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The Hibrid Control System of a Permanent Magnet D.C. Motor from within the Model of a Hydroelectric Power Plant

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Abstract

This paper presents the results of previous studies on the small hydroelectric power plants experimental models. This model uses a permanent magnet direct current motor (PMDCM) and a voltage supply instead of a real mechanical turbine. The scope of this paper is to propose a solution for hydroelectric power plants system control. A wired serial bus communication is used for data transmission between the processing element of the model, represented by a microcontroller and the central control station, represented by a PC (Personal Computer). A digital cascade control-system for the PMDCM speed and armature current could be implemented throughout the microcontroller in order to control the system. The results obtained in real conditions by using a digital cascade system control are compared with the results of an analog cascade control-system for the PMDCM speed and armature current simulation process.

Keywords: *PI controller, microcontroller, model, digital, analog, speed, current, cascade.*

Introduction

The small hydroelectric power plants located in insolated areas that cannot be permanently controlled have to be monitored from a central control station trough the wireless communication. In this work, an experimental model that uses instead the turbine a permanent magnet direct current motor (PMDCM) a voltage supply and a battery was studied. The PMDCM was wired to the voltage supply and the battery was the load of the generator. Because the experimental model and the control system were close, and to reduce the costs of the experiment a wired serial bus communication was used. (Figure 1)

An ATMEL series – ATmega 16 microcontroller-based control system was chosen to acquire, compute, and monitor the experimental system. The system parameters were the voltage, the current and the speed of the DC motor, the excitation current of the generator, and the voltage and the current of the battery. A digital cascade control-system for the PMDCM speed and armature current could be implemented throughout the microcontroller.

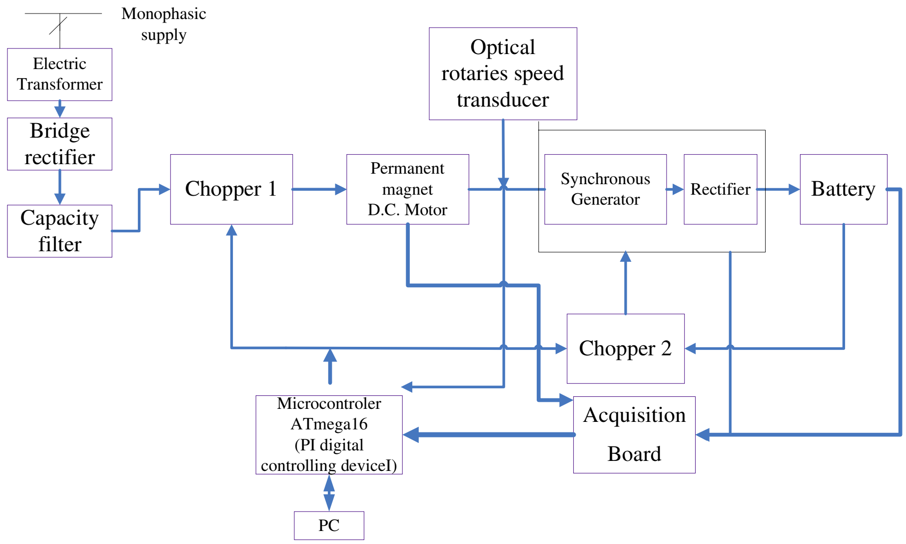

Fig. 1. The hydroelectric plant model block diagram

The Cascade Control System Modeling and Simulation

The PMDCM specifications are:

P_N=360W; V_{aN}=12V; I_{aN}=30A; n_N=50rot/min; R_a=0.2Ω; L_a=2mH; J=$4.57\cdot10^{-6}$Kgm^2; B=$2\cdot10^{-3}$Nm/(rad/s); k_e=0.027V/(rad/s).

