d I_d + R_q I_q + L_q\frac{dI_q}{dt} + \omega M_E I_E + \omega M_D I_D + M_Q\frac{dI_Q}{dt}$$

$$UE = M_E\frac{dI_d}{dt} + R_E I_E + LE\frac{dI_E}{dt} + M_{ED}\frac{dI_D}{dt}, \qquad 0 = M_D\frac{dI_d}{dt} + M_{ED}\frac{dI_E}{dt} + R_D I_D + L_D\frac{dI_D}{dt}$$

$$0 = M_Q\frac{dI_q}{dt} + R_Q I_Q + L_Q\frac{dI_Q}{dt}, \qquad J\frac{d\omega}{dt} = p_1\begin{bmatrix}(L_d - L_q)I_d I_q + M_E I_q I_E - \\ -M_Q I_d I_Q + M_D I_q I_D\end{bmatrix} - M_{motor} \tag{7}$$

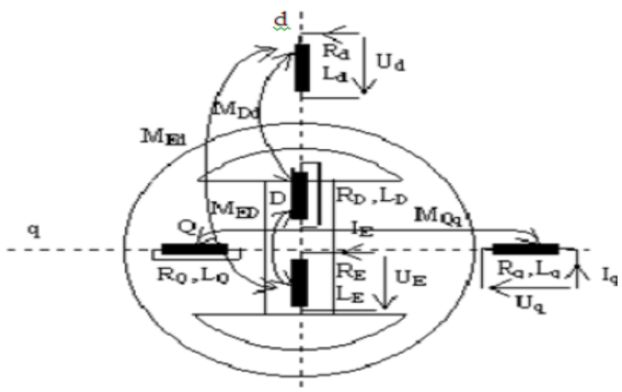

Fig. 5: Ortogonal model

The parameters of damping winding, R_D, L_D, R_Q, L_Q influence the duration of the transitory process. For the SG, the initial conditions (initial functioning point) are deducted from the algebraic system, defined by the initial torque M_{motor}:

$$-U\sqrt{3}\sin\theta = R_1 I_d - \omega L_q I_q,\; U\sqrt{3}\cos\theta = \omega L_d I_d + R_1 I_q + \omega M_E I_E,\; M_{motor} = p_1(L_d - L_q)I_d I_q + M_E I_q I_E \tag{8}$$

or in case of SGMP having the flux ψ_M:

$$-U\sqrt{3}\sin\theta = R_1 I_d - \omega L_q I_q,\; U\sqrt{3}\cos\theta = R_1 I_q + \omega L_d I_d + \omega\psi_M,\; M_{motor} = p_1(L_d - L_q)I_d I_q + \psi_M I_q \tag{9}$$

3. Simulation results and discussion

The system SGPM + WT works initially, for example, at the angular speed ω, having the value: ω_{SGPM}= 314[rad/s] or ω_{WT} = 20[rad/s], being therefore at the maximum power point P_{max} for v = 5 [m/s]. The mechanical characteristics, at different wind speed v, for WT, are (figure 6):

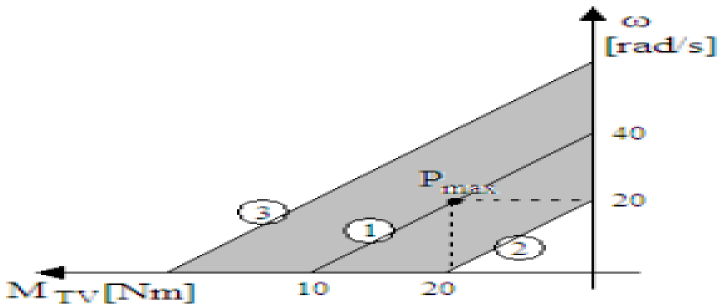

Fig. 6: Mechanical characteristics of the WT

The mechanical characteristics change with wind speed, as it can be seen in figure 6: curve one for v = 5 [m/s], curve two for v = 3 [m/s] and curve three for v = 7 [m/s]. For a sinusoidal wind variation v = (5+2sin0.3t), the mechanical characteristics of the WT are in the shaded area.

The reference speed / mechanical angular speed, results from the energy balance:

$$\int_0^T M_{TV}(t)\omega(t)dt = \int_0^T M_{SGPM}(t)\omega(t)dt \tag{10}$$

The value of ω_{ref}, is determinate through the maximization of the mechanical energy W_m on a time period T resulted from the wind variation:

$$Wm=\omega_{ref}\int_0^{21} M_{WT}dt=\int_0^{21}\left(-9.541\cdot10^{-2}\cdot V^{0.6}\cdot\omega_{ref}+2.25V^{1.8}\right)\frac{20}{314}dt=\omega^2_{ref}\int_0^{T1}\left(-9.541\cdot10^{-2}\cdot V^{0.6}\right)\frac{20}{314}dt+\omega_{ref}\int_0^{T1}\left(2.25\cdot V^{1.8}\right)\frac{20}{314}dt \tag{11}$$

By $dWm/d\omega = 0$, it will be obtain:

$$\omega_{ref} = \frac{\int_0^T \left(2.25\cdot V^{1.8}\right)\frac{20}{314}dt}{2\int_0^T \left(9.541\cdot 10^{-2}\cdot V^{0.6}\right)\frac{20}{314}dt} \tag{12}$$

By the wind speed change in form of: v_1 = a + bsin(2π/T)t= (10+2sin0.3t), the following result is obtain: $\omega_{ref} = 189.75[rad/s]$. At this value of the mechanical angular speed ω_{ref}, the average torque of the wind turbine M_{WT}, in a time period of T = 21[s], has the value: $M_{WT} = 4.5865$ Nm.

