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Open-Loop Control of Hybrid Stepper Motor with Two Phases Using Voltage to Frequency Converter

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***Abstract*- Positioning systems are powered by different types of electric motors. A special category of electric motors, which are increasingly used in systems, are hybrid stepper motors (the most common example are with two phases). Due the simplicity of construction, command and control, they are used even in other electric drive systems. This paper presents a new method of Matlab simulation of a controller driver for a hybrid stepper motor with full step sequence, using a voltage to frequency converter. The results of the simulation of the proposed control scheme are quite satisfactory.**

***Keywords*: full step, combinational logic, hybrid stepper motor**

I. INTRODUCTION

The Hybrid Stepper Motors (HSM) are motors that convert a digital pulse train in precise incremental movements [1-5]. The above properties show that HSM motor is compatible with digital command and control systems[3-4].

Most popular HSM are composed of a stator and two rotors. The motor stator has two control windings, each is placed on two diametrically opposed statoric poles. Rotors are spaced axially by a permanent magnet at the periphery, which shows teeth uniform distributed and the first rotor is radially shifted with on tooth [3].

The HSM develops mechanical torque higher than the torque produced by stepper motors with variable reluctance [3][4].

The HSM is commanded in the following modes: wave drive, normal full step, half step[3-5]. Wave drive mode involves a single phase power sequential alternating voltage phases. Normal full step mode involves of two phases power alternating voltage phases. Half step mode involves alternated one phase - two phases-one phase power [3-4].

This study refers to a hybrid stepper motor controlled by the pulse train coming from a voltage-frequency converter (V/F converter) simulated in Matlab-Simulink software using full step sequence (one-phase-on).

II. THE MATHEMATICAL MODEL OF THE HSM

The mathematical model of HSM used is described in [1-5]. Motor differential equations are:

$$\frac{di_a}{dt} = \frac{1}{L_a}\left[U_a - R_a i_a + k_m \omega sin(N_R\theta)\right],$$
$$\frac{di_b}{dt} = \frac{1}{L_b}\left[U_b - R_b i_b - k_m \omega cos(N_R\theta)\right],$$
$$\frac{d\omega}{dt} = \frac{1}{J}\left[-k_m i_a\, sin(N_R\theta) + k_m i_b\, cos(N_R\theta) - B\omega - k_D - Mr\right],$$
$$\frac{d\theta}{dt} = \omega \;. \qquad (1)$$

where: i_a and i_b are the phase currents, U_a and U_b are the phase voltages, L_a and L_b are the phase inductances, R_a and R_b are the phase resistances, Nr are the number of rotor teeth, J is the rotor inertia, B is the viscous friction constant, k_m is the rotor torque constant, ω is the rotor speed, θ is the rotor position and Mr is the load torque. [1],[3-5]. The $k_D{\cdot}sin(4Nr{\cdot}\theta)$ represents the produced torque due to the permanent rotor magnet interacting with the magnetic material of the stator poles and k_D is typically 5% to 10% of the value of $k_m{\cdot}i_0$, where i_0 is the rated current [3],[5]. Implementation of differential equations described in (1) in in Matlab-Simulink is illustrated in Fig 1.

