DESIGNING A PICO-HYDRO POWER PLANT CONTROLLER

*Camelia BARBU[*], Roxana BUBATU***

Abstract: The objective of this paper is to design a Pico-hydro power plant controller based on his mathematical model. First, the natural hydro process is considered consisting of water lake, supply pipe, hydro turbine, DC generator and controller. Second, for each part of the Pico-hydro is written the mathematical model and after that the entire system is simulated in open loop. Then the controller is designed and the system is simulated in closed loop. These two control modes are compared and presented the advantages of each of them. The simulation results are as expected and can be used to design and validate the controller.

Keywords: renewable energy, mathematical model, simulation

Introduction

The Pico-hydro means a plant of small power, having no more 10 kW representing lately the biggest challenges in clean energy generation, due to the following advantages:

- Use sources of low water flow and fall and are environment friendly ;
- Can autonomously function and useful for isolated areas;
- The initial investments are low.

The Pico-hydro plant has the following important elements: water lake and vane; supply pipe; hydro turbine; DC generator and controller.

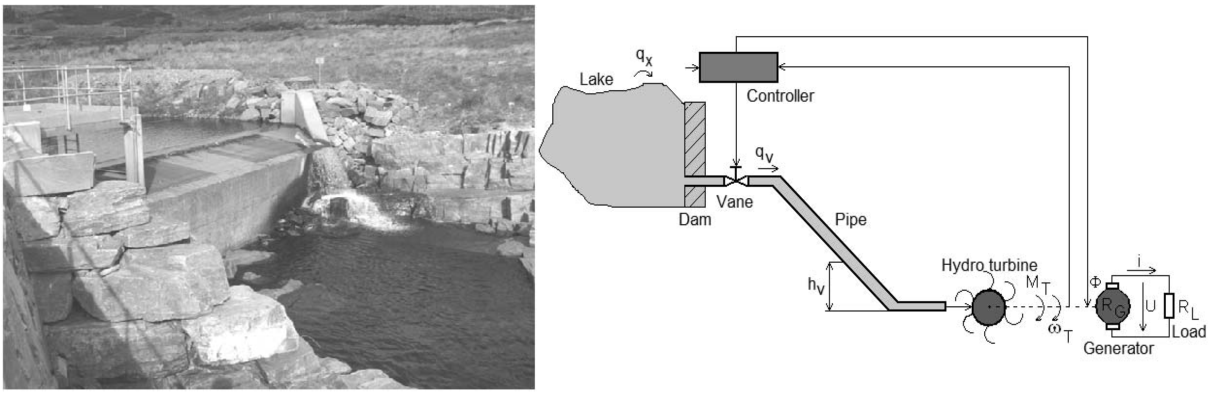

Fig.1. Pico-hydro power plant: the real situation and the diagram

In this analysis we will consider the above case of a DC generator with a common power bus.

The Pico-hydro plant can be considered as a system with the block diagram from fig.2.

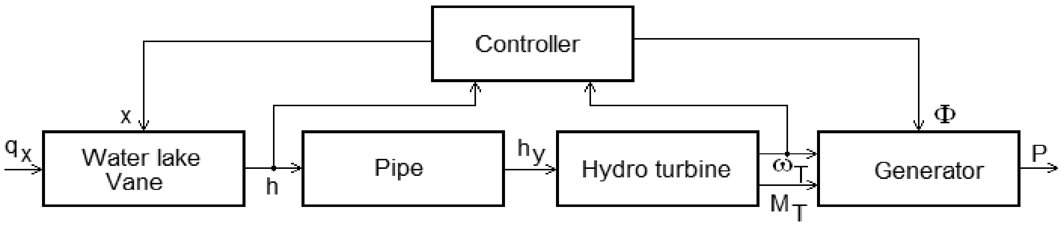

Fig.2. Pico-hydro system block diagram

The water lake has as input a q_x uncontrollable flow and as output a vane that controls the h water level in the lake, producing a q_v controllable flow. There are two water levels: the minimum N_0 level and the maximum N_1 level. The water level h must be controlled by the on/off position x of the vane between these two levels.

