TOWARDS AN OVERALL SIMULATOR FOR A SYNCHRONOUS WIND ENERGY SYSTEM

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1. Introduction – The amount of electrical energy obtained from renewable sources, specially wind energy, is rising quickly. The interface of this distributed generation with the electrical network will have soon an important influence on control, power quality and voltage stability issues of the whole energy net. In order to be prepared to that change it is necessary to simulate, with a sensible accuracy, the transient events, which happen during normal operation or during faults, and have influence in either net or inner variables. So in this way, it is important to model a wind energy system, taking into account every subsystem that have a significant influence over the transient behavior of the compound system.

Some important and recent papers are oriented to analyze the stability [1] and the power quality of the wind systems [2]. In the first one, a doubly fed generator is analyzed from an electrical stability point of view; and in the second one the RMS values of the main electrical variables have been simulated in an overall wind energy system. An interesting paper describing the transient problems in relation with the grid integration of wind turbines can be seen in [3].

In this paper, as a preliminary design of an overall simulator, a variable speed system with a wound rotor synchronous generator is analyzed and a connection of the windmill with a variable wind is simulated.

2. Results and Discussion - The full system has been divided in 4 subsystems: aerodynamic, mechanical, generator and electrical load subsystems, in order to study them in a separate way.

Generator model has been developed starting from modelization done in [4] where the magnetic saturation effects are assume to be negligible. This assumption is made for convenience in analysis, however in some cases saturation effects are important, so it will have to be corrected in further papers. With these considerations a non dimensional system of equations for the dq0 reference frame is found:

$$e_d = \frac{d\psi_d}{dt} - \psi_q \cdot \omega_g - R_a \cdot i_d \qquad e_{fd} = \frac{d\psi_{fd}}{dt} + R_{fd} \cdot i_{fd}$$

$$e_q = \frac{d\psi_d}{dt} + \psi_d \cdot \omega_g - R_a \cdot i_q \qquad 0 = \frac{d\psi_{kd}}{dt} + R_{kd} \cdot i_{kd}$$

$$e_0 = \frac{d\psi_0}{dt} - R_a \cdot i_0 \qquad 0 = \frac{d\psi_{pq}}{dt} + R_{pq} \cdot i_{pq}$$

$$T_g = e_d i_d + e_q i_q + 2 e_0 i_0$$

where e_d, e_q and e_0 are the direct, quadrature and homopolar voltage components, respectively; i_d, i_q and i_0 are the current components of the stator circuits; i_{fd} and e_{fd} are the current and the voltage in the field winding; i_{kd} and i_{pq}, where k = 1, 2, ..., n_d and p = 1,2, ..., n_q, are the current components of the $n_d + n_q$

equivalent damper circuits in the rotor; ω_g is the angular velocity of the generator rotor; T_g is the electromagnetic torque; and finally, the different inductances and resistances are build parameters of the generator and the magnetic flux expressions are given in [4].

The electrical load subsystem is the relationship between stator voltage and current components and the rotor position. It represents the interaction between electrical generator and energy consumers. We have used a isolated electric load modeled by a 3 phase symmetrical RL load that is not connected to earth, then we have the following relations

$$e_d = R \cdot i_d + L \frac{di_d}{dt} - L \cdot \omega_g \cdot i_q \quad ; \quad e_q = R \cdot i_q + L \frac{di_q}{dt} + L \cdot \omega_g \cdot i_d \quad ; \quad i_0 = 0$$

Mechanical model consists of a soft shaft representation and a two masses twist model, one for the turbine rotor and one representing the generator rotor. It has been found that it is possible to obtain good results from an electrical point of view using this model [5]. The equations for this model can be written in the form

$$2 H_r \frac{d\omega_r}{dt} = T_t - K(\theta_t - \theta_g) - c(\omega_g - \omega_r) \quad ; \qquad \frac{d\theta_r}{dt} = \omega_r$$

$$2 H_g \frac{d\omega_g}{dt} = K(\theta_t - \theta_g) - T_g + c(\omega_g - \omega_r) \quad ; \qquad \frac{d\theta_g}{dt} = \omega_g$$

where Hg and Hr are the non dimensional inertia parameters of respectively the generator and the wind turbine; K and c represents the stiffness and the damping coefficient of the shaft connecting both masses; θ_t and θ_g are respectively the angular position of turbine and generator rotors; and ω_t is the wind turbine rotational speed.

