

Lab Model for a Low Power Wind Turbine System

C. Ghiță¹, D. I. Deaconu¹, A. I. Chirilă¹,
V. Năvrănescu¹ and D. Ilina¹

¹ Electrical Machines and Drives Department
Electrical Engineering Faculty, Universitatea Politehnica București
Splaiul Independenței 313 (Romania)
E-mail: ghita.constantin@gmail.com

Abstract. Paper presents a lab low power wind turbine of 2.5 kW. The driving propeller is modeled with an assembly of variable frequency converter, three-phase induction motor and speed reducer. Thus the motor's speed can be easily driven in the range of (300 – 1500) rpm and its size is little. The speed reducer lowers the speed 5 times so that the generator will spin in the range (60 – 300) rpm. This range is usual for the propellers of wind turbines. In the end the trials of the system are presented using a specific data acquisition system.

Key words

Wind turbine, Electric energy generation, Trials.

1. Introduction

Renewable energy resources are fully developing from both industrial and research points of view highlighting the environment's protection [1],[2]. The development of these resources is the global trend due to the diminishing of classical energy resources. The wind energy does not pollute, it is unlimited and easy to get. The main issues are linked with the conversion efficiency and optimization [3],[4], the impact over the economic development [5], numerical simulation of the devices and the conversion processes [6]-[8]. Most used generators for wind turbine systems are permanent magnet synchronous generators [9]-[11] because the excitation field does not require a DC voltage source. The literature in the field of wind energy is very rich and it is a special chapter in electrical engineering [12]-[15].

The newest solutions for wind turbine systems do not use a gear box between the propeller and the generator due to its disadvantages, such as: bigger size, difficult maintenance, noise source, lower efficiency, lower reliability, supplementary mechanical bounds [16]. As a consequence the electric generator being directly coupled with the propeller is designed for low speeds. Thus, it has numerous pole-pairs, increased mass and volume.

In this paper a lab model for a low power wind turbine system (2.5 kW) is presented. To test such a system it would require an aerodynamic tunnel that it is available only in specialized labs. Because of this, the propeller is modeled by a system made from three main components: variable frequency converter, induction motor and a mechanical speed reducer. The waveform of the propeller's speed can be modeled with the converter's output frequency by applying a proportional control voltage. This voltage follows the propeller's speed profile. The range is between (0 – 10) V. The presented lab model simulates a system without gear box.

2. Lab model

The Lab model is presented in Fig. 1. The denotes are:
(RST) three-phase grid voltage: 3x380 V, 50 Hz;
(RN) single-phase voltage grid: 220 V, 50 Hz;
1 - frequency converter: 4 kW, 3x380 V, (5 – 60) Hz;
2 - three-phase induction motor: 3.2 kW, 3x380 V, 50 Hz, 1425 rpm;
3 - speed reducer: ratio 5.16;
4 - propeller simulator;
5 - torque sensor: maximum torque 200 Nm;
6 - permanent magnet synchronous generator: 2.8 kW, 3x380 V, 240 rpm, 52 Hz;
7 - temperature thermocouple;
8 - single-phase rectifier: 2.8 kW, 550 V;
9 - single-phase inverter with grid filter: 2.5 kW, 220 V, 50 Hz;
10 - voltage resistive transducer;
11 - data acquisition system;
12 - current transducers;
13 - data processing computer;
14 - speed sensor.

The driving propeller is modeled with assembly 4 shown in Fig.1. The speed reducer 3 was necessary in order not to use an induction motor of 3 kW with 240 rpm. In this

case the motor would have been heavier than the used electric motor along with the existing speed reducer.

The wind energy is great variable and the propeller's speed usually ranges in (60 – 300) rpm. The synchronous generator 6 has NdFeB permanent magnets (large energy), low rated speed with large number of pair-poles ($2p = 26$) and a rated frequency of 52 Hz. Due to the large number of poles, the generator has large diameter

and weight but not so heavy as it would be the high speed generator and the appropriate gear box.

