STUDY OF THE REGULATION OF A MICRO HYDROELECTRIC POWER PLANT PROTOTYPE

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In this article we present the study of the regulation of a micro hydroelectric power plant (MHPP) prototype. The Prototype is installed in our laboratory in the Faculty of Science and Technology. A model of the MHPP was developed with simulink based on some of our preceding works. The downstream regulation ensures good frequency regulation results. The used controllers are the "P" and "PI". The practical results obtained are not far from those in simulation. Measurement and the command are done by an acquisition card controlled by computer.

Keywords: micro hydroelectric power plant, modelling, regulation, simulation.

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Introduction

A Micro Hydroelectric Power Plant (MHPP) is equipped generally with an upstream hydraulic system which forwards water to the turbine equipped with a motorized injector which controls the turbine's flow. The MHPP is coupled with a generator that supplies a mini electrical network. The regulation system must guarantee a good level of voltage with an industrial frequency (50 Hz). In the event of low consumption, it act on the opening of the injector to adapt the production to the needed power. The surplus of energy is switched on a resistance. Some departures are disconnected in the moment of overload.

In this article, we present a model of the MHPP developed with simulink [1, 2]. The simulation results of the downstream regulation are compared with the practical ones used on a prototype of the MHPP. The downstream regulation used on the prototype uses a resistance of dissipation controlled by an electronic variator. Measurement is made by a acquisition card and the regulations used are P (proportional) and PI (proportional and integral) implemented in computer and control permanently the system.

Description of the MHPP

Real MHPP

The upstream hydraulic part of the MHPP consists of [3]: water supply on a river, a feeder canal, a regulation basin, a pressure pipeline whose section is accorded to the flow and the available power.

Nozzles direct water jet against a series of spoon-shaped buckets mounted around the edge of a turbine. The system ensures the hydraulic energy transformation into mechanical energy. The wheel of the turbine is coupled to a generator. The general diagram of this system is represented in Fig. 1. The servo-motor related to the nozzle must be relatively slow to minimize the water hammers effect.

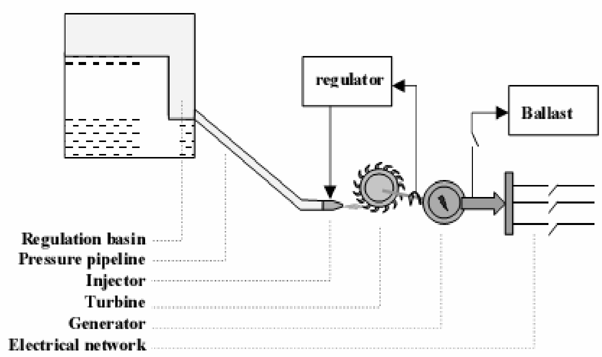

Fig. 1. *Synoptic diagram of a micro hydroelectric power plant*

Description of the MHPP prototype

The nominal values of the system parameters are:

Electric power:	185 W
Frequency:	50 Hz
Voltage:	220 V
Flow:	10 l/s
Speed of racing:	1400 tr/min

The installation allows to impose a variable flow between 0 and 20 l/s. The functional plan of the installation is represented in Fig. 2. The used turbine is of type "Pelton". The generator is a synchronous machine which feeds directly a load formed by lamps. The frequency is measured by a frequency sensor "ARDETEM DIP 605". The numeric regulation is done using an acquisition card. The actuator is an analogue power controller "Type ACI 30-1". In the Fig. 3, we give the real system prototype photo.

