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Regulation of the Position of the Directors of the Turbines of the Hydroelectric Generators case of the Hydroelectric Plant of Imboulou in The Republic of CONGO

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***Abstract*— The purpose of this publication is to present the classical modeling of hydroelectric generators and their regulators. These models make it possible to understand the behavior of the generators and the settings of their regulators using the control theory. The different operating configurations of the hydroelectric generator are first illustrated. The linearity assumptions used for the modeling are then exposed. The modeling of the mechanical speed controllers and PI are subsequently performed.**

***Index Terms*— About Directors, hydroelectric generators, modeling, Regulator, turbines..**

I. INTRODUCTION

The turbine is used to convert the kinetic energy of translation of the water into rotational kinetic energy of the rotor. The power of the machine being proportional to the product of the flow by the pressure. During a rapid increase in the opening of the guides, the water cannot accelerate immediately in the penstock, the flow is therefore constant. However, the larger opening causes a decrease in pressure on the blades of the turbine and produces a decrease in power. When the hydroelectric generator is running to provide power to the electrical grid, it is imperative to control the position of the pipe heads to regulate the flow of water rotating the turbine to produce the desired amount of power (Figure 1-1.). We will take for the numerical application the case of the hydroelectric generators of the hydroelectric power station of IMBOULOU in the Republic of Congo.

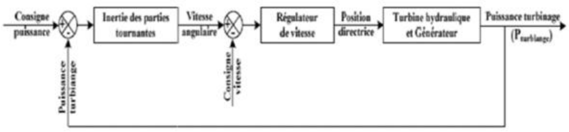


Fig. 1 Functional diagram of the process of regulation of the turbines

II. MODELING OF THE HYDROELECTRIC SYSTEM FOR THE STUDY OF GENERATOR STABILITY ON THE ELECTRICITY NETWORK

Linear models are derived from the physical equations of the system. These models are based on the fundamental equations of hydraulics, mechanics and electricity.

A. Hypotheses of modeling a hydroelectric plant

The modeled turbine is of the Francis type. The assumptions used for modeling are as follows:

- The hydraulic resistance is negligible in the penstock
- The water in the penstock is inelastic
- The active power output of the machine is directly proportional to the position of the directors.

B. Generator Modeling during idle operation

The elements of the vacuum generator model are the penstock, the turbine and the alternator. The transfer function representing the vacuum generator is :

$$G_v(s) = \frac{\frac{1}{f}(1 - T_w s)}{\left(\frac{T_w}{2}s + 1\right)\left(\frac{T_m}{f}s + 1\right)} \quad (1)$$

Where
Gv (s): is the transfer function of the empty generator
f: is the generator's own damping coefficient by friction (p.u.)
S: is the operator of Laplace
Tm: is the mechanical time constant (s)
Tw: is the hydraulic time constant (s)

The functional diagram representing the vacuum generator is shown in Fig. 2.

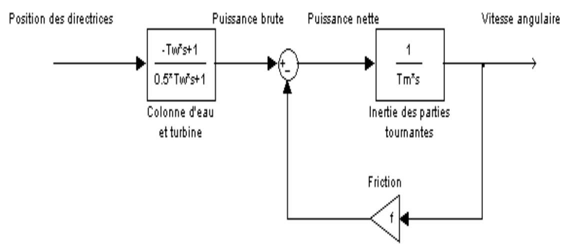


Fig. 2 Functional diagram of the vacuum generator

C. Modeling the generator supplying a load during uninterconnected grid operating

The transfer function of the generator operating on uninterconnected grid is as follows.

$$G_i(s) = \frac{(1 - T_w s)}{\left(\frac{T_w}{2}s + 1\right)(T_m s + (D + f))} \qquad (2)$$

. Where

Gi (s): is the transfer function of the uninterconnected grid

D: is the damping of the load (eg active power / p.u. frequency)

f: is the generator's own damping coefficient by friction (p.u.)

S: is the operator of Laplace

Tm: is the mechanical time constant (s)

Tw: is the hydraulic time constant (s)

The Functional diagram of the generator operating on uninterconnected grid is shown in Fig. 3.

