Modeling an autonomous wind turbine electric pump system

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***Abstract* – Being one of the variable renewable energy sources, wind energy integration can be made using storage methods. All of these have been developed during time, but one might be more accessible than others because is using a free natural resource, water. This is pump storage. The purpose of this paper is modeling an autonomous wind turbine connected to an electric pump, in the aim of storage, and finally the determination of the efficiency.**

***Keywords:* wind turbine, pump storage, efficiency.**

I. INTRODUCTION

Some renewable energy sources are characterized by unpredictability and big fluctuations in small periods of time [1]. When integrating the energy given by this kind of sources there occur some problems regarding grid stability, [5], [6]. Thus, for controlling the lack or surplus of energy there are needed systems for storing this energy [7].

In this paper is studied a system for storing wind energy and that is pump storage. This is the most widespread energy storage with more than 100 GW worldwide [4], [8]. Some examples are the Okinawa Seawater Pumped Storage Power Plant in Yanbaru, Japan - 30 MW system with an effective vertical drop of 136 m, the Dinorwig plant in Wales [11], UK - the six huge pump turbines can each deliver 317 MW, producing together up to 1,800 MW from the working volume of 6 million m^3 of water and a head of 600 m, the Bath County Pumped Storage Station in Virginia's Allegheny Mountains has a 2,100 MW pumped hydro system with six turbines that pump 11 million gallons per minute and generation uses 14.5 million gallons per minute [8].

This kind of storage presents many advantages such as long tine scale storage, no toxic materials involved, high capacity range, and fast respond in the demand of energy [8]. Also it is not to neglect the fact that pump storage uses free resources, wind and water, and the only thing that has to be done is to make the necessary measurements in order to choose the proper location.

Pump storage presume the existence of two basins of water at different levels and using the supplemental wind energy, water is pumped from the inferior basin in the superior one. When more energy is needed, in the peak periods, the water is released and the lack of energy is covered [2], [4], [5], [8], [7], and [9].

It was chosen pump storage considering the fact that storing energy will be made for MW wind turbines and nowadays other systems for storing so much quantities of energy are not developed yet.

II. DESCRIPTION OF THE SYSTEM

In this paper is considered a 1.1 kW wind turbine, which will be seen forward, but this is a case study, to see what happens in small power case first. This is an autonomous system in which wind turbine generates energy for pumping water. The reason for choosing an autonomous system is the fact that according to the Romanian geographic condition it is possible to use such a system (ex, the wind generated is close to the storage lake). The system supposes a connection between the wind turbine and the pump and therefore, some elements are needed in order to realize the energetic conversion, which form an electro-energetic chain. The minimum of elements are the following: wind turbine, synchronous generator, electric converter (optional), asynchronous machine, and finally the pump, as it is seen in figure 1. Obviously, many losses will appear until the wind energy will be transformed in hydraulic energy. For eliminating the losses every element of the electro-energetic chain has to be properly adjusted, to obtain the maximum of efficiency, so the global efficiency will rise.

III. MATHEMATICAL MODEL

In order to simulate the elements of the electro-energetic chain, mentioned above, the mathematical model of each is needed.

The wind turbine is modeled with the equation (1), and for the global efficiency established bellow it is considered that c_P the performance coefficient is 0.4 for three blades wind turbine [10]. The gearbox is considered having a constant efficiency of 98% and his transformation ratio is k=3.5, being modeled with equation (2). The synchronous generator is modeled through the product between the torque and the speed.

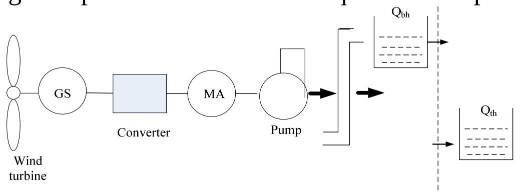

Fig. 1 Scheme for connecting wind turbine to a pump

The electric converter is introduced in order to fit the power transfer to the pump by adjusting the motor mechanical curve and to exploit also the low speed energy given by the wind turbine at low wind speed. This is done by increasing as much as possible the speed of the induction motor in order to avoid the low speed - low efficiency region of the pump (see fig. 3). The converter is modeled using the law: $U = kf^3 + U_0$ where in the experimental model, k=0.0029 and U_0=19 V representing the voltage necessary to assure the voltage drop on the stator reactance of the asynchronous motor.

Forward, in asynchronous motor model is introduced a law that equivalents slip compensation. In this simulation, this law is a simple one $s \cdot f = const$ in the idea of maintaining the flux inside de machine constant and so the voltage is assured.