The data acquisition system shown in Fig.1 has the following parts: torque sensor 5 is slip-ring type; speed sensor 14 is an incremental encoder; temperature sensor 7 is a thermocouple; current transducer 12 has primary rated current of 25 A; voltage sensor 10 has primary rated current of 10 mA; data acquisition card (11) is based on a commonplace communication port, i.e.

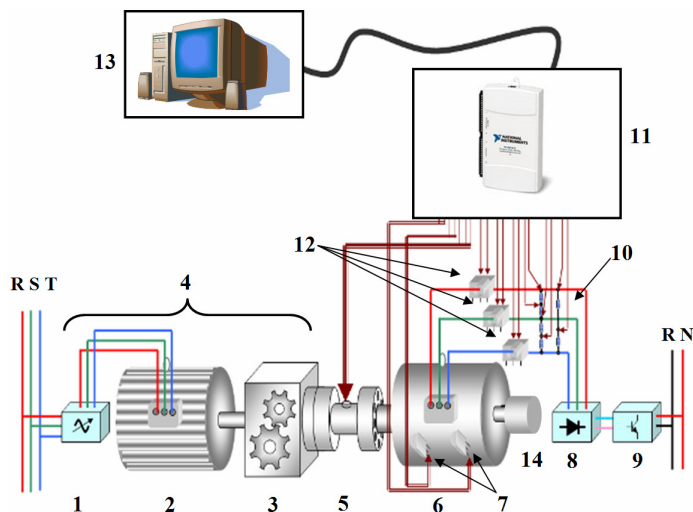


Fig. 1. System global view

USB, Windows and LabView compatible, 16 SE/8 DI analog inputs, 16-bit resolution, $\pm 10V$ maximum voltage range, accuracy 1.92 mV, 24 DIO digital input/output, maximum source frequency 80 MHz.

3. Turbine speed profile modeling

The dependency between the wind speed and turbine speed is influenced by various factors such as: turbine inertial momentum, propeller's blades type and number, controlling system of the wind turbine. Thus there is an important difference between the wind profile and turbine's speed profile. As a consequence, it is modeled the turbine's speed profile and not the wind speed profile that drives the turbine. In Fig. 2 is presented an example for a possible variation of the turbine's speed in per unit (the reference can be a convenient value).

In order to study the wind turbine system dynamics at time $t = 0$ s it is applied a speed profile $\Omega(t)$ like the one shown in Fig. 2. This is achieved by applying a control voltage $U_c(t)$ with a similar profile as speed. The same is for the generator's frequency $f(t)$. In Fig. 3 is presented a block diagram of the system where main quantities are shown.

In order to model the propeller speed using a voltage ranging from (0 – 10) V a convenient amplification is chosen. This amplification can be set in order to obtain for 3.2 V the reference speed. Thus, the system can model over the triple speed reference.

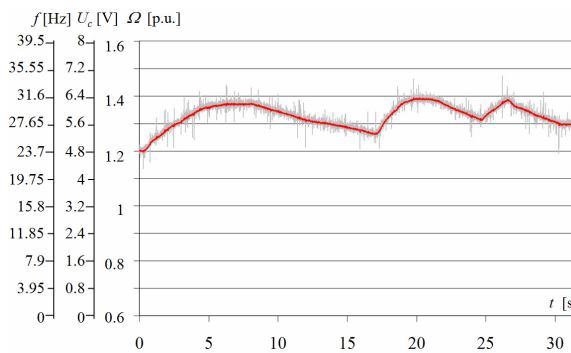


Fig. 2. Speed, control voltage and frequency profiles

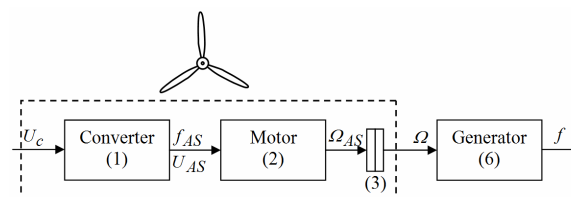


Fig. 3. Propeller model - block diagram

Control voltage $U_c(t)$ can be obtained from a signal generator where the user can set up any variation. This

generator can be based on a digital to analog converter if the reference has been previously sampled.

