

A New Fuzzy Logic Controller to Improve the Captured Wind Energy in a Real 800 kW Variable Speed – Variable Pitch Wind Turbine

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Abstract-This paper presents an application of fuzzy controllers for improving the captured wind energy and the performance of variable speed wind turbines using fuzzy controllers. The simulated fuzzy model has been satisfactorily implemented using a programmable logic controller as the designed fuzzy controller. Transition between power optimization and power limitation of the wind turbine is greatly improved especially in the rated wind speed working conditions. Fuzzy controller also permits to increase captured wind energy in low and high wind speed.

I. INTRODUCTION

It is known that variable speed, horizontal axis grid integration wind turbines using torque and blade-pitch control improve the captured wind energy [1][2][3][4]. The use of variable speed generators in this kind of systems allows the reduction of sudden load surges and permits to extend the range of operation. The pitch control of a wind turbine makes possible to regulate energy extraction [4]. Maximum power coefficient C_p and optimum tip-speed-ratio λ will be achieved using blade pitch control.

The wind turbine performance with torque and blade-pitch linear control can be enhanced by using a controller based

on fuzzy logic. Proper design of fuzzy controllers makes them superior to traditional linear control techniques [5][6][7]. Relevant fuzzy logic applications can be found in non-linear control because a fuzzy controller can outperform traditional PI and PID controllers [8][9][10].

This paper starts with a brief introduction. In the following section the description of the real dynamic system with the technical characteristics and control methods of the wind turbine is explained. In section 3 the simulated and implemented fuzzy model is described. In section 4 simulation results at different wind speed inputs are shown, specially in rated wind and high wind working conditions. The results using the linear and the fuzzy control model are compared. Conclusions are included in the last section.

This work presents a possibility for exploiting wind energy optimally adapting appropriately the performance of the system to the grid integration.

II. DESCRIPTION OF THE DYNAMIC SYSTEM

A non-linear dynamic model of a real wind turbine from the inputs is used. In reference [11] the simulation model used in this work is explained.

A. Technical characteristics of the real wind turbine

The prototype AE-52 of 800 kW wind turbine of the Monteahumada wind farm is situated on Tarifa (Spain). This

variable speed and blade-pitch wind turbine presents the advantages of high performance and high reliability.

The power converter used in this application is shown in Fig. 1.

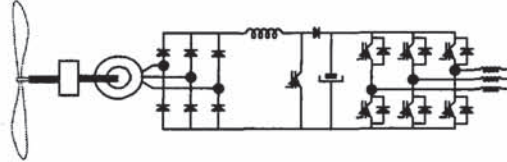


Fig. 1. The power converter used in this application

A four poles synchronous machine with a gearbox of 1:58,344 is used. Where the function of the gearbox is to adapt the low rotation speed of the rotor axis to the higher one in electric generator. The cost of these systems is justified if, by adjusting the turbine speed to the prevailing wind speed, the compatibility of the plant to the environment and the grid can be improved, leading to a higher energy output and reduced drive-train loading.

A frequency converter decouples the generator from the grid, allowing the rotor speed to vary by controlling the generator reaction torque. The power converter is used to adjust the generator frequency and voltage to those of the grid, particularly in these variable speed systems. This power converter works as a driver, controlling the torque generator. The power converter used (Fig. 1) in this wind turbine consists in a non controlled diode rectifier in series with a boost converter and finally a three phase inverter to delivery the power to the utility grid. IGCT's semiconductor have been used on the boost converter and the three phase inverter due to the power requirement of the system. It is capable of supplying the variable-frequency electrical energy from the turbine generator to a grid of almost constant frequency and voltage.

The voltage source is 1000V and the considered grid frequency is 50Hz \pm 2%.

The rated power is 800 kW. The rotor has three LM 25,1 p blades. The rotor diameter is 52 m. Wind turbine starts to provide power from 3,5 m/s wind speed. Maximum power is given for nearly wind speed to 12m/s. Wind speed higher than 25 m/s is recommended to brake wind turbine.

The tower height is 48,5 m and the wind turbine total weigh is 95000 kg. In Fig. 2. MADE AE-52 wind turbine is shown.