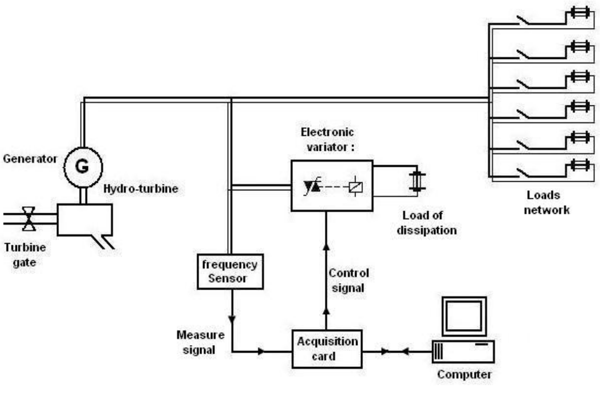

Fig. 2. *The functional plan of the installation*

Fig. 3. *The real prototype*

Modelling of the MHPP

Model of the Pelton turbine

The Pelton turbine is used for the high falls and small flows. It Consists of a set of specially shaped buckets mounted on the periphery of a circular disc. It is turned by jets of water discharged from one or many nozzles which strike the buckets (see Fig. 4).

The flow is adjustable using a mobile needle inside the nozzle, which is moved by an electric servo-motor.

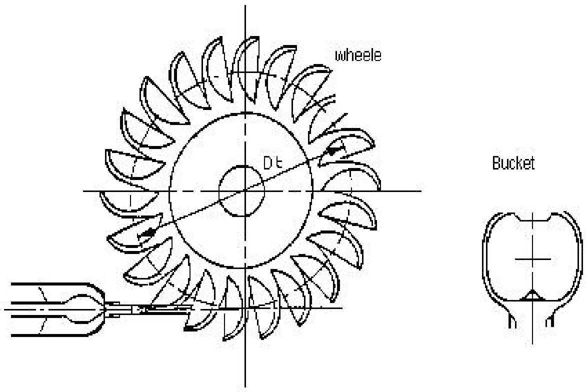

Fig. 4. *The geometrical shape of a Pelton turbine*

The water fall power is given by:

$$P_t = \rho g Q_t H_e \qquad (1)$$

with: P_t – turbine power [W], Q_t – water flow of the turbine [m^3/s], g – gravity acceleration [m/s^2], ρ = = 1000 kg/m^3 – water's density, H_e – effective high [m].

The parameter H_e in (1) is calculated by the following expression [2, 4, 5]:

$$H_e = \frac{U}{g}(V_1 - U)(1 + m\cos\beta) \qquad (2)$$

with: U – drive speed of the turbine, V_1 – water speed in the contact of the jet with buckets, m – report of V_1 and V_2 the water speed at the exit of the bouckets, β – angle between $\vec{V}_1$ and $\vec{V}_2$.

The torque provided by the turbine is:

$$C_t = \frac{P_t}{\Omega_t} \quad (3)$$

with: Ω_t – angular speed of the turbine (rd/s).
The linear speed of the turbine expression is:

$$U = \Omega_t \frac{D_t}{2} \quad (4)$$

with: D_t – Diameter of the turbine (m).
With the relations (1) – (4) we obtain:

$$C_t = \rho Q_t \frac{U}{\Omega_t}\left(V_1 - \frac{D_t}{2}\Omega_t\right)(1 + m\cos\beta). \quad (5)$$

In this paper we use the "IS" unities for the physical values and the reduced sizes "per unit system: pu" for the model.
q_t – Turbine flow (pu), γ_t – Jet speed (pu), n_t – Turbine speed (pu), c_t – Turbine torque (pu), Q_{tn} – nominal flow of the turbine (m^3/s), C_{tn} – nominal torque of the turbine (N.m), V_{1n} – nominal speed of the jet (m/s), Ω_{tn} – nominal speed of the turbine (rd/s).
The relation (5) becomes:

$$c_t = \rho q_t Q_{tn} \frac{D_t}{2C_{tn}}\left(\gamma_t V_{1n} - \frac{D_t}{2}\Omega_{tn} n_t\right)(1 + m\cos\beta). \quad (6)$$