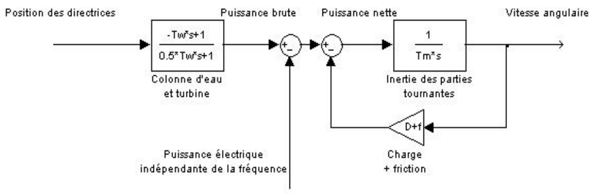


Fig. 3 Functional diagram of the generator operating on uninterconnected grid.

D. Generator modeling during interconnected grid operating

The function of transfer of the speed of the generator according to the position of the directors is shown below:

$$G_r(s) = \frac{\frac{s}{K_s\omega_0}(1 - T_w s)}{\left(\frac{T_w}{2}s + 1\right)\left(\frac{T_m}{K_s\omega_0}s^2 + \frac{K_D}{K_s\omega_0} + 1\right)} \qquad (3)$$

Where

Gr (s): is the transfer function of the generator in network

KD: is the damping coefficient of the generator (p.u.)

Ks: is the synchronizing torque (p.u.)

S: is the operator of Laplace

Tm: is the mechanical time constant (s)

Tw: is the hydraulic time constant (s)

ω0: is the nominal angular velocity (rad /s).

The generator has a speed resonance frequency when it is hooked to a network. The equation of motion of the machine is given by:

$$s^2 + \frac{K_D}{T_m}s + \frac{K_s\omega_0}{T_m} = 0 \qquad (4)$$

The natural frequency of undamped oscillation of the rotor speed is given by:

$$\omega_n = \sqrt{K_s \frac{\omega_0}{T_m}} \text{ (rad/s)} \qquad (5)$$

The damping factor of the rotor speed is given by:

$$\varsigma = \frac{1}{2}\frac{K_D}{\sqrt{K_s T_m \omega_0}} \qquad (6)$$

The Functional diagram of the generator connected to the infinite grid is shown in Fig. 4.

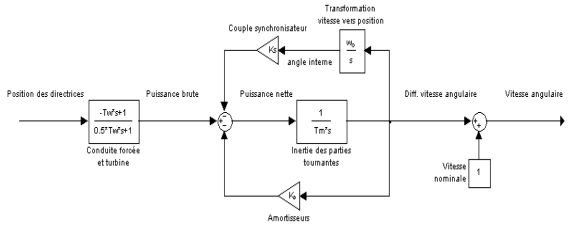


Fig. 4 Functional diagram of the generator connected to the infinite grid

E. Mechanical speed controller modeling

The input of the mechanical speed controller is the speed error and its output is the position of the steers. The elements of the model are the pilot valve represented by a first-order transfer function. The transfer function of the closed-loop mechanical regulator is as follows:

$$G_{cmec}(s) = \frac{\frac{1}{R}(T_d s + 1)}{\frac{T_d T_p}{K_p R}s^3 + \left[\frac{T_p}{K_p R} + \frac{T_d}{K_p R}\right]s^2 + \left[\frac{1}{K_p R} + \frac{K_d T_d}{R} + T_d\right]s + 1} \qquad (7)$$

Where

Gcmec (s): is the transfer function of the mechanical regulator

Kp: is the gain of the pilot valve (s-1)

Kd: is the gain of the damper (without units)

R: is the droop (without units)

Td: is the time constant of the damper (s)

Tp: is the time constant of the pilot valve (s).

The speed controller functional diagram is shown in Fig. 5.

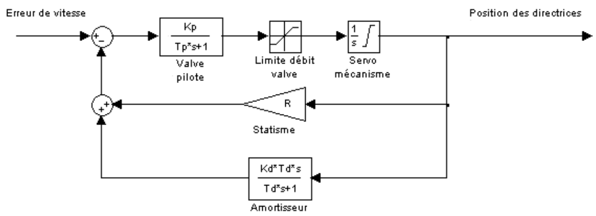


Fig. 5: Functional diagram of the mechanical speed controller

F. Integral proportional speed controller (PI) modeling

The transfer function of the PI regulator is as follows if one neglects the time constant of the pilot valve, the dynamics of the servomechanism and that one distributes the gain of the inner loop on Kc and Ki:

$$G_{cpi}(s) = \frac{\frac{1}{R}\left(1 + \frac{K_c}{K_i}s\right)}{\left(\frac{K_c}{K_i} + \frac{R}{K_i}\right)s + 1} \qquad (8)$$

Where

Gcpi (s): is the transfer function of the PI regulator

Kc: is the proportional gain (without units)

Ki: is the integral gain (s-1)

R: is the droop (without units)

The functional diagram representing the PI speed controller is shown in Fig. 6.