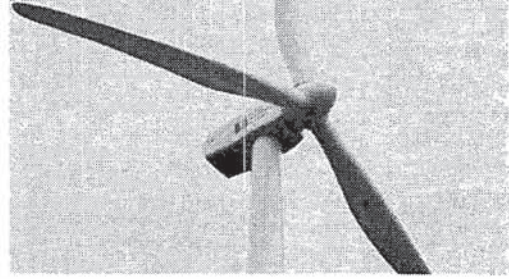


Fig. 2. MADE AE-52 wind turbine

B. Methods of control of the wind turbine

Reliable operation must be guaranteed for wind power plants in all operations conditions. As well as a appropriate dimensioning of the wind turbine, drive train and tower, the control and management systems are of particular importance.

The following equation provides the expression of the aerodynamic torque Q_L of the wind turbine:

$$Q_L = \rho C_p(\lambda, \beta) \pi R^5 \omega_L^2 / 2 \lambda^3 \quad (1)$$

where ρ is the air density, R is the radius of the blade, ω_L is the rotational speed of the low shaft, λ is the tip ratio defined as $\lambda = \omega_L \cdot R / W$, where W is the wind speed, b is the blade pitch, and C_p is the power coefficient which characteristic is shown in Fig. 3.

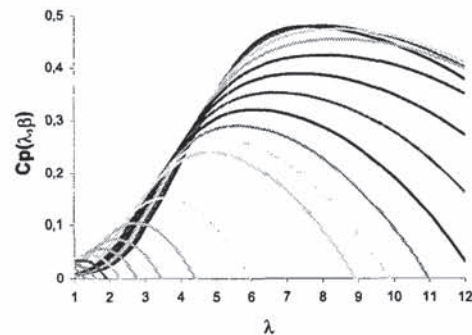


Fig. 3. $C_p(\lambda, \beta)$ characteristic

For steady state operation at tip speed ratio for optimum power coefficient, C_{p_0} , the equation can be reduced to:

$$Q_L = \rho C_{p_0}(\lambda) \pi R^5 w_L^2 / 2\lambda_0^3 = K_\lambda w_L^2 \quad (2)$$

This equation is often used for open loop variable speed control of a wind turbine. When the generator torque demand is set to $K_\lambda w_L^2$. Where w_L is the measured generator speed. This ensures that in the steady state the turbine will work with an optimum tip speed ratio and the corresponding maximum power coefficient. If pitch angle control is used in the system along with variable speed, better performance is obtained. The power and speed can be limited through rotor pitch regulation. In reference [11] the figure of the variable speed pitch regulated operating curve is explained.

III. FUZZY LOGIC CONTROLLER

The main objective of replacing linear by fuzzy control is to improve the speed control and captured energy of the MADE AE-52 800 kW wind turbine.

The developed control system has been integrated a fuzzy controller for torque and blade pitch control. The fuzzy sets have been heuristically defined. Given the rules and membership functions, the fuzzy controller produces the crisp and continuous nonlinear input/output (I/O) map [10].

The inputs of the fuzzy controller are the speed error and the measured rotor speed. The outputs are the reference angle and the reference electrical torque. The fuzzy controller employs normalized membership functions. The fuzzy rules and membership functions have been designed to optimize the captured power at low wind speed and to limit the captured power at high wind speed. Besides, the transition between the control regions is improved.

IV. SIMULATION RESULTS

In this work, the fuzzy control strategy as well as allows to improve the energy capture in low and high wind speed, it can also enhance performance in the transition between power optimization and power limitation in rated wind speed. This model has been implemented using a specific wind turbine software (BLADED) by Garrad-Hassan Ltd.(Fig. 4).