The Armature Current (Torque) Control System

The armature current control system block diagram is represented in Figure 2. [1]

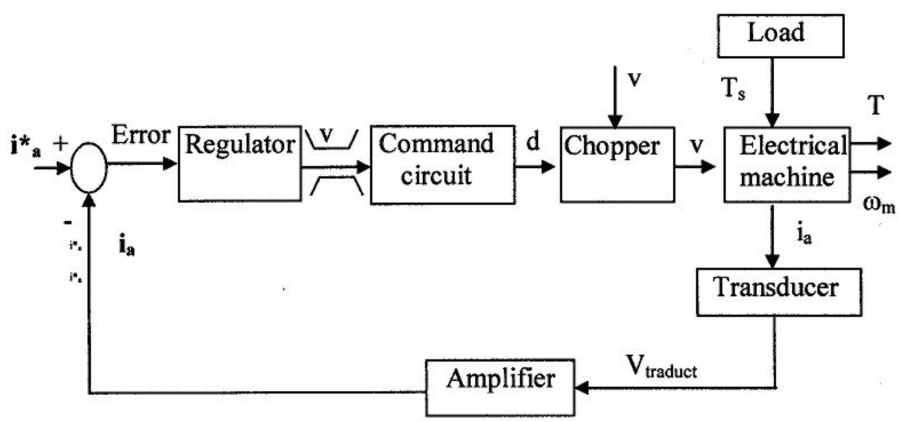

Fig. 2. The armature current control system

The input data for the classical design of the armature current controller are: setting time less than 60ms, the over-dumping σ<10%, and zero stationary error. A proportional plus integral (PI) controller has to be used. [2]

The transfer function of the PI controller is:

$$G_{ri}(s) = k_{Pi} + k_{Ii} / s \tag{1}$$

A frequency response-based algorithm will be used in purpose to compute the controller's coefficients k_{Pi} and k_{Ii}. A f_I=3750Hz cutoff frequency was chosen because the dominant pole is situated at the 750.301Hz frequency. With a 60^0 (1.134rad) phase margin the computation are given the following values: k_{Pi}=0.318 and k_{Ii}=250. The computations were done in the MathCAD software environment.

The system's step response with rated current amplitude is representing in Figure 3.

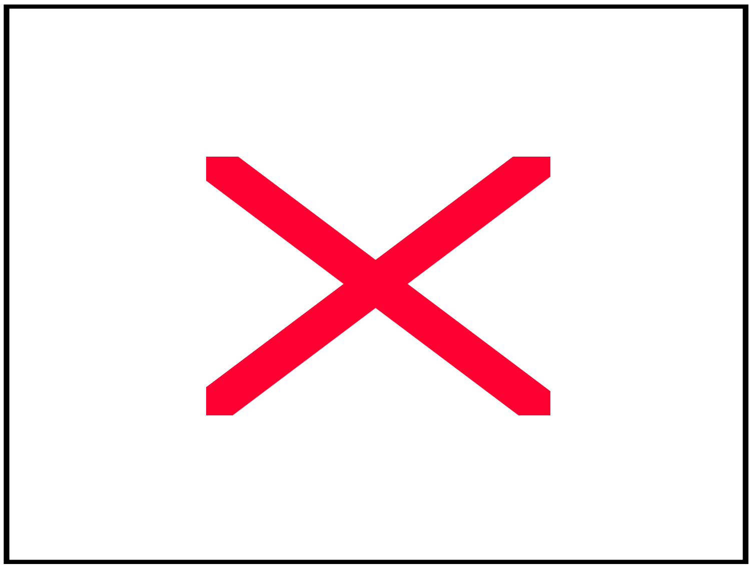

Fig. 3. Time characteristic of the system at load with rated current.

The results prove 6% over dumping, 30ms setting time and a stable system.

The speed control system

According to the cascade model, the speed controller is outer the current controller, the output of the speed controller is the current controller input. The desired characteristics for the PI controller are: over dumping σ<10%, and setting time <30ms. The previous algorithm for the PI controller coefficients computation is used. The cut-off frequency is 10 times smaller than the current regulation thus f_I=375Hz and the phase margin is 60^0. Follows k_{Pw}=3.04 and k_{Iw}=1289. In Figure 4 the Bode diagram when the armature voltage is the input and the axle angular speed is the output of the state system are shown. [3]

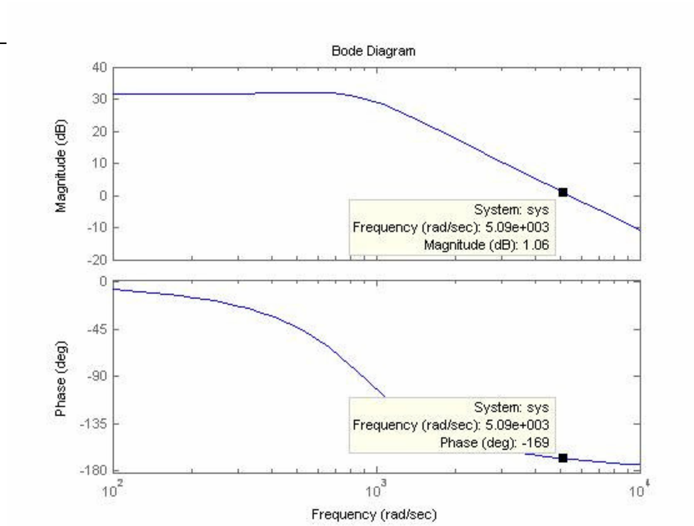

Fig. 4. The Bode diagrams of the state system. The input is the armature voltage, and output is the axle angular speed