The second component is the hydro turbine, which is a nonlinear element, having as input the h_y pressure and as outputs the M_T torque and the ω_T speed.

The DC generator is a nonlinear element, too. The inputs of the generator are the M_T torque, the ω_T speed, the Φ control flux and the output is the DC power P.

The controller has two inputs, the h pressure and the ω_T speed and two outputs, one for on/off control of the vane and the other for generator flux Φ control.

*Lect.eng.Ph.D University of Petroşani
**Eng. Ph.D student University of Petroşani

Mathematical model for hydraulic process

In this section we will model and simulate the hydraulic process of power plant and we will present the simulation results.

Considering the volume V, surface S and level h of the tank, we can write the relationship:

$$\frac{dV}{dt} = q_x - q_V$$

In order to model the on-off control principle of the vane we will introduce in the above relation the step distribution $\theta(x)$, resulting:

$$q_V = \frac{1}{k_V} \cdot \Delta h_V \cdot \theta(x)$$

With $V = S \cdot h,\ \Delta h = h, T_V = k_V \cdot S$, we get the mathematical model of the process and the transfer function:

$$T_V \cdot \frac{dh}{dt} + h \cdot \theta(x) = k_V \cdot q_x$$

$$G_W = \frac{h(s)}{q_x(s)} = \frac{k_V}{\theta(x) + T_V \cdot s}$$

$$= \begin{cases} \dfrac{k_V}{T \cdot s}; & \theta(x) = 0\ (closed\ vane) \\ \dfrac{k_V}{1 + T_V \cdot s}; & \theta(x) = 1\ (opened\ vane) \end{cases}$$

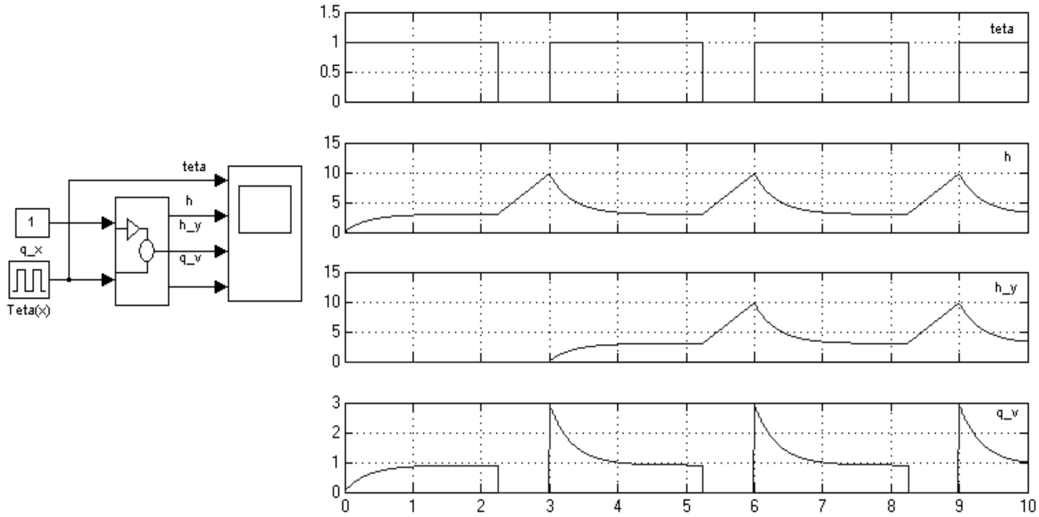

Fig.3. Simulation of hydraulic process: a) model; b) simulation results

Mathematical model of the DC generator

We begin from the hydraulic turbine equations, in linear form, where *a* and *b* are constants. When only the q_T flow and the ω_T speed are modified, we get the mathematical relations for torque:

$$M_T = a \cdot q_T - b \cdot \omega_T$$

In dynamic regime the dependence between torque M_T and pressure h_y can be written to a linear differential equation:

$$T_T \cdot \frac{dM_T}{dt} + M_T = k_T \cdot h_y$$

where: T_T is time constant and k_T is the steady state gain.