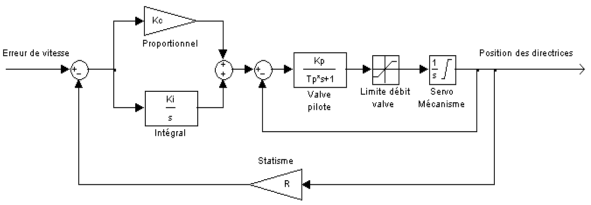


Fig. 6: Functional diagram of integral proportional speed (PI) control

G. *Values of the studied generator parameters*

The values of the machine parameters are grouped in Table1-1:

Generator Settings		Symbol	Value
Hydraulic time constant at nominal load (s)		Tw	1.07
Hydraulic time constant vacuum (s)		Tw’	0.16
Mechanical time constant (s)		Tm	5.61
Three-phase rated output power (MVA)		SB3	28
Rated output voltage (kV)		Vnom	13.8
Rotational inertia (kg m2)		J	535179
Rotation speed (RPM)		n s	163.6
Coefficient of Depreciation of Estimated Load (p.u.)		D	1.5
Coefficient of friction (p.u.)		f	0.15
Estimated torque (power(p.u.) / angle(p.u.))		Ks	0.66
Régulateur mécanique	Gain of pilot valve (p.u.)	Kp	5
	Constant time of the pilot valve (s)	Tp	0.05
	Statism (p.u.)	R	0.05
	Damper gain (p.u.)	Kd	0.44
	Time constant of the damper (s)	Td	5.3

III. Analytical Calculations of the Transfer Functions Values

The transfer functions of the generator in the three configurations are subsequently presented. The transfer function of the vacuum generator is:

$$G_v(s)=\frac{(1-0.16s)}{(0.08s+1)}\frac{6.7}{(37.3s+1)} \tag{9}$$

The transfer function of the generator operating on uninterconnected grid is as follows:

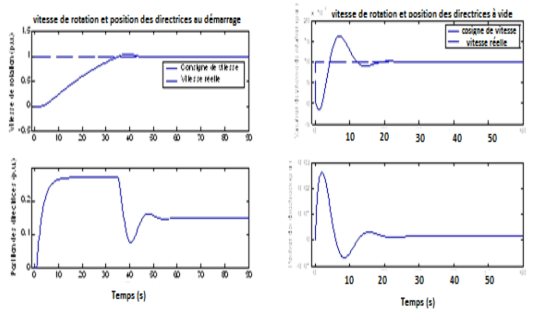
$$G_i(s)=\frac{(1-1.07s)}{(0.535s+1)}\frac{0.67}{(3.74s+1)} \tag{10}$$

The transfer Function of the generator connected to the infinite grid is as follows:

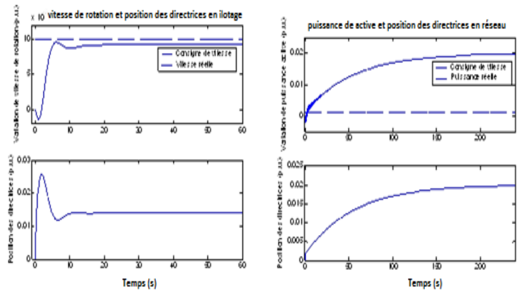
$$G_i(s)=\frac{(1-1.07s)}{(0.535s+1)}\frac{1.5}{(8.5s^2+2.5s+1)} \tag{11}$$

IV. Simulation Results: Responses to the Generator Level Studied

The mathematical equations, the transfer functions of the generator and functional diagrams obtained above are implemented in MATLAB SIMULINK in order to carry out the following simulations. The responses of the generator at startup and at the speed step in the different configurations obtained are shown in the graphs of Figure 1-7.



a) Démarrage à partir de l’arrêt b) Réponse à l’échelon de vitesse à vide



c) Réponse à l’échelon de vitesse en îlotage d) Réponse à l’échelon de vitesse en réseau

V. Analysis of the Results of the Simulation

The position of the starting directors is limited so as not to cause significant over speed. As shown in Figure 1-7a, this constraint is removed as soon as the speed reaches the nominal value for the first time. The droop causes a static speed error with respect to the set point.