We note:

$$k_t = \frac{D_t \Omega_{tn}}{2V_{1n}}. \quad (7)$$

For nominal values: $q_t = 1$; $\gamma_t = 1$; $n_t = 1$; $c_t = 1$.
From the relations (6), (7) we can write:

$$Q_{tn} = \frac{2C_{tn}}{\rho D_t V_{1n}(1 - k_t)(1 + m\cos\beta)}. \quad (8)$$

Replacing Q_{tn} in (6) by its expression in (8) we end at:

$$c_t = \frac{q_t(\gamma_t - k_t n_t)}{1 - k_t}. \quad (9)$$

The turbine power is given by:

$$p_m = c_t n_t. \quad (10)$$

By considering some approximations, we have:

$$V_1 = \sqrt{2gH_t}, \quad (11)$$

where H_t the effective fall is given by:

$$H_t = h_t H_{tn} \quad (12)$$

with: H_{tn} – nominal fall, h_t – effective fall in "pu".
The relation (11) is written by using "pu" units as:

$$V_1 = \gamma_t V_{1n} \quad (13)$$

from where the expression of the turbine speed in (pu) is:

$$\gamma_t = \sqrt{h_t}. \quad (14)$$

The turbine can be represented by the following model (Fig. 5):

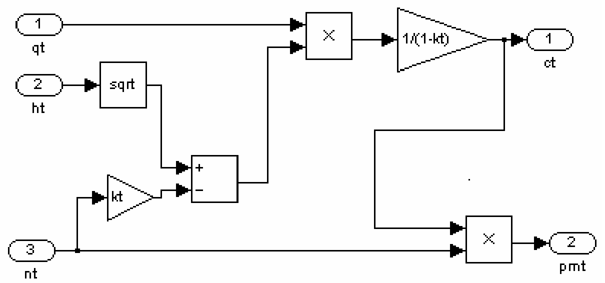

Fig. 5. *Simulink model of a Pelton turbine*

Model of the injector

The injector is formed by a needle which moves in a conical form, its model is obtained by calculation of the area trough which the water jet passes [4, 5]. By taking an injector with the following form (Fig. 6):

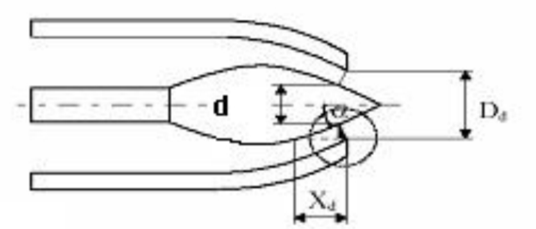

Fig. 6. *Diagram of an injector*

The surface by which water passes is:

$$S_d = \pi \frac{D_d - d}{2} X_d \sin\alpha \quad (15)$$

with: D_d – external diameter of the injector, d – tangential diameter of the needle with the opening of the injector, α – aperture angle of the punch, X_d – opening in meter of the punch (advance).
However:

$$d = D_d - 2X_d \cdot \sin\alpha \cdot \cos\alpha. \quad (16)$$

By replacing d in (16) we obtain S_d:

$$S_d = \pi\sin\alpha\left(D_d X_d - X_d^2 \frac{\sin 2\alpha}{2}\right). \quad (17)$$

The flow in the turbine is:

$$Q_t = S_d V_1. \quad (18)$$

In pu, surface S_d and the needle advance X_d are expressed by:

$$S_d = s_d D_{dn}, \quad (19)$$

$$X_d = x_d X_{dn}. \quad (20)$$

By combining the relations (19), (20) and (17) we end:

$$s_d = \frac{\pi D_d X_{dn} \sin\alpha}{S_{dn}}\left(x_d - k_d x_d^2\right) \quad (21)$$

with: $$k_d = \frac{\sin 2\alpha^2}{2D_d} X_{dn}. \quad (22)$$

For nominal values: $s_d = 1$; $x_d = 1$ we have:

$$1 = \frac{\pi D_d X_{dn} \sin\alpha}{S_{dn}}(1 - k_d). \quad (23)$$

Thus:

$$S_{dn} = \pi \sin\alpha D_d X_{dn} (1 - kd). \quad (24)$$

After replacing S_{dn} by his value we will have:

$$S_d = \frac{x_d(1 - k_d x_d)}{1 - k_d}, \quad (25)$$

and:

$$q_t = S_d \gamma_t \quad (26)$$

from where the following model of the injector (Fig. 7):