The response to speed set-point changes (rated step response) is represent in Figure 5.

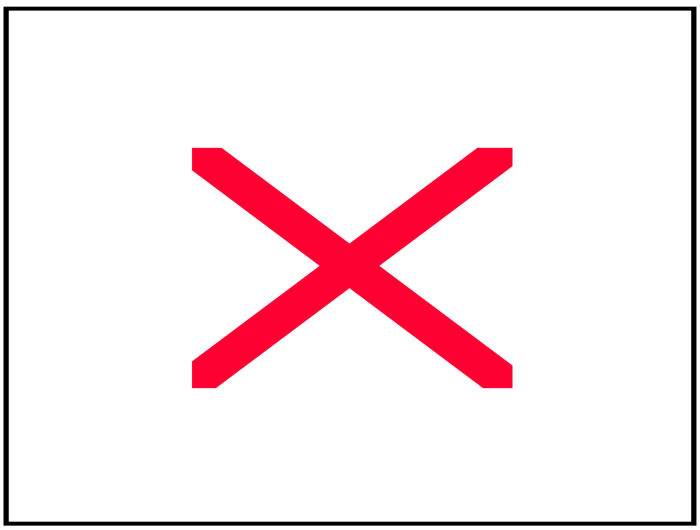

Fig. 5. Time characteristic of the system to speed set-point changes for rated step speed input

The stationary regime is achieved at t_s=10ms<30ms.

The Current's PI Digital Controller

The ATmega 16 microcontroller has a 11.05Hz clock and embedded analog-to-digital converter. This converter can implement the computation unit of the PI control law in the time domain, the pulse-width modulation of the command pulses, and the analog-to-digital conversion of the analog inputs. The PI control law in the discret time domain is given by the equation:

$$d[n] = d[n-1] + a \cdot e[n] + b \cdot e[n-1], \tag{2}$$

where:

d[n] - is the actual value of the control variable;

d[n-1] - the previous value of the switch duty ratio ;

e[n] - the actual value of the error (the input variable that has to be controlled);

e[n-1] – the previous value of the error;

a, b – the controller's characteristics; to compute these characteristics an algorithm that accounts quality indicators and controlled system's performances has been used.

The hardware structure of the system and the signals fluxes are presented in Figure 6. [5]

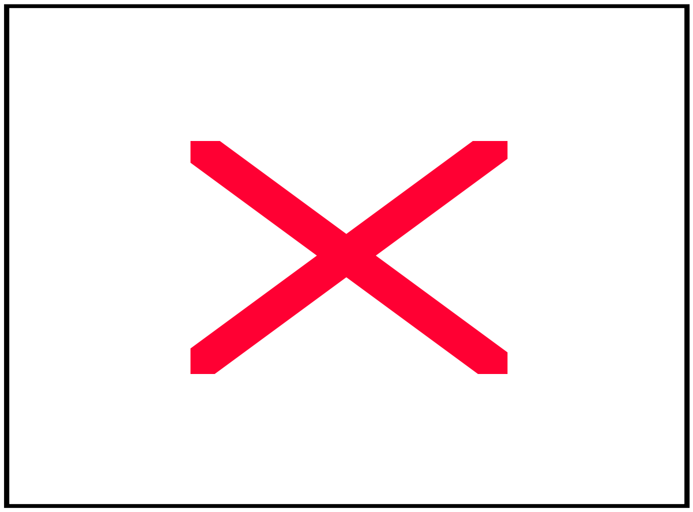

Fig. 6. The block diagram of the digital controller – chopper system

The values of the variables at consequently time instants are multiplied with the specific coefficients of the controller. When using the digital multipliers the multiplication is a heavy work because they are large and slow components. Therefore, table data storage is a better option (Figure 7).