The behavior of the vacuum generator is characterized by a very low static error because the process behaves almost like an integrator since the friction draws only a small part of the power of the machine.

The response to the speed step of the island generator according to the conventional settings has a damping which depends on the characteristic of the load. Fig.7c is derived from a simulation performed with typical load damping of 1.5p.u. The lower the load damping, the higher the overshoot.

The response at the grid generator stage involves a high frequency oscillation of the rotor of the machine caused by the synchronizing torque. This oscillation generated by an oscillation of the velocity around the point of equilibrium of phase with the network is visible in Fig. 7d. In this configuration, the response is characterized in power because the speed varies only very slightly and for a short time to change the internal angle of the machine. The rise time of the power is much larger in the network than that of the no-load or islanding speed.

VI. Conclusion

The models of the hydroelectric generators presented in this document make it possible to reproduce the behavior of the generators at startup, empty, islanding and network. The study of the different configurations taken by the generator makes it possible to grasp the variety of behaviors adopted by the generator according to the load connected to it. The understanding of the behavior of the generator and its stability is facilitated by the study of the resulting linear equations.

The results of the simulations allow us to choose a PID corrector for the regulation of hydroelectric generators. We will therefore remember for the PID corrector based on the model we studied and the data collected at the SNE level,

References

[1] G. O. Young, "Synthetic structure of industrial plastics (Book style with paper title and editor)," in *Plastics*, 2nd ed. vol. 3, J. Peters, Ed. New York: McGraw-Hill, 1964, pp. 15–64.

[2] W.-K. Chen, *Linear Networks and Systems* (Book style). Belmont, CA: Wadsworth, 1993, pp. 123–135.

[3] H. Poor, *An Introduction to Signal Detection and Estimation*. New York: Springer-Verlag, 1985, ch. 4.

[4] B. Smith, "An approach to graphs of linear forms (Unpublished work style)," unpublished.

[5] E. H. Miller, "A note on reflector arrays (Periodical style—Accepted for publication)," *IEEE Trans. Antennas Propagat.*, to be published.

[6] J. Wang, "Fundamentals of erbium-doped fiber amplifiers arrays (Periodical style—Submitted for publication)," *IEEE J. Quantum Electron.*, submitted for publication.

[7] C. J. Kaufman, Rocky Mountain Research Lab., Boulder, CO, private communication, May 1995.

[8] Y. Yorozu, M. Hirano, K. Oka, and Y. Tagawa, "Electron spectroscopy studies on magneto-optical media and plastic substrate interfaces(Translation Journals style)," *IEEE Transl. J. Magn.Jpn.*, vol. 2, Aug. 1987, pp. 740–741 [*Dig. 9th Annu. Conf. Magnetics* Japan, 1982, p. 301].

[9] M. Young, *The Techincal Writers Handbook.* Mill Valley, CA: University Science, 1989.

[10] (Basic Book/Monograph Online Sources) J. K. Author. (year, month, day). *Title* (edition) [Type of medium]. Volume(issue). Available:

[11] J. Jones. (1991, May 10). Networks (2nd ed.) [Online]. Available:

[12] (Journal Online Sources style) K. Author. (year, month). Title. *Journal* [Type of medium]. Volume(issue), paging if given. Available:

[13] R. J. Vidmar. (1992, August). On the use of atmospheric plasmas as electromagnetic reflectors. *IEEE Trans. Plasma Sci.* [Online]. *21(3).* pp. 876—880. Available: http://www.halcyon.com/pub/journals/21ps03-vidmar

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