THE ANNALS OF "DUNAREA DE JOS" UNIVERSITY OF GALATI
FASCICLE III, 2002 ISSN 1221-454X
ELECTROTECHNICS, ELECTRONICS, AUTOMATIC CONTROL, INFORMATICS

REAL TIME WIND TURBINE SIMULATOR BASED ON FREQUENCY CONTROLLED AC SERVOMOTOR

Nicolaos Antonio CUTULULIS, Mihai CIOBOTARU, Emil CEANGĂ, Mina Emil ROŞU

[2] *University "Dunarea de Jos" of Galati, Faculty of Electrical Engineering, Domneasca-57, Galati-6200, ROMANIA*

Abstract: This paper is a contribution to the development of a real time wind turbine simulator. The simulator is designed to generate wind power on its shaft, and provide the static and dynamic characteristics of a given turbine. The general structure of the simulator is composed of two subsystems: a “soft simulator” which realizes the real time simulation of the wind turbine, on the basis of the mathematical model, an electromechanical tracking system which receives the reference signal from the soft-simulator, and provides a measurable output variable transmitted as response variable to the soft-simulator. The work concerns a wind turbine simulator using a tracking system realized on the basis on a frequency controlled AC servo-motor. This servo-motor is mechanically coupled with a pendulum machine, which realises the shaft torque of the electrical generator. The experimental system is built around the DS1103 PPC Controlled Board (dSPACE), which offers a rapid control prototyping, by Matlab-Simulink software tools. Experimental results from the real time WTS are presented.

Keywords: Windmills, simulator, real time system, digital signal processor, AC servo-motor.

1. INTRODUCTION

A real time wind turbine simulator (RTWTS) is conceived to generate the “wind power” on its shaft, providing the static and dynamic characteristics for a given turbine. It eliminates the difficulties due to the uncontrollable weather conditions, in the experimental studies concerning the wind power system optimization. There are different categories of real time wind turbine simulators, depending on their conception approach:

Simulators based on the current control of DC motor (Nunes, *et al*, 1993; Battaiotto, *et al*, 1996; Rodriguez-Amendo, *et al*, 1998). The most usual simulator structure is based on the DC motor current control. This current is considered as the electrical image of the torque developed on the shaft. The set point of the current loop is obtained according to a mathematical model that includes different dynamic effects, produced by inertia, elastic coupling, etc.

Simulators with a general structure, using any type of servomotor (Nichita, *et al*, 1998; Diop, *et al*, 1999). In this approach, the RTWTS structure consists in two sub-systems:
- a real time software simulator (RTSS hereafter), that implements the static and dynamic characteristics of a wind turbine:
- an electromechanical tracking system (ETS hereafter), which receives the reference signal (set point) from the RTSS and “offers” a shaft which has the static and dynamic characteristics of the wind turbine.

The simplified block diagram, which illustrates the RTWTS’s architecture, is given in Figure 1. The used symbols are: $v(t)$ – wind velocity, $\beta(t)$ – blades pitch angle, W_G – numerical wind generator, D – controlled electric drive, of any type, T_r – transducer for mechanical variables measured on the shaft, C – controller, EG – electric generator, tested with the simulator.

This paper was recommended for publication by Ion BIVOL

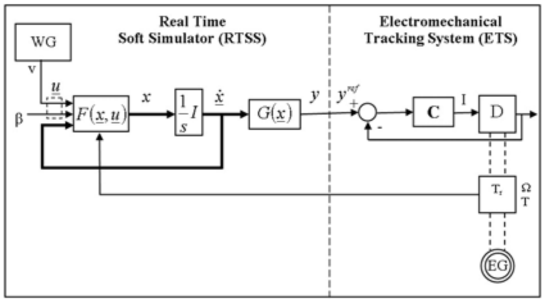

Figure 1. RTWTS's architecture

The RTSS is based on the mathematical model of the wind turbine, in the state description

$$\dot{x} = F(x,u) \quad (1)$$

$$y = G(x) \quad (2)$$

where x, u are the state vector and the input vector, respectively. The output variable y is a mechanical variable, which characterizes the wind turbine's behaviour on its shaft.
Depending on this reference variable, the simulator may be used with a speed control strategy, when y is the shaft speed reference and T_r is a torque transducer (or a torque estimator), or with a torque control strategy, when y is the shaft torque reference and T_r is a speed transducer.
This paper concerns a wind turbine simulator using a tracking system realized on the basis on a frequency controlled AC servo-motor. The paper is organized like in the following. In Section 2 the control structure of the implemented RTWTS is presented. Section 3 presents the experimental system, built around the DS1103 PPC Controller Board (dSPACE), and, finally, some experimental results are illustrated.