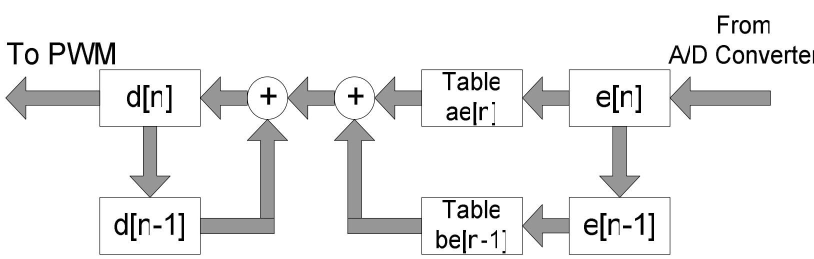

Fig. 7. Table-based PI digital controller

As we can see, the actual command value is the sum between the previous command and the table outputs. This is important from the memory space management: because the switch duty ratio varies into large scope values and computation results would require large tables.

It is important to find an optimal structure that satisfies both the static and dynamic specifications of the controller. The system has two components (Figure 8):

- the state-space in continuous-time domain;
- the state-space in discrete-time domain.

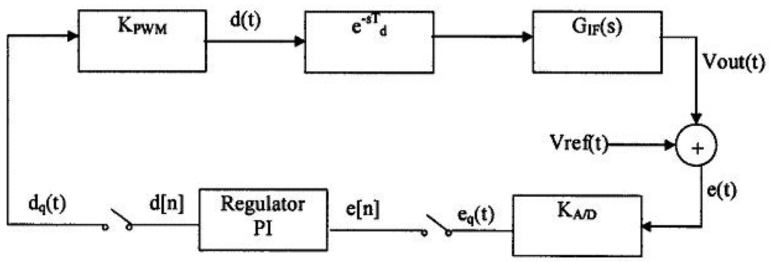

Fig. 8. The block diagram of the continuous-time system, the data sampling and the discrete-time system.

The transfer function of the PI controller can be written in the continuous-time domain as follows: [4]

$$G_r(s) = K_p(1 + s/Q\omega_N)/s, \tag{3}$$

where:

ω_N – is the natural frequency;

K_P – is the gain of the controller;

Q – is the resonance factor.

In the expression (3) the Z-transformation is applied. Results the PI control law in the discret-time domain (the zero-poles transformation method is to be used):

$$d[n] = d[n-1] + K_p\left(e[n] - 2\cdot r\cdot \cos\left(2\pi\frac{f_n}{f_e}\right)e[n-1]\right) \tag{4}$$

where:

f_n – is the natural frequency corresponding to the zero-pairs of the PI controller;

f_e – is the sampling frequency.

The following representation was used:

$$r = \exp(\pi f_n / Qf_e) \tag{5}$$

With ω_N=131.42rad/s, from par. 2.1, $f_n=\omega_N/2\pi=20.92s^{-1}$.

Te sampling frequency is usualy chosen:

$$\omega_e = \frac{2\pi}{T_e} = (6 \div 25)\omega_B,$$

where $\omega_B = \omega_n\sqrt{1-2\zeta^2+\sqrt{2+4\zeta^2+4\zeta^4}} = 1{,}5-\zeta^2$

for $\zeta = (0{,}5 \div 0{,}9)$.

The sampling frequency was chosen with respect to the microcontroler ATmega 16 embedded analog-to-digital converter conversion time-delay. When choosing the 75μs speed for the value 11.05MHz of the clock's frequency the minimum ε=3% conversion error is achieved. The sampling frequency $f_e=133s^{-1}$ is obtained after the required transformations are applied. The corresponding sampling angular frequency is $\omega_e=2\pi f_e$=835rad/s thus $\omega e\approx 6.27\omega_B$.

The resonance factor can be computed using the relation:

$$Q = \frac{M(j\omega_r)}{M(0)} = \frac{M_v}{M(0)} = \frac{30dB}{30dB} = 1 \qquad (6)$$

The variables M_v and M(0) are given from state-system Bode diagram (Figure 4).

Afterwards we compute: $\cos(2\pi f_n/f_e)=0.99$ and r=0.493.