Lastly, the aerodynamic subsystem relates the thrust force in the turbine rotor with the wind speed. The model described in [6], that describes that relation in terms of the power coefficient Cp, has been used.

Assembling all of these subsystems, it is found the complete system, which consists in a non linear ordinary differential equation system of $6+n_d+n_q$ equation with the following state variable vector:

$$\bar{x} = \left(i_d, i_q, i_{fd}, i_{1d}, \ldots, i_{n_d d}, i_{1q}, \ldots, i_{n_q q}, \omega_g, \omega_r, \Delta\theta \right)$$

This differential equation system has a "stiff" numerical behavior.
An appropriate method has been chosen in order to make a numerical integration of the previous system [7], this method is compound of a initialization stage and an ordinary stage. The first one is done by an Euler method with step size h^k. And the ordinary stage where variables are calculated through a predictor-corrector pair that is being applied in PECE mode. This method uses the explicit k-step Adams-Bashforth method as predictor and the implicit k-step BDF as corrector, which is solved using a fixed point iteration.

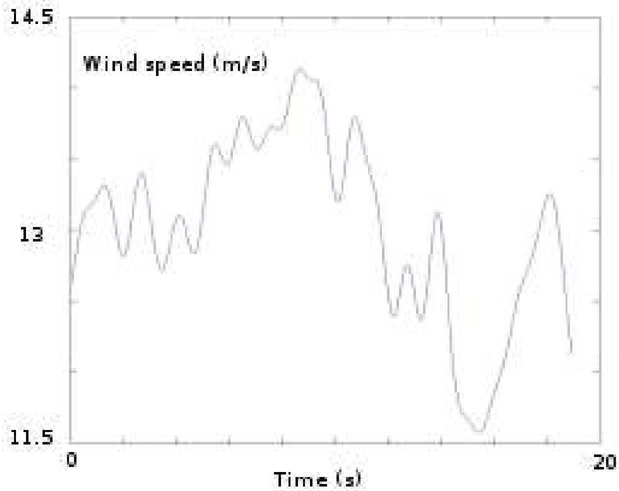


Figure 1. Temporal distribution of the wind velocity

As example, a load connection of the windmill with a turbulent wind is simulated. A rigid shaft is used in this simulation.

In figure 1 the turbulent wind during the connection is shown. The figure 2 displays the power generated by the system.

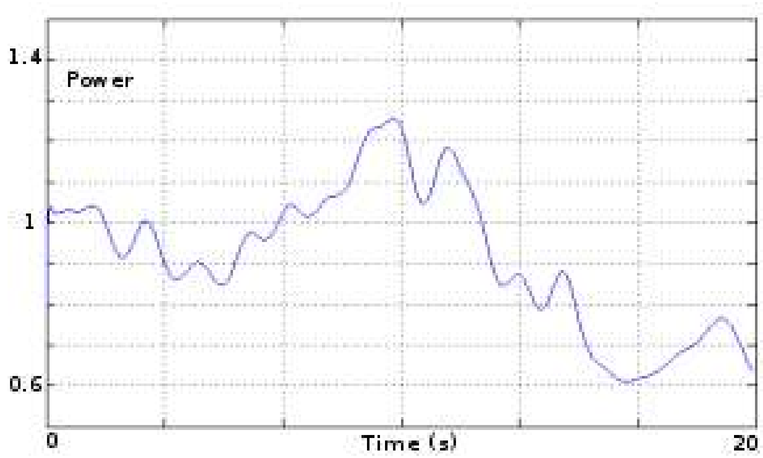


Figure 2. Power consumed in the RL load.