2. CONROL STRUCTURE OF RTWTS

The wind turbine's simplest dynamic model is given by its motion equation:

$$J\frac{d\Omega}{dt} = T_w(\Omega, v) - T_l(\Omega) \quad (3)$$

where: Ω - the shaft rotation speed, v - wind velocity, J - the total moment inertia, $T_w(\Omega,v)$ - the wind torque characteristic, $T_l(\Omega)$ - the static characteristic of the electrical generator. The wind torque is calculated using the relation

$$T_w = \frac{1}{2}\cdot\rho\cdot\pi\cdot C_T(\lambda)\cdot v^2\cdot R^3 \quad (4)$$

where R is the blade radius, λ is the tip speed ratio

$$\lambda = \frac{R\cdot\Omega}{v} \quad (5)$$

and $C_T(\lambda)$ is the torque coefficient characteristic. This characteristic has been modelled by a six order polynomial regression:

$$C_T(\lambda) = a_0 + \sum_{i=1}^{6} a_i\cdot\lambda^i \quad (6)$$

In our experimental studies, the speed control strategy has been adapted. The simplified block diagram of the implemented RTWTS is given in Figure 2. The used symbols axe: i – the transfer ratio of the gear box, *AC-M* – the frequency controlled AC motor, α – the slope of the AC motor's mechanical characteristic. The AC motor control is made in open loop structure, by the frequency f. This variable is the response of the RTSS, corrected with frequency deviation, Δf, of the AC motor's mechanical characteristic.

3. RTWTS DEVELOPMENT

The hardware block diagram of the RTWTS is presented in Figure 3. The pendulum machine