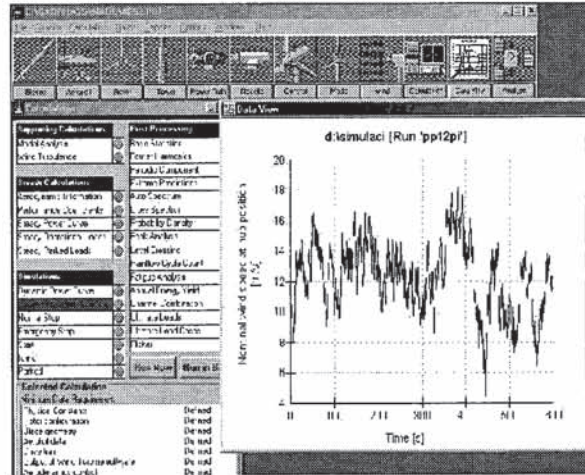


Fig. 4. Software used for simulation: BLADED

Simulations from different wind speed inputs cases show better results for the fuzzy control system if it is compared with the linear control system. It is used for improving wind energy capture.

Fig. 5. shows the wind speed used for the simulations. The mean speed is 12m/s that is the nominal speed value. In this case the system works in the transition zone.

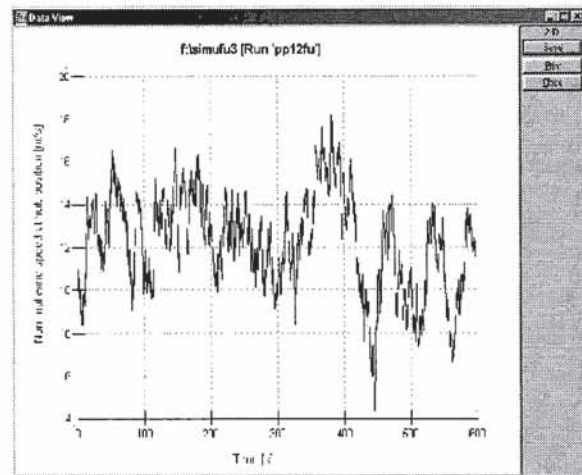


Fig. 5. Wind speed used for the simulations

Fig. 6 - 9 show improvements in energy capture in the transition between power optimization and power limitation in rated wind speed.

Simulation results in rated wind speed conditions (12 m/s mean value) are shown in table I. As it can be observed in this table, the improvement of captured energy obtained at rated wind using fuzzy control is very important, about 2.94%.

	PI	Fuzzy
Energy (kWh)	111.32	114.58
Max. Gen. Speed (rpm)	1558	1545
Q_{maximum} (Nm)	5094	5094
T_{average} (Nm)	4420	4531
T_{rms} (Nm)	1019	972

Table I. Simulation results in rated wind speed (12m/s average value)

A comparison between the captured wind energy of the turbine using the PI and the Fuzzy logic controllers for different wind speed condition is shown in Fig. 10. As it is possible to observe in this figure, there is an increase of the capture wind energy for wind speed in the range from 10 m/s to 14 m/s using the proposed fuzzy logic controller. Although the increase of the captured wind energy is around the 3%, this is a significant amount of energy when the production of the wind turbine is evaluated during long periods (kWh/years).

In reference [12] an interesting fuzzy logic application for improving speed control and captured energy using the wind speed information for wind turbines was presented.

V. CONCLUSIONS

In this work, a fuzzy logic application has been developed for improving captured energy and speed control for variable speed and blade pitch wind turbine.

The main objective of replacing linear by fuzzy control is to improve the speed control and captured energy of the MADE AE-52 wind turbine.

The developed control system has integrated a fuzzy controller for torque and blade pitch control. Simulation

results show the robustness of the fuzzy controllers in power plants of wind energy. Soft and nonlinear control actions of this controller can improve the wind turbine performance at low, rated and high wind speed.