The torque average value of a WT is equal to that of the generator M_G, and therefore M_G = -4.5865[Nm]. In this conditions, in stationary regime, from the algebraic system

$$-RI_d = 1.6I_d - \omega\cdot 0.08I_q,\ -RI_q = 1.6I_q + \omega\cdot 0.07I_d + \omega\psi_M,\ M_G = -0.01I_dI_q + \psi_M I_q$$
$$\omega = 189.75,\ \psi_M = 1.3,\ M_G = -4.5865,\ R = 65.749,\ I_q = -3.5068,\ I_d = -0.7904 \tag{14}$$

the generator SGPM load results R_1=1.02[Ω] and R_2=65.749[Ω].

Getting two solutions for R, the problem is to choose the right solution. The operation of the WT + SGPM system is stable, at values of the resistance load. The voltage and current values on the generator, have the following values: U = 236.35 [V], I = 3.5948[A]. Those values for voltage and current are obtained through the rectifier control.

The reference speed / mechanical angular speed ω_{ref}, is extremely important because it allows an optimum control of the system (WT + SGMP), so that the maximum of mechanical energy is extracted, by on alternative wind speed.

Next the paper presents the dynamic behaviour of the system. The initial considerate conditions, are ω_{ref} and $M_G = M_{WT}$, where $R_{(0)}$= 65.749[Ω]. The following results are obtained:

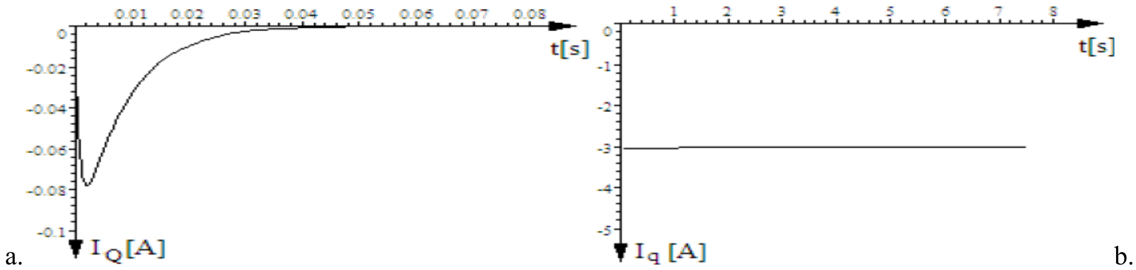

Fig. 7: a. Variation of the depreciation current b. Variation of the stator current

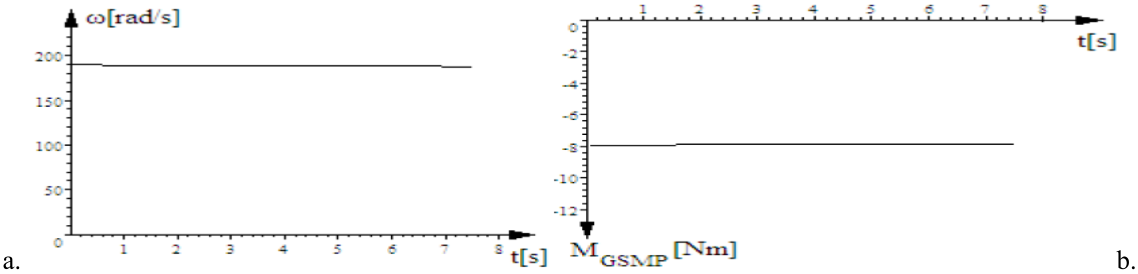

Fig. 8: a. Variation of mechanical angular speed b. Variation of the electromagnetic torque

From those upper presented diagrams, the time variation of the main system sizes can be followed: deprecation current, stator current, mechanical angular speed and the electromagnetic torque**.** The modifications of a time interval of 8[s] are small, confirming that the systems (WT + SGPM) have a high mechanical inertia, so that the influence of the damping windings, is reduced [10].

4. Conclusions

The article presents a simple and useful method of calculation of the load at the electric synchronous generator with permanent magnet, to achieve the optimum conditions, imposed by the operation of the wind turbine at the maximum captured energy. The end of the paper presents the behavior of the system (WT + SGPM) in dynamic conditions to sudden changes in electric charge, seen the inertial character, which is given by the large mass in rotating moving.

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