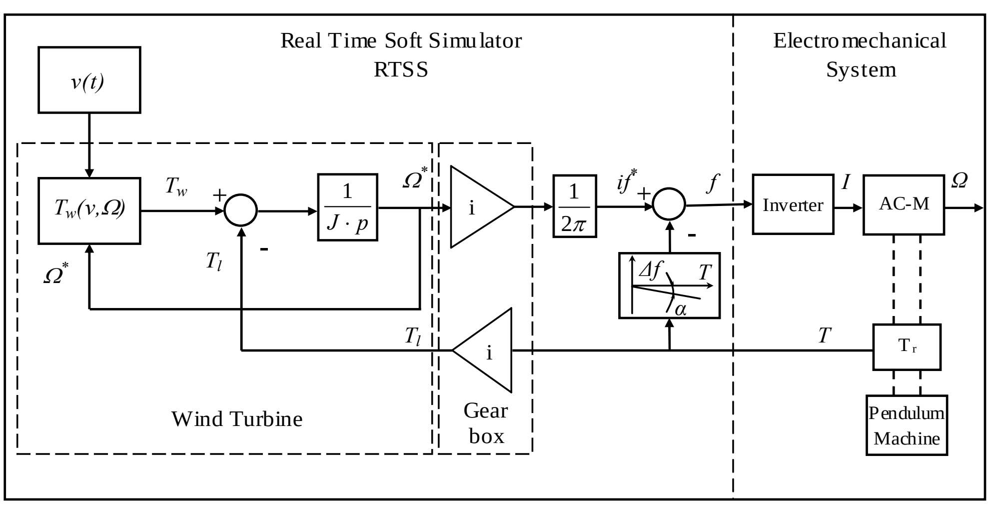

Figure 2. Simplified block diagram of the implemented RTWTS

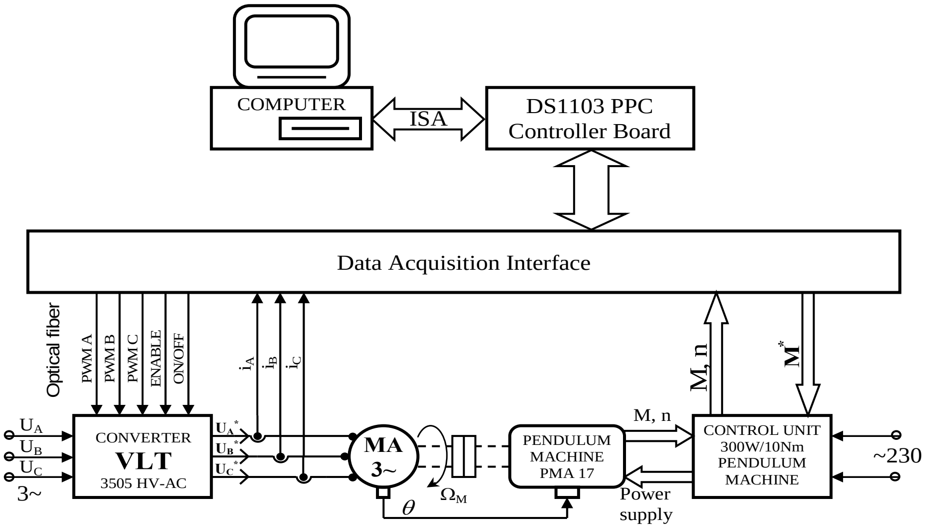

Figure 3. Hardware structure of the implemented RTWTS

PMA17 replaces, during tests and development with the simulator, the electrical generator of the wind system. It has its control unit, containing analogical torque and speed control loops. This controlled pendulum machine realizes the electrical generator characteristic. In particular, we used a linear load torque characteristic.

The DS1103 PPC controlled board (dSPACE) is equipped with a Power PC processor for fast floating-point calculation at 400 MHz. With Real-Time Interface (RTI), programming has been done via Matlab-Simulink.

In Figure 4 and Figure 5, two software blocks are plotted:

- part of the RTST (wind turbine model);
- part of the Sine Triangle with Third Harmonic (STTH) block, which synthesises intermediate control signals for DSP, in view of PWM based inverter control. The inputs for the algorithm are: the reference frequency for the inverter and the sampling period T_s. The outputs are the intermediate signals, which are presented as the control inputs of the DSP.

4. EXPERIMENTAL RESULTS

The used graphic interface – ControlDesk, offered by the DS1103 PPC Controller Board, is an integrated tool to control, monitor and automate Simulink and real-time experiments, which has permitted the use of virtual instruments and improved control management software. A capture of this graphic interface is plotted in Figure 6