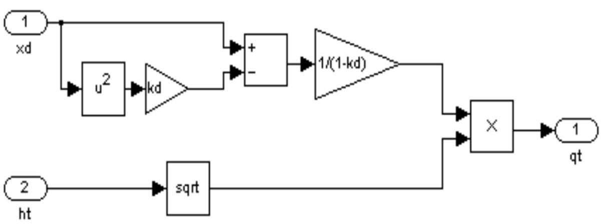

Fig. 7. *Simulink model of the injector*

Regulation of the MHPP and simulation results

Speed regulation of the MHPP

The regulation of a MHPP consists in maintaining fixed the frequency of the electrical network by action on the injector position [2, 5, 6]. This usual regulation is represented in Fig. 8.

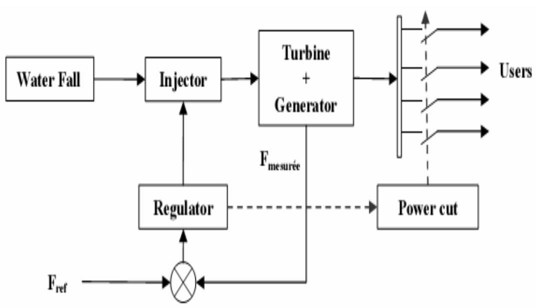

Fig. 8. *Synoptic of an upstream regulation with PID*

The regulation based on a simple PID becomes insufficient in case of an important discharges [5, 7] (see Fig. 9). At the moment of important overload, the needle's speed saturates and generates oscillations of frequency. The stability of the system can be completely lost as show in Fig. 10, 11.

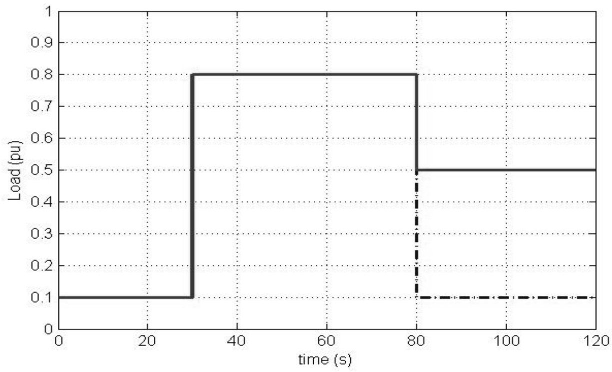

Fig. 9. *Charge and discharges implemented to the turbine: discharge from 70 % (dotted line) and 30 % (solid line)*