Subsequently we obtain the control law with the so-determined coefficients:

$$d[n] = d[n-1] + 3,04(e[n] - 0976e[n-1]) \qquad (7).$$

The Control Law Implementation

The PI control law (7) was software implemented within the ATmega 16 microcontroler. The PMDCM speed has to be controlled in purpose to obtain both the desired output voltage and load current. Using the graphical user interface realized in the Visual BASIC software environment the predicted speed is introduced. The microcontroler code-program receives the actual speed value via the serial bus and compares it with the predicted speed value. If an error occurs, the DC-converter command pulse width ratio is modified according the PI control law. In the operation interface a controller that allows the predicted value's input is added; next a stop button is introduced and the *Send* button will become the system's start button (Figure 9).

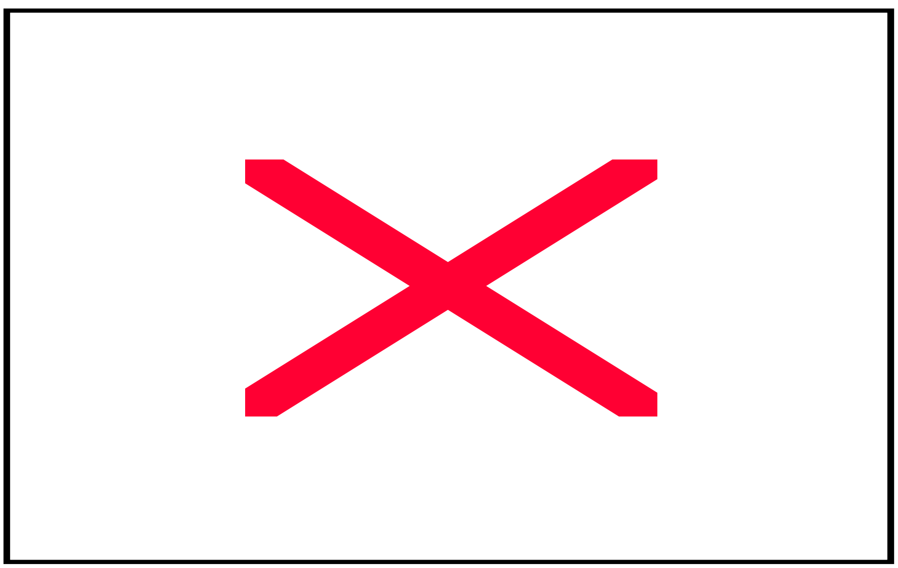

Fig. 9. The application interfaces for system control

When the excitation of the generator is modified the load variation occurs. The test results revealed that when high speed is achieved electric energy is produced. Thus a greater than 25rot/min of the predicted speed value must be introduced when the disturbance occurs.

Conclusion

The modeling and simulation of the cascade control system allowed fulfilling a current continuous-time controller that achieves the specifications: over-dumping, short value setting time, zero stationary error (when ramp input in applied) and stable system. The computation algorithm was based on the Bode diagram results and implemented in the MathCAD software environment; both were easy-to-use and gave the expected results.

The control-law of the current's digital controller was based on the simulation's results. It was implemented into the microcontroller ATmega 16 that allows a properly sampling frequency.

An upgraded ATmega 128 microcontroller has an additional 16 bits timer that allows the speed signal processing simpler than in the first case without the counter saturation storage. The received values are integrated so the errors are eliminated. When using the ATmega 128, the data transmission was realized through a special function located in a special library called ICCAVR – Image Craft Developer; this allowed to eliminate a lot of conversions.

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Sistem de reglare hibridă al motorului de curent continuu cu magneți permanenți din modelul unei hidrocentrale electrice

Rezumat

În această lucrare sunt prezentate rezultatele obținute în urma unor studii precedente asupra unui model experimantal reprzentat de o mică hidrocentrală electrică. Acest model utilizază în locul turbinie mecanice un motor de curent continuu cu magneți permanenț și o sursă de alimentarei. Scopul lucrării este de a propune o soluție în ceea ce privește realizarea unui sistem de reglare pentru hidrocetrală.. Pentru transmisia datelor și a comenziilor între elementele de procesare a modelului, reprezentat în cazul de față de un microcontroler și stația centrală, reprezentată de un PC se utilizează o rețea cablată de comunicație serială. Pentru a realza controlul modelului un sistem digital de reglare în casacadă a curentului și turației motorului de curent continuu cu magneți permanenți este implementat utilizând un microcontroler. Rezultatele obținute în condiții reale în urma utilizării unu sistem digital de reglare în cascadă sunt comparate cu cele obținute din simularea sistemului analogic de reglare în casacadă.