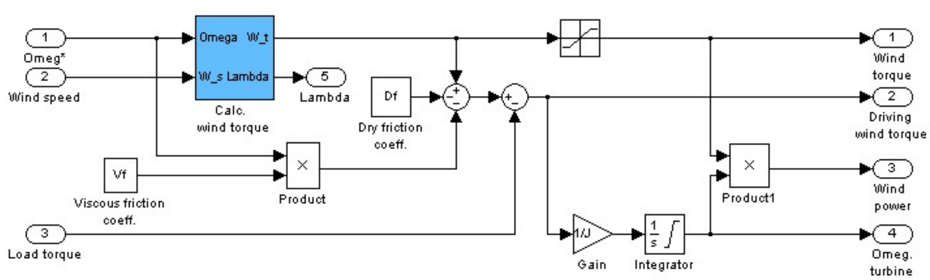

Figure 4. Wind turbine model

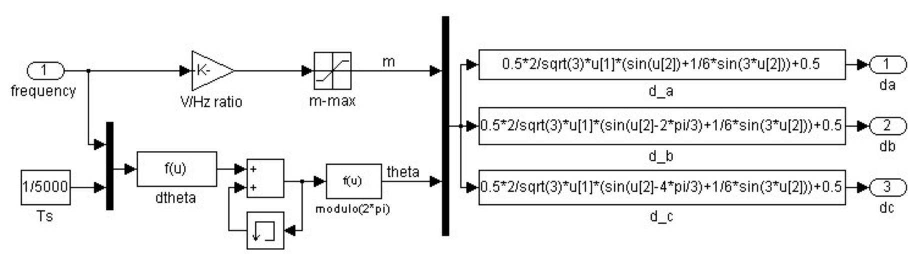

Figure 5. STTH harmonic algorithm based modulator

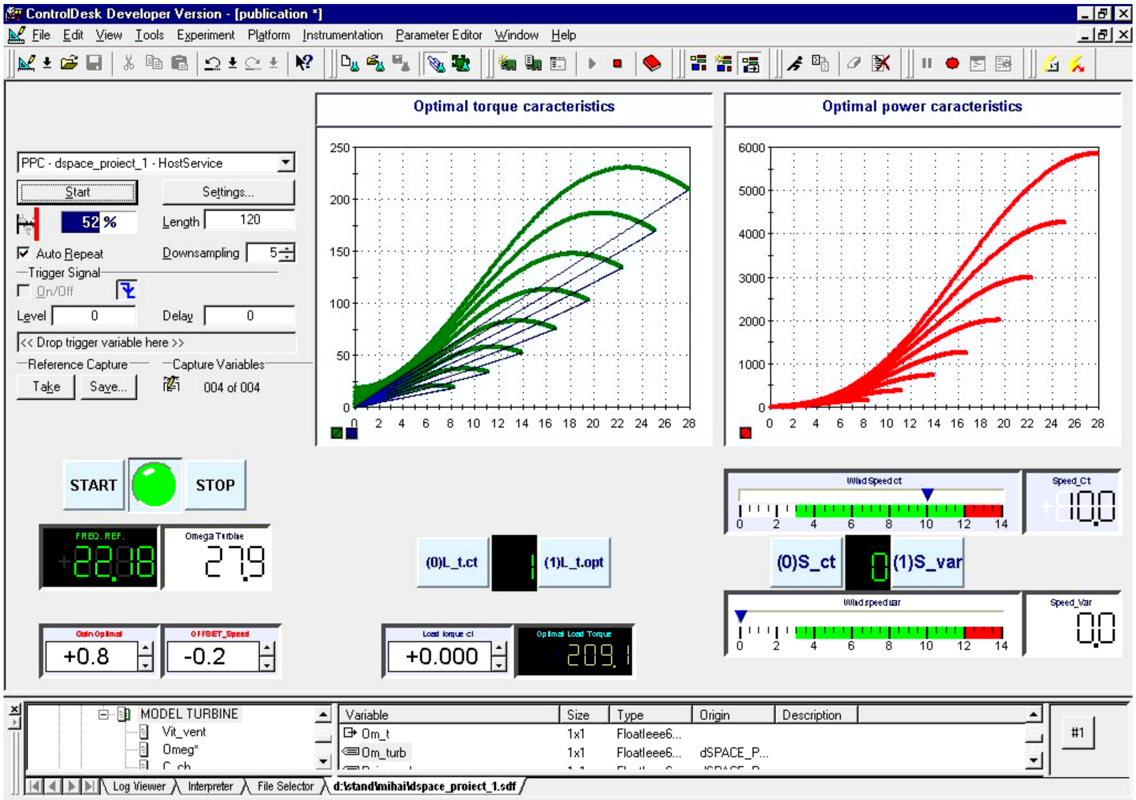

Figure 6. Graphic interface of the implemented RTWTS

In Figure 7, Figure 8 and Figure 9 are plotted: starting regime of the wind turbine, dynamic behaviour for windspeed steps and for load torque steps, respectively. The use of the RTWTS in studies concerning the optimal control of wind energy conversion is illustrated in Figure 10 and Figure 11, which present the obtaining of the optimal torque and power characteristics, respectively.