The converter supplies the RMS voltage U_{AS} that has the frequency f_{AS} . This frequency is in correspondence with the control voltage $U_c(t)$. Additionally, the frequency converter operates with $U/f = ct.$ control algorithm. Thus the maximum torque of the motor remains unchanged when frequency f_{AS} changes. If this frequency is 25 Hz then the RMS voltage applied to the motor's terminals is half of the rated voltage, i.e. 190 V.

4. Model trials

B. Constant speed trials

For the beginning the system behavior at constant speed has been analyzed. Using the measurement and data acquisition system for different speed values the following quantities have been acquired: synchronous generator's driving speed (n_G), driving induction motor speed (n_{AS}), generator's driving mechanical torque (M), induction motor supplying voltage frequency (f_{AS}), generator's line currents (i_A, i_B, i_C), intermediate circuit DC voltage (u_{DC}) between the rectifier and the grid connected single-phase inverter, intermediate circuit DC current (i_{DC}), grid's voltage (u_R) where the synchronous generator is connected, generator's active power (P_G), synchronous generator's stator yoke temperature (θ_G).

As expected the measurements are affected by the noise. Its intensity depends on the place where the measurements are performed. In this case the measured signals have been filtered. In Fig.4 and Fig. 5 the driving torque of the synchronous generator is presented for two different frequencies (f_{AS}) of the induction motor: 25 Hz and 35 Hz.

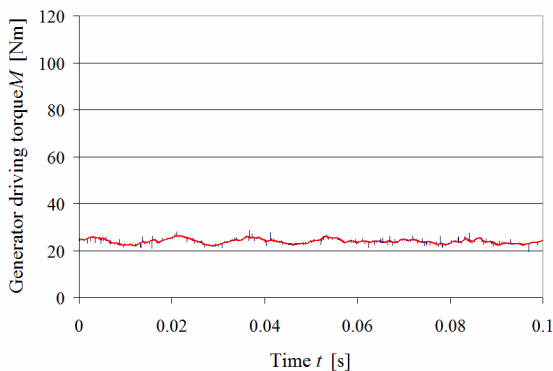


Fig. 4. The synchronous generator's driving torque for $n_G = 139.3$ rpm, $f_{AS} = 25$ Hz, $u_{DC} = 379$ V, $P_G = 261$ W

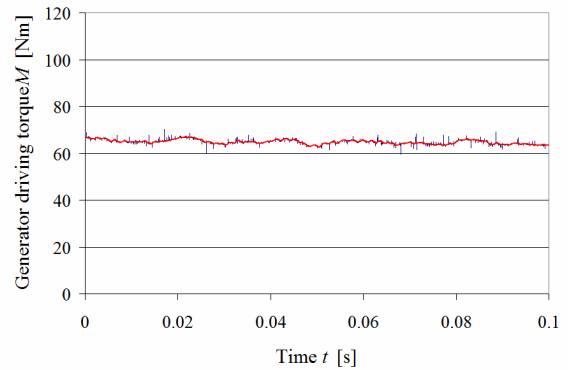


Fig. 5. The synchronous generator's driving torque for $n_G = 189.2$ rpm, $f_{AS} = 35$ Hz, $u_{DC} = 450$ V, $P_G = 1042$ W

From Fig.4 and Fig. 5 can be observed that when the speed increases the synchronous generator driving torque is also increasing and so the active power injected into the grid. The dependency between the speed and the injected active power is shown in Fig. 6.

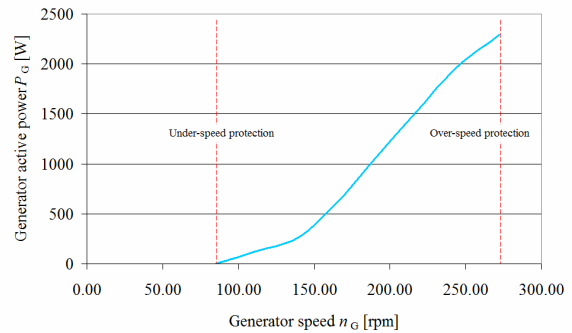


Fig. 6. Speed – generated active power curve

C. Variable speed trials

In case when the profile shown in Fig. 2 is required, using the data acquisition system all the quantities mentioned at the beginning of paragraph A can be recorded.