Results the transfer function of the turbine:

$$G_{MT}(s) = \frac{M_T(s)}{h_y(s)} = \frac{k_T}{1 + T_T \cdot s}$$

In fig.4 are presented the modeling and simulation results for the nonlinear and linear approach, having the following data: a=400, b=1.5, k_1=300, k_2=50, k_3=0.02, k_4=0.03.

In this simulation we will consider the input h_y constant of 5 m and the input ω_T fluctuating between 7 and 8 rad/s. As outputs we will represent the M_T torque and the q_T flow.

The torque is presented both by nonlinear and linear model in order to see the approximation done by linearization. As can be seen, these differences are acceptable, so in the following paragraphs there will be used the linear approximation.

Second, we will write the DC generator mathematical model. This because the Pico-hydro generally use the DC solution in order to charge the batteries. The generator equations for the input torque M_T and the outputs voltage U and power P are as follows:

$$U = k_e \cdot \Phi \cdot \omega_T - (R_G + R_L) \cdot i - L_G \cdot \frac{di}{dt}$$

$$M_T = k_m \cdot \Phi \cdot i$$

$$P = Ui = M_T \omega_T - \frac{R_G + R_L}{k^2{}_m \cdot \Phi^2} M^2{}_T - \frac{L_G}{k^2{}_m \cdot \Phi^2} M_T \frac{dM_T}{dt}$$

where: Φ, i and U are generator's flux, current and voltage; R_G and L_G are internal generator's resistance and impedance and R_L is the load. In this case L_G can be neglected.

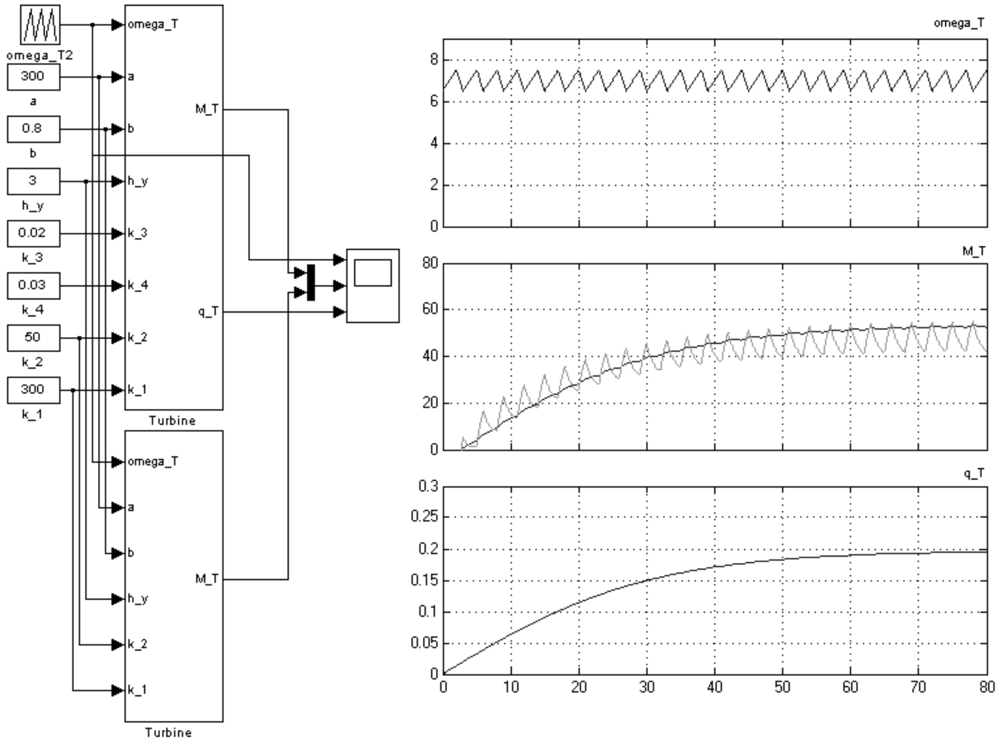

Fig.4. Hydro turbine, model and simulation results

In order to maintain an approximately constant output voltage, there can be introduced a loop on speed. In fig.5 are presented the model and simulation results for the two cases, open loop and closed loop.