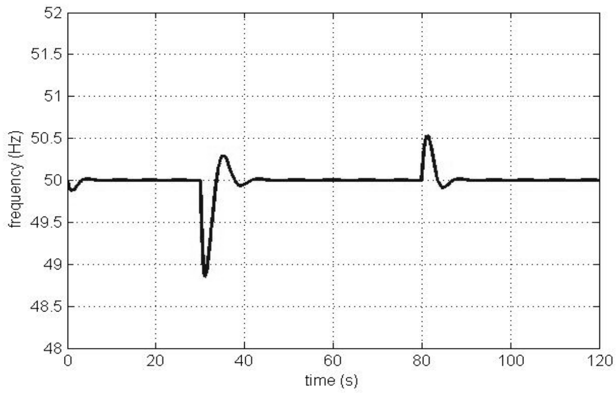

Fig. 10. *Upstream regulation with PID: stability for the small discharges*

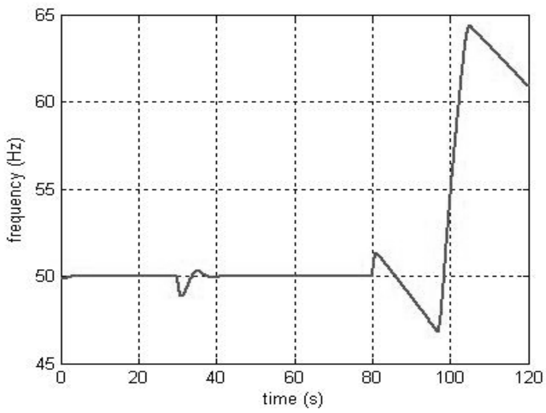

Fig. 11. *Upstream regulation with PID: instability for the important discharges*

Downstream regulation

The downstream regulation is used in order to simplify the MHPP regulation systems and to limit damages caused by the motorized injector [8]. It consists in putting a resistance of dissipation in parallel with the mini electrical supply network (see Fig. 2). The regulator ordres an electronic variator whose time reponse is very short, that makes it possible to absorb immediately the disturbances of the netwark and guarantee a better stability.

The injector is opened to the maximum then the stability is obtained by the dispatching of the electrical power between the load and the resistance of dissipation.

The P controller gives good simulation results with a tiny static error. PI controller cancels the static error and gives good simulation results [9-10] (Fig. 12).

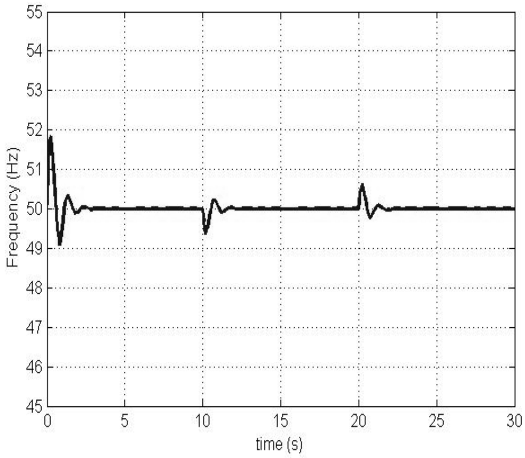

Fig. 12. Downstream regulation with PI controller: stability after an important discharge at 20 s

Practical results and discussion

The practical study is made on MHPP prototype described previously. The electrical load will be considered as a disturbance. It causes the variation of prototype's output (Frequency), as shows in the following Fig. 13.

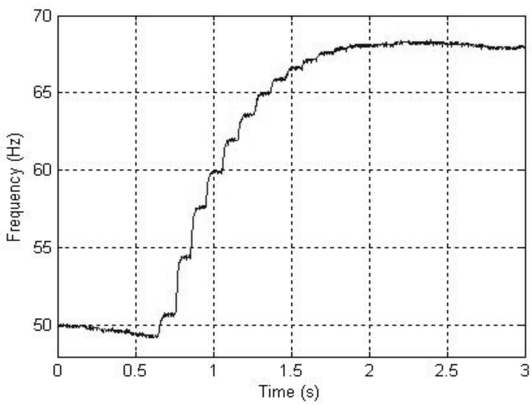

Fig. 13. Evolution of real system's output after a variation of disturbance (P = – 85W) in open loop

The functional plan of our system regulation which we proposed, is given by the Fig. 14. The Fig. 15 shows the components of the real chain of regulation.

Simulation with measured or calculated parameters of the MHPP, gives good result of regulation.