Figure 3 shows the rotational speed of generator rotor, that speed appears zoomed in figure 4, in order to show the transient response to the connection. These figures shows that first there is a quick transient due to the connection of the generator to the load and after, a dynamic fluctuation caused by the wind turbulence.

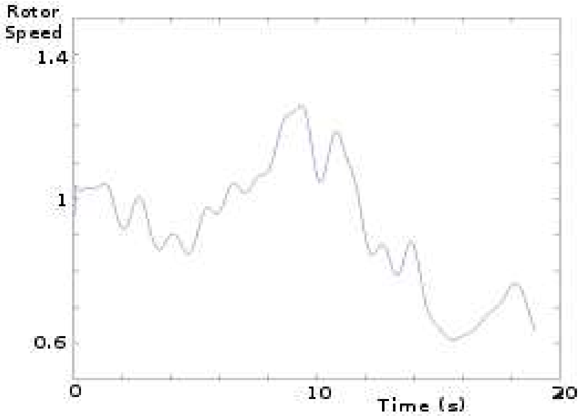


Figure 3. Angular velocity of the rotor.

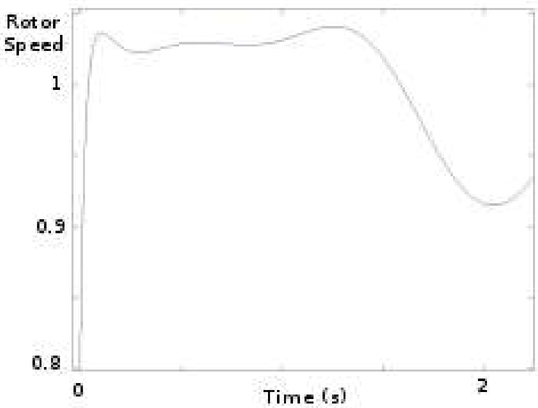
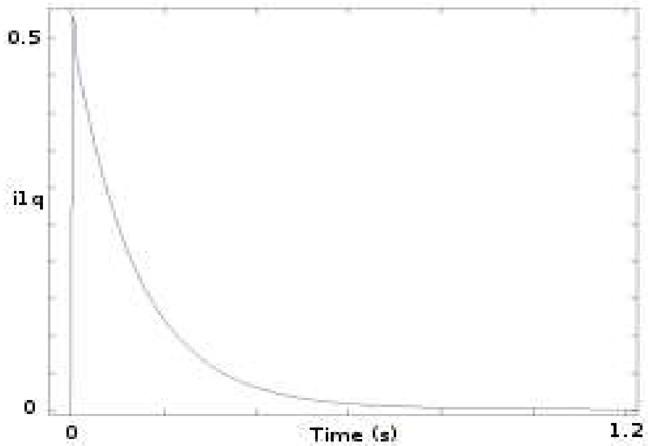


Figure 4. Angular velocity of the rotor in the first seconds.

This behavior is reproduced too in the direct current, the field winding current, the quadrature current (but in a damped way) and in other dependent variables like the generated power. However, as we can see in figure 5, that fluctuation is insignificant in the currents of the damper circuits. The current of these circuits are very near to zero, after the connection transient has finished. Thus, the effect of these amortisseur circuits could be neglected in future simulations oriented to obtain the wind turbulence effects in energy quality, but not in the case of net faults or other grid disturbances.



3. Conclusions – It has been developed a suitable model to study the electrical transient of a windmill with a rotor fed synchronous generator connected to an RL load, which represents an isolated electrical load.
A simulator program has been made using C (GNU C).
A visual and comfortable MATLAB interface for the C program has been designed reading in order to make easier its use.
Some simulations have been shown using that new tool and they showed that it is possible to neglect damper circuits when analysing problems of flicker emission or harmonic current injection due to the variations in the wind velocity, but they could have a considerable influence in faults or grid disturbances like the connection of the load shown in this paper.

Some open problems which are being attacked are the following:
The upgrade of the aerodynamic subsystem, including dynamic stall effects and the effects of the spatial distribution of wind speed.
The inclusion of a dynamic model for the usual electronic devices.

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