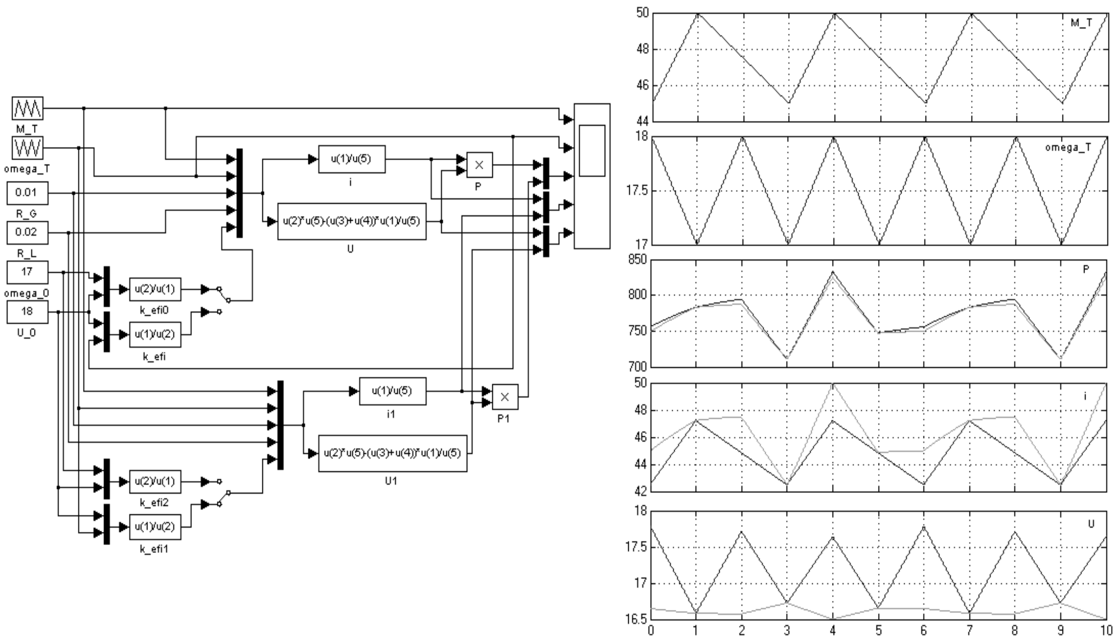

Fig.5. DC generator: model and simulation results

Mathematical model of the plant

For modeling and simulation of the plant we consider the hydraulic and electrical parts together with the dedicated controller.

This controller is based on on/off principle and controls the input flow of the turbine and stabilizes the output voltage of the DC generator.

First, we will design the controller that has two inputs and two outputs. The inputs are the pressure h and the speed ω_T.

The outputs are the on/off control signal for the lake vane and the DC generator flux Φ. In fig.6 is presented the controller model and simulation results.

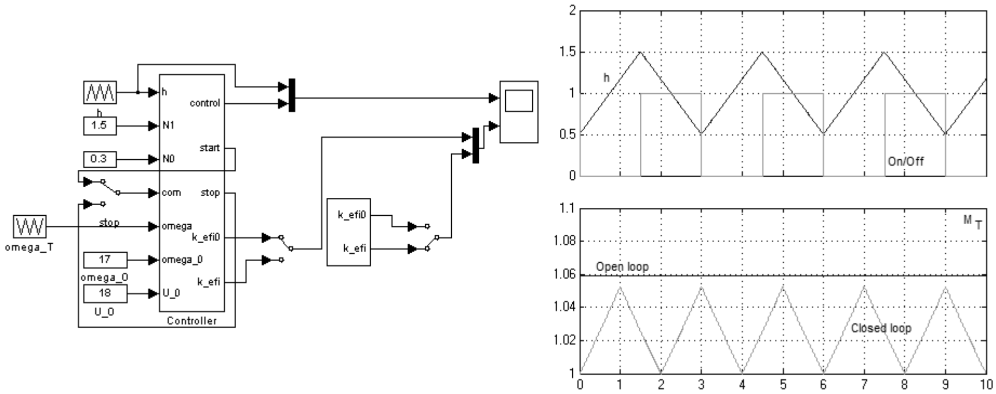

Fig.6. Controller: a) block model; b) simulation results

The plant complete model was obtained connecting all the elements presented above and the controller.