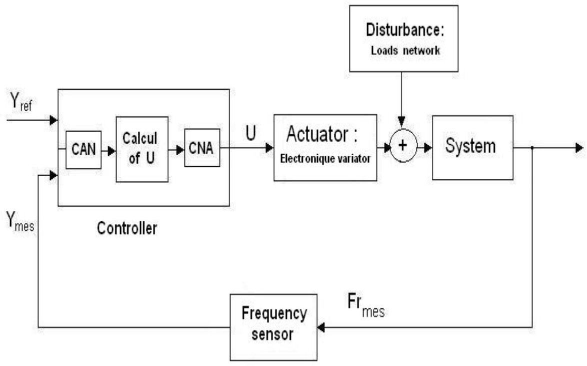

Fig. 14. Functional diagram of the regulation chain

Fig. 15. The real chain of regulation

regulator gives an excellent frequency response after an important discharge (see Fig. 12).

This is practically confirmed with the MHPP prototype (see Fig. 16). The system finds stability in approximately 2 s after the important discharge at 0.3 s and the important overload at 5 s.

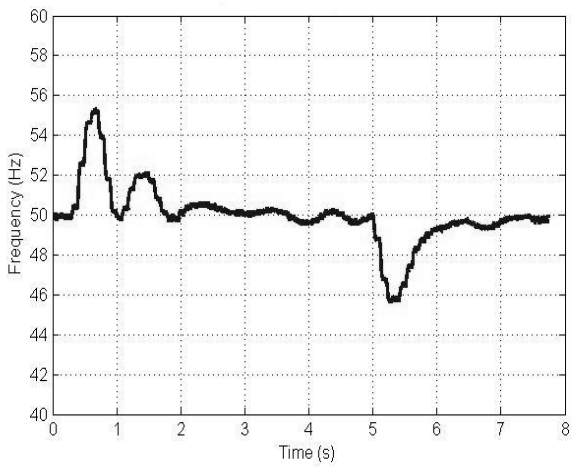

Fig. 16. Downstream regulation with PI (MHPP prototype): stability after the important discharge at 5 s

Conclusion

Hydroelectric energy is renewable, clean and free. Its exploitation requires good regulation systems to produce alternative current with an industrial frequency (50 Hertz). The simulation allows us to test various techniques of regulation: upstream regulation, mixed and downstream regulation.

The technique tested practically and in the simulation is the downstream regulation. It gives good results with few equipments.

The prototype allows the realization of the simulation; the obtained results are satisfying with a PI controller. The regulation is implemented on a PC connected to an acquisition card. Our system can be installed on the existing MHPP and ensure an alternative replacement solution of the complicated and irreparable systems after failure.

References

1. The math works, Inc (1997), simulink user's guide.
2. Chennani M., Doubabi S. Study in simulation of the regulation and the improvement of the output of a micro hydroelectric power station // ICM 05: MARRAKECH, Novembre 2005.
3. CDER. Manuel d'entretien de l'équipement électromécanique de la micro centrale hydraulique de Ouinskra, 1997.
4. Hugo N. Project dynasim // EPF Lausanne Laboratoire d'électronique industrielle, 1999.
5. Chennani M., Doubabi S. Simulation numérique de la régulation d'une micro-centrale hydroélectrique // CIFA 2004: conférence internationale francophone d'automatique, Douz Tunisie, 22-23-24 Novembre 2004.
6. Oscar Daniel Quiroga. Modelling and nonlinear control of voltage frequency of hydroelectric power plants // Doctoral thesis, Universidad Politécnica de Cataluna, Instituto de Organizacion y Control de Sistemas Industriales, July 2000.
7. Göran Andersson. Dynamic and control of electric power system // Lectures 35-528; ITET ETH, March 2003.
8. PACER. Petites centrales hydrauliques, régulation et sécurité d'exploitation // Programme d'action PACER-énergies renouvelables, 1992.
9. Äström K.J, Rundquist L. Integrator windup and How to avoid it // Proceeding of the America control conference, Pittsbourgh, 1989. P. 1693-1698.
10. Hanus R. A new technique for preventing control windup // Journal A. 1980. Vol. 21, No. 1. P. 15-20.