The control voltage $U_c(t)$ is applied at the converter's 1 input (Fig. 1). Its time variation is similar to the wind's profile shown in Fig. 2. The converter provides a three-phase voltage system to the induction motor with variable frequency that change similar to the control voltage (Fig. 2). Due to the control algorithm of the converter its thus, the synchronous generator's speed is also varying as the profile presented in Fig.2 and so does the frequency of the output voltage. When the dynamics of the system is studied the following instantaneous quantities are acquired using the data acquisition system: synchronous generator's driving torque, induction motor's voltages and currents, synchronous generator's voltages and currents. In consequence, Fig. 7 depicts the generator's driving torque and Fig. 8 and Fig. 9 show the phase currents of the synchronous generator and the induction motor respectively.

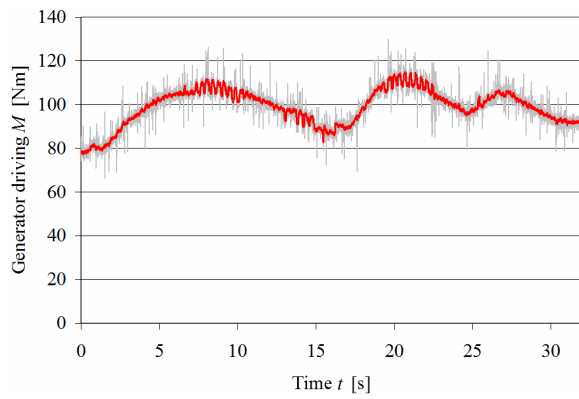


Fig. 7. Time variation of the generator's driving torque for the wind profile shown in Fig. 2.

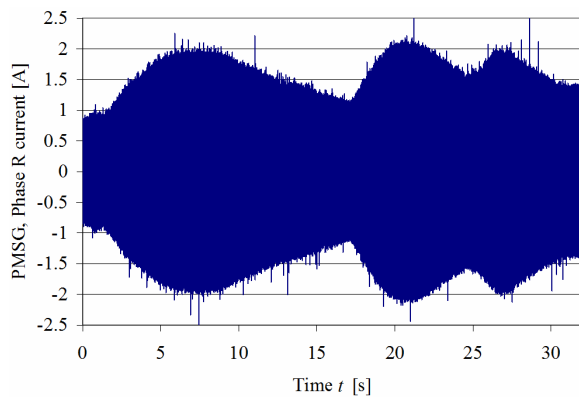


Fig. 8. Generator's phase current time variation for the wind profile shown in Fig. 2.

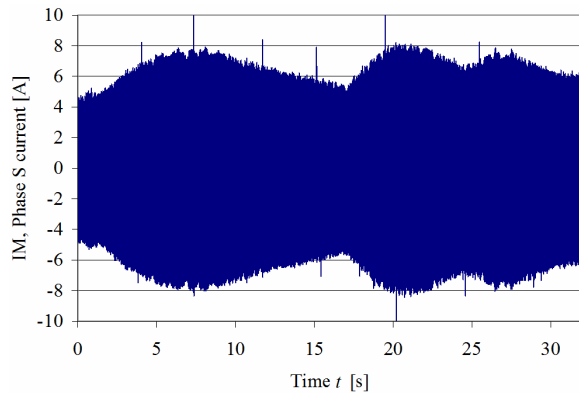


Fig. 9. Induction's motor phase current time variation for the wind profile shown in Fig. 2.

It can be observed that the torque's variation is similar to the system's speed because the converter keeps a constant ratio U/f . The same shapes have the envelopes of the motor's and generator's currents. The synchronous generator has a constant field due to the permanent magnets. As a result the phase back-emf of the generator has an envelope similar to the profile depicted in Fig. 2.