In fig.7 are shown the simulation model and results for this system. There were used the following data: $q_x = 6\ m^3/s$; $S = 12\ m^2$; $N_1 = 1.5$ m; $N_0 = 0.4$ m; $\omega_0 = 15$ rad/s; $U_0 = 18$ V; $h_0 = 8$ m; $R_L = 0.02\ \Omega$; $R_G = 0.01\ \Omega$; $T_p = 5$ s; $k_T = 7.5$; $T_T = 5$ s; h = 0.5 .. 2 m; $\omega_T = 18$ .. 20 rad/s.

The system can run in two modes that are open loop and speed closed loop. In fig.7.b there can be noticed the very good results in closed loop control.

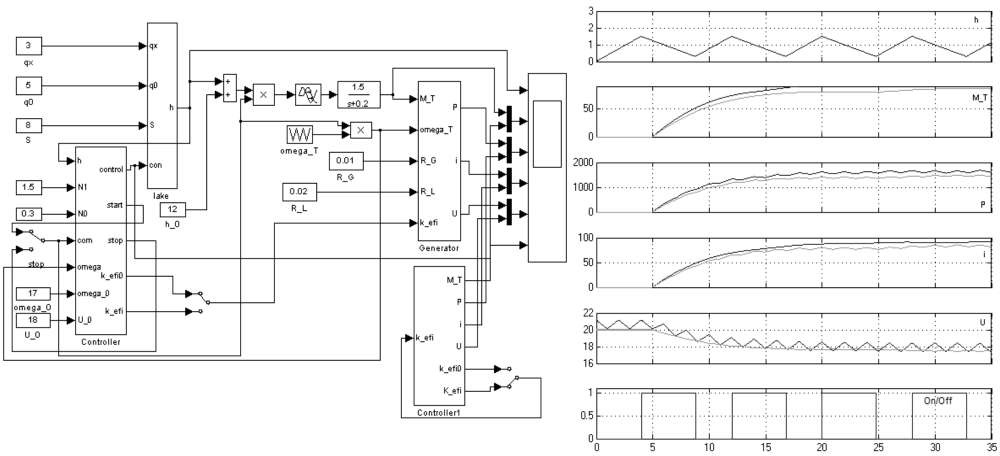

Fig.7. Complete plant: a) model; b) simulation results

Conclusions

Many years the small rivers and the fresh running water were an important life resource for the little communities around them. Today, due to the technology of pico-hydro, this running water represents also an important clean energy resource too. This paper presents a systemic approach on the Pico-hydro plant, starting with the achievement of the process and continuing with the controller design.

The hydraulic part and the electrical part were modeled and simulated. Then, there is designed, modeled and simulated the controller and are obtained the simulation results for the plant.

The results of this paper prove the correctness of this solution and can be used in practical applications, like controllers design for Pico-hydro plants.

References

1. Fraile-Ardanuy, J., Wilhelmi, J.R., Fraile-Mora, J., Pérez, J.I., Sarasúa, I.
A Dynamic Model of Adjustable Speed Hydro Plants, 9 Congreso Hispano Luso de Ingeniería Eléctrica, Marbella, Spain, 2005

2. Pop, E., Leba, M., Tabacaru-Barbu, I.C., Pop M.
Modeling, Simulation and Control of Pico-Hydro Power Plant, Control Systems, Proceedings of the 4th WSEAS/IASME International Conference on Dynamical Systems and Control, Corfu, GREECE, October 26-28, 2008, ISBN 978 960 474 014 7, ISSN 1790 2769, pp. 103-108

3. Leba, M., Pop, E.
*New distribution Properties and Applications in Digital Control***,** Proceedings of the 7th WSEAS International Conference on Advanced Topics on Signal Processing, Robotics and Automation (ISPRA'08), Cambridge, U.K., ISBN 978 960 6766 44 2, ISSN 1790 5117, pp. 43-48, 2008

4. Tabacaru-Barbu, I. C.
Contributions Regarding the Modeling, Simulation and Implementation of Methods and Techniques of a Sustainable Integrated Renewable Energetic System Achievement, Ph.D. Thesis, Univ. of Petrosani, 2009