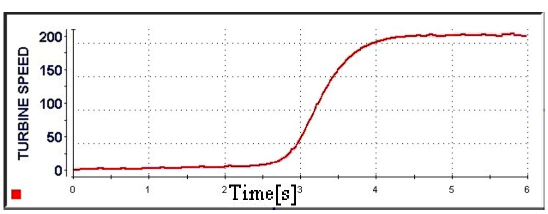

Figure 7. Starting wind turbine

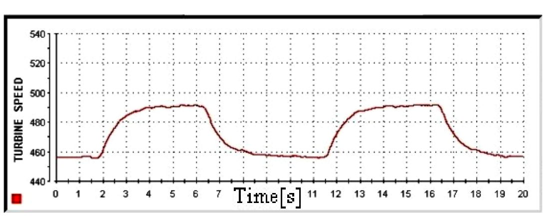

Figure 8. Wind turbine's behaviour for windspeed steps

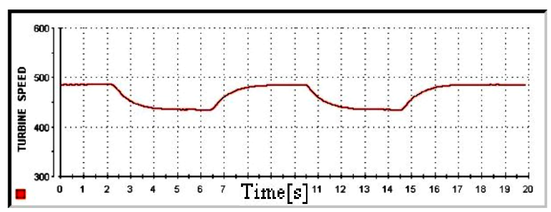

Figure 9. Wind turbine's behaviour for load torque steps

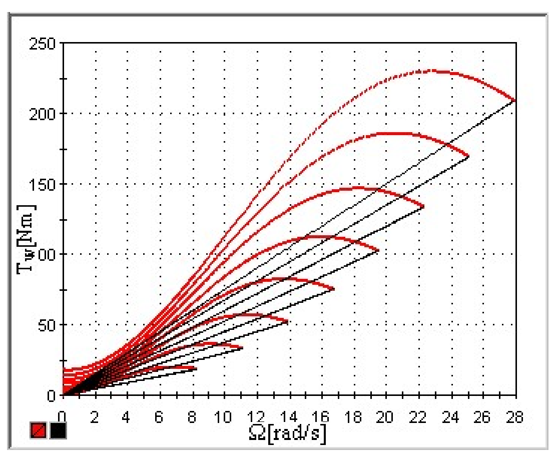

Figure 10. Optimal torque characteristics

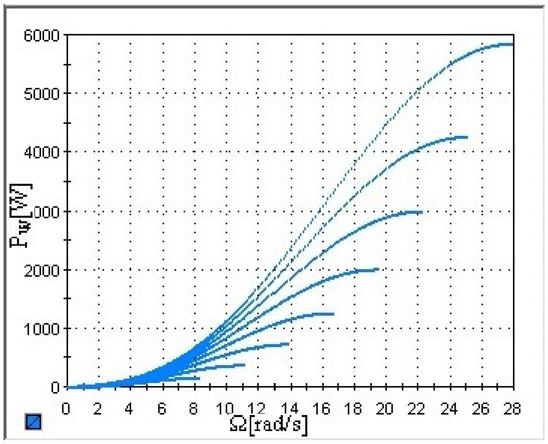

Figure 11. Optimal power characteristics

5. CONCLUSIONS

This paper shows a method for the realisation of a RTWTS based on AC servomotors. By using the DS1103 PPC Controller Board (dSPACE) it was possible to realise a wind turbine simulator with high performances concerning the real-time controlling and monitoring facilities.

6. REFERENCES

Battaiotto, P.E., R.J. Mantz, P.F. Puleston, “A Wind Turbine Emulator Based on a Dual DSP Processor System”, Control Engineering Practice, Vol.4, No.9, 1996, pp. 1261-1266.

Nichita, C., A.D. Diop, J.J. Belhache, B. Dakyo and L. Protin, “Control Structures Analysis for a Real Time Wind System Simulator”, Wind Engineering, Vol.22, No.6, 1998, pp. 275-286.

Rodriguez-Amenedo, J.L., F. Rodriguez-Garcia, J.C. Burgos, M. Chinchilla, S. Arnalte and C. Veganzones, “Experimental Ring to Emulate Wind Turbines”, Proceedings of ICEM, Vol.3/3, pp.2033-2038,1998, Istanbul, Turkey.

Diop, A.D., C. Nichita, J.J. Belhache, B. Dakyo and E. Ceanga, “Modelling of a Variable Pitch” HAWT, “Characteristics for a Real Time Wind Turbine Simulator”, Wind Engineering, Vol.23, No.4, 1999, pp.225-243.

Nunes, A.A.C., P.C. Cortizo and B.R. Menezes, “Wind Turbine Simulator Using a DC Machine and a Power Reversible Converter:, Proceedings of ICEMA, pp. 536-540, 1993, Adelaide, Australia.