The phase voltage of the generator is instead constant because the voltage drops across the internal reactance are variable since the phase current is appreciable changing. In Fig. 10 is presented the output phase voltage of the generator. Its amplitude varies with less than 10 percents. This proves that the injected active power by the generator is also variable and follows the system's speed well enough.

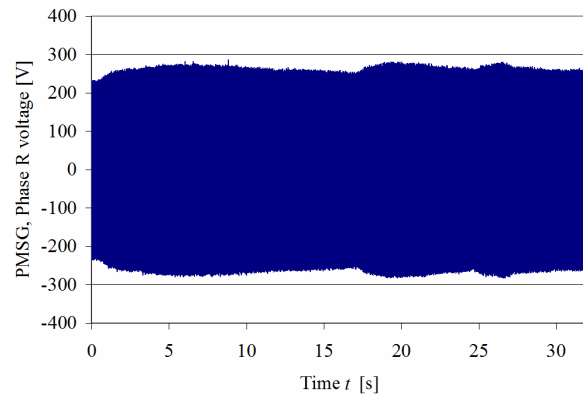


Fig. 10. Generator's phase voltage time variation for the wind profile shown in Fig. 2.

D. Protection system

The system is protected for both under-speed and over-speed. For 70 rpm the wind system does not generate power. The same is for speed above 275 rpm, where the system disconnects from the grid and connects on a three-phase protection appropriate sized resistance.

The system's protections are tested when the dynamic behavior of the system is analyzed. If the generator is over-speeding there is the risk that the power injected into the grid to increase over the rated one. Such disconnection due to this over-speed is shown in Fig. 11. If the speed drops below the maximum limit then the system automatically reconnects the generator to the grid. This behavior can be observed in Fig. 12.

The system behaves quite well in abnormal operating situations by cutting off the flux power and introducing a protection resistor at generator's terminals.

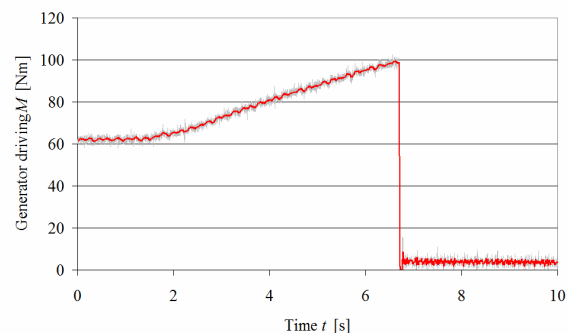


Fig. 11. System's automatic disconnection from the grid due to an over-speed event

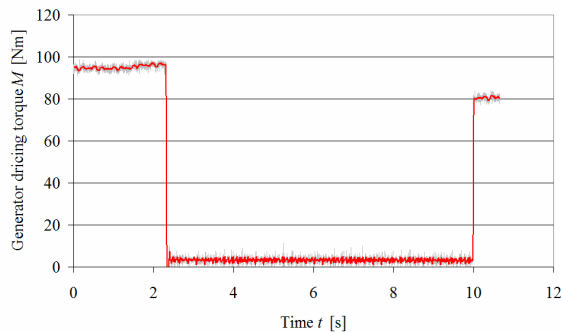


Fig. 12. System's automatic disconnection from the grid due to an over-speed event and automatic reconnection to the grid when speed is below the upper limit

5. Conclusion

The development of the lab model for the wind turbine system and its trials lead to the following main conclusions:

- the present trend is that the wind turbine systems not to have a gearbox;
- the generator can be induction or synchronous type, the latter one for permanent magnet variant is mostly used due to its stability on operation;
- the generator's voltage is rectified then inverted and filtered at the grid's frequency in order to be able to connect to and protect the grid from distorted generated power;
- when the generator is driven at low speed then the harmonic content of the generator's voltages and current is high;
- the protection for under-speed and over-speed is automatically performed.
- In case of substantially variable system's speed the injected active power is also variable and follows the same law as the speed does.

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