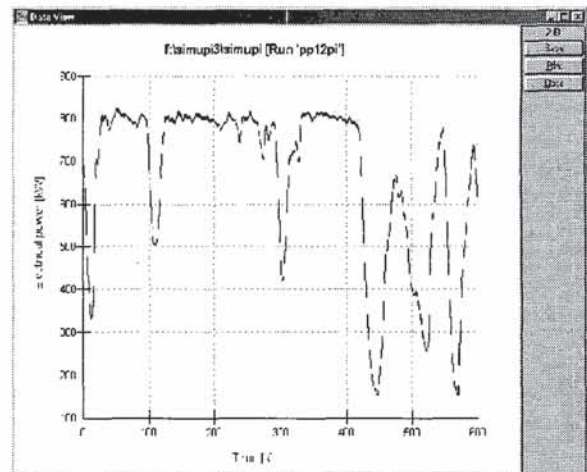


Fig. 6. Generator power for the rated wind Time series of the PI control system

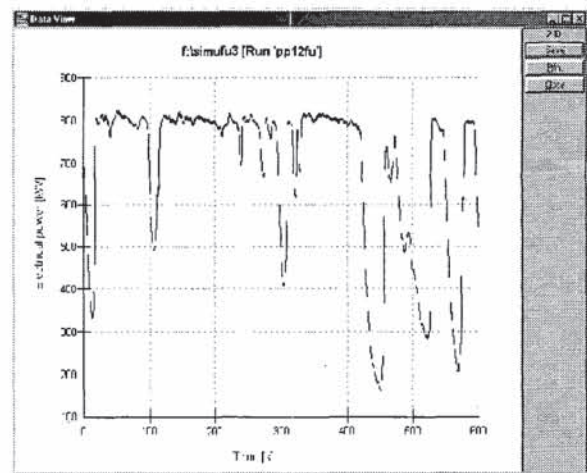


Fig. 7. Generator power for the rated wind time series of the Fuzzy control system

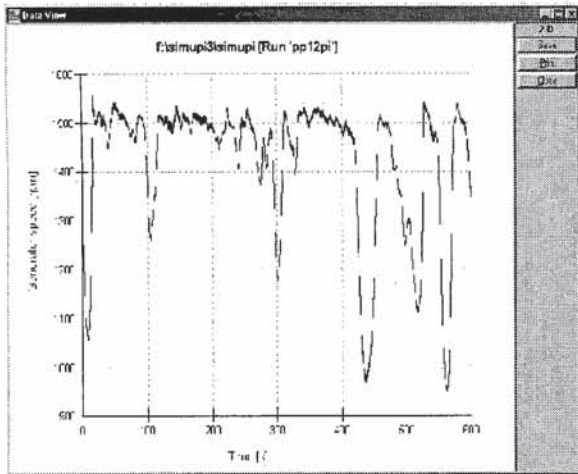


Fig. 8. Speed control for the rated wind time series of the PI control system

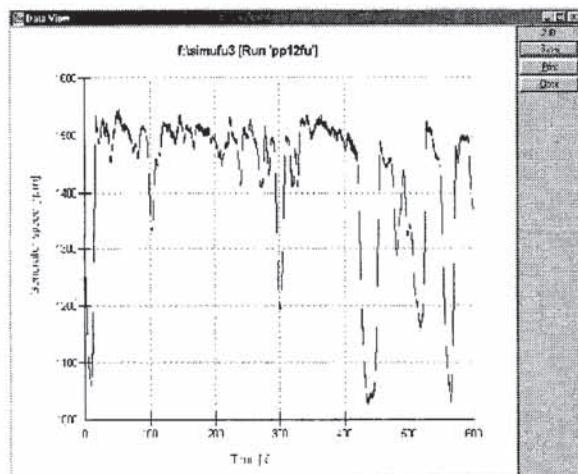


Fig. 9. Speed control for the rated wind time series of the Fuzzy control system

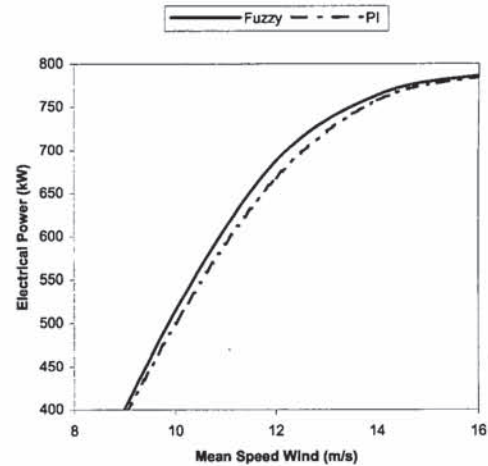


Fig. 10. Captured electrical power by Fuzzy and PI controllers.

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