Finally, the centrifugal pump is modeled using the equations (3), (4), (5), (6) [3].

$$P_W = \frac{\rho}{2} c_p(\lambda, \vartheta) A_R \upsilon_W^3 , \quad (1)$$

where:

P_W - wind turbine power (W);

ρ - air density (1,225 kg/m^3);

c_P - performance coefficient;

A - aria covered by the blades (m^2);

υ_W - wind speed (m/s).

$$k = \frac{n_1}{n_2} = \frac{T_2}{T_1} , \quad (2)$$

where:

K – transformation ratio;

n_1 - input speed (rpm);

n_2 - output speed (rpm);

T_1 - input torque (Nm);

T_2 - output torque(Nm).

$$\frac{Q_1}{Q_2} = \frac{n_1}{n_2} , \quad (3)$$

$$\frac{H_1}{H_2} = \left(\frac{n_1}{n_2}\right)^2 , \quad (4)$$

$$\frac{P_1}{P_2} = \left(\frac{n_1}{n_2}\right)^3 , \quad (5)$$

$$\eta_2 = 1 - (1 - \eta_1)(n_1 / n_2)^{1/10} , \quad (6)$$

where:

Q_1 - flow corresponding at speed n_1, (m^3/s);

Q_2 - flow corresponding at speed n_2, (m^3/s);

H_1 - delivery lift corresponding at n_1, (m);

H_2 -delivery lift corresponding at n_2, (m);

P_1 - pump power corresponding at n_1, (W);

P_2 - pump power corresponding at n_2, (W);

$n_{1,2}$ - pump speed (rpm), $n_1 < n_2$;

η_1 - efficiency corresponding at n_1;

η_2 - efficiency corresponding at n_2.

Also for the pump an efficiency characteristic is established, using equation (6), which is an empirical equation concerning pump efficiency obtained in the various speed case. This is shown in figure 2.

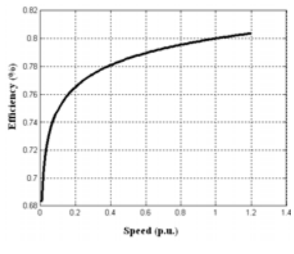

Fig. 2 Pump efficiency

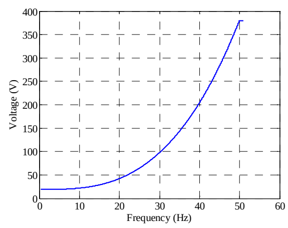

Fig. 3 Variation law imposed for the electric converter

IV. SIMULATION RESULTS

To observe the behavior of the elements during the electro-energetic conversion a certain setup is considered, which is modeled using the Matlab Simulink software. The experimental setup considered elements are: a 1 kW Joliet wind turbine with 3 blades [6], a gear box with constant efficiency of 98%, a synchronous generator with rated power of 1 kW, an electric converter, an asynchronous generator with rated power of 1.1 kW, and a centrifugal pump. The reason for using a motor with a higher rated power than the generator is having little losses in the windings. The block scheme in Matlab Simulink is represented in figure 4 and the results in figures 5, 6, 7, 8, 9 and 10. A more detailed illustration of the simulation results is given in Table 1.

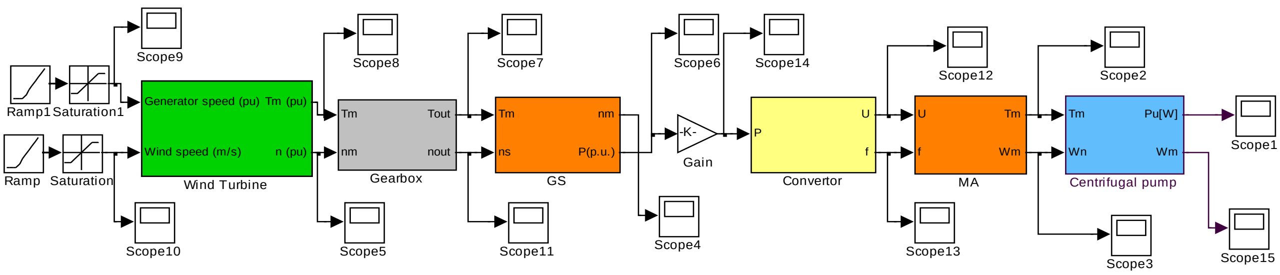

Fig.4 Block scheme of the model in Matlab Simulink

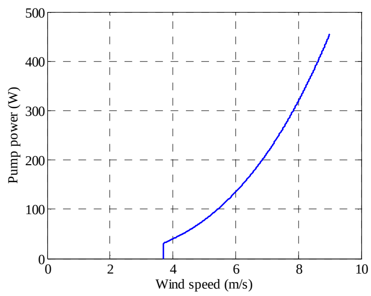

Fig. 5 Pump power depending on the wind speed

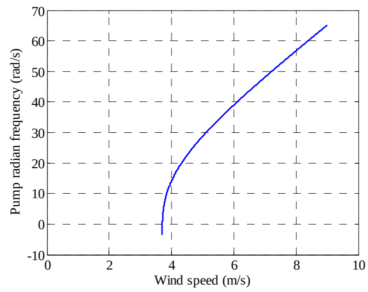

Fig. 6 Pump radian frequency depending on the wind speed

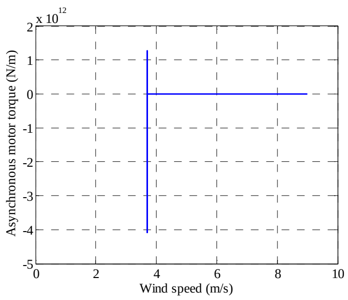

Fig. 7 Asynchronous motor torque depending on the wind speed

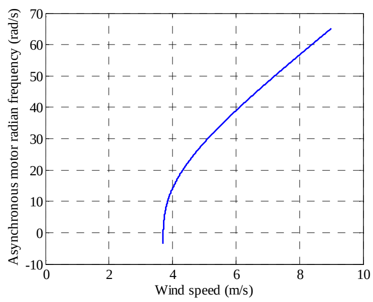

Fig 8 Asynchronous motor radian frequency depending on wind speed

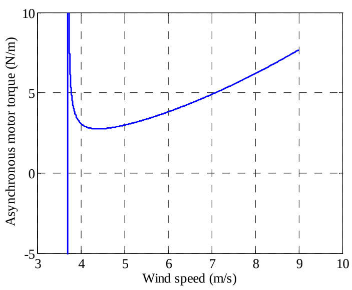

Fig. 9 Asynchronous motor torque depending on the wind speed

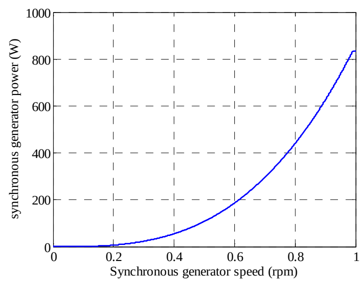

Fig. 10 Synchronous generator power depending on wind speed

Table 1 Simulation results

Wind speed (m/s)	Wind turbine torque T_t(p.u.)	Power GS P_{GS} (W)	Voltage U (V)	Frequency f (Hz)	Torque MA T_{MA} (Nm)	Speed Ma n_{MA} (rpm)	Pump power P_{pump} (W)	Pump speed n_{pump} (rpm)	Efficiency	Global efficiency
0	0	0	0,1	0	0	0	0	0	0	0
1	0,125	1,14	0,55	0	0	0	0	0	0	0
2	0,05	9,14	4,4	0	0	0	0	0	0	0
3	0,11	30,8	14,85	0	0	0	0	0	0	0
4	0,2	73	35,19	17,74	3.1	14.1	39.3	14.11	0.45	0.17
5	0,31	143	68,73	25,79	2.98	28.6	77.51	28.68	0.45	0.18
6	0,45	250	118,8	32,52	3.79	38.8	134.36	38.88	0.45	0.18
7	0,61	390	188,6	38,82	4.88	48	213.76	48	0.46	0.18
8	0,79	580	281,5	44,9	6.17	56.6	319.7	56.66	0.46	0.18
9	1,01	832,7	380	50,87	7.66	65	455.69	65.07	0.46	0.18
10	1	833	380	50,87	7.66	65	455.83	65.07	0.46	0.18
11	1	833	380	50,87	7.66	65	455.83	65.07	0.46	0.18
12	1	833	380	50,87	7.66	65	455.83	65.07	0.46	0.18

V. CONCLUSIONS

As results from the simulations it seems that appears a problem regarding the asynchronous torque. This may be caused by the slip compensation at slow speed. This can be solved by introducing a scalar or a vectorial control, for slip compensation, which will be studied forward. Also, it can be seen that the global efficiency is small, 18%, but this may be caused by the small power of the system (1 kW), that involves small efficiency to the elements of the electro-energetic chain and the global efficiency will decrease. In large power wind turbine case, which involves electro-energetic chain elements with higher efficiency, it is clear that the global efficiency will increase. For example, if wind turbines with rated power higher than 1 MW are considered, the generator efficiency is over 97%, the asynchronous motor is over 96%, thus results a global efficiency of 33%. Furthermore, a conversion efficiency of the system of 66% results, excepting the conversion efficiency of the wind turbine.

ACKNOWLEDGEMENT

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