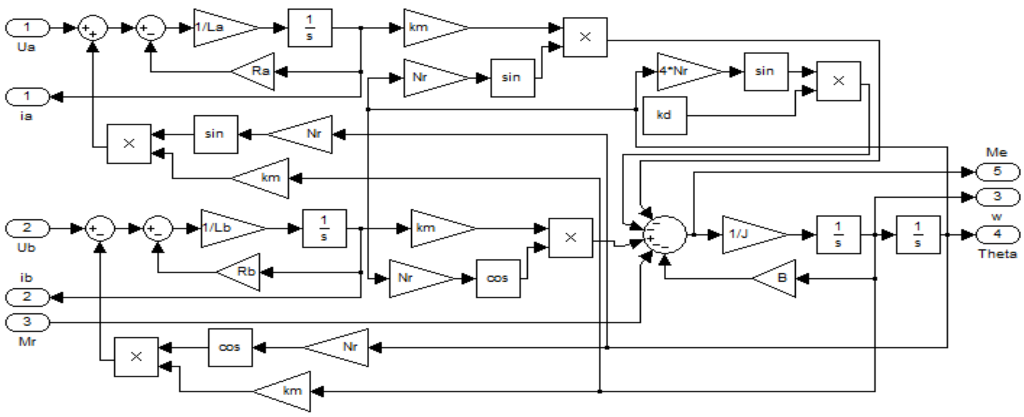

Fig. 1.Implementation in Matlab-Simulink of the mathematical model.

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III. THE SIMULATED CONTROL SYSTEM

Over the years there have been a number of systems designed for command and control in wired logic. Today, these systems are partially or fully replaced by microprocessors. The system control implemented in Matlab-Simulink is illustrated in Fig. 2.

Through combinational logic circuits, the problem can be solved by implementing logic functions with a minimum logic gates. [8].

Truth table of minimized logical functions shown in TABLE 1.

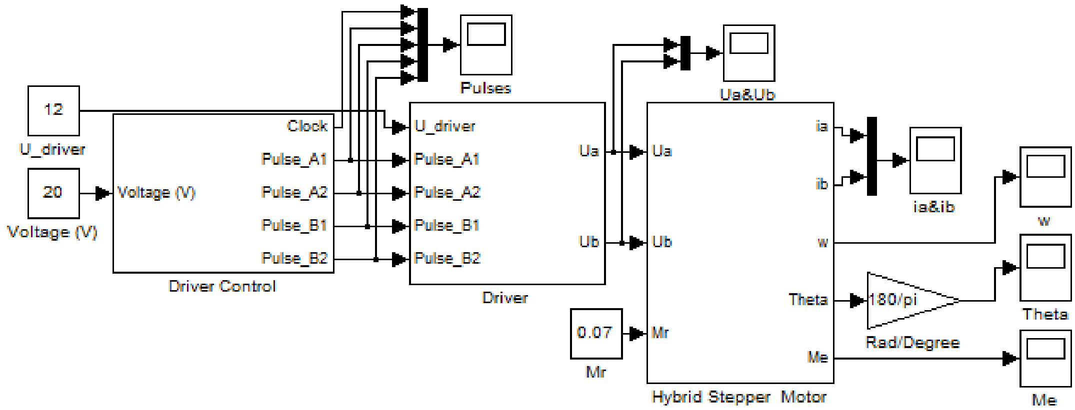

Fig. 2. System control implemented in Matlab-Simulink.

The simulated control system is composed of controller driver, hybrid stepper motor and load torque (Mr). The controller driver generates pulses for driver command wave drive mode. The driver powers motor phases. Motor phases are energized bipolar voltages pulses. In this case the voltage pulses frequency for steady state also illustrates the property of the operation motor in stepping mode.

The simulated controller driver is composed of V/F converter and pulses generator for wave drive mode.

A. Voltage to Frequency Converter

V/F Converter is intended to convert the voltage into a digital pulse train with frequency equal to that of voltage input [6]. This can be done using timer 555, operational amplifiers and circuits specialization. For example, one V/F converter commonly is used LM331 [3][6-7].

Control voltage may come from resistive divider (potentiometer) or a controller. If the simulated converter has a variation input voltage of 1V then after it will have to get a variation of digital pulse frequency of 1Hz.

Pulse train at the output converter is shown in Fig. 3.

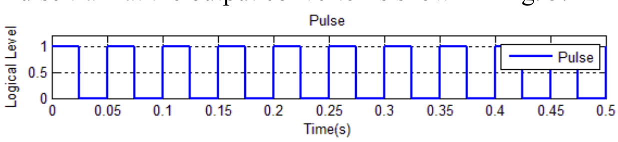

Fig. 3. Pulse train at the output converter.

B. Pulse Generator for Full Step Sequence

The motor is powered using one phase only [3-4]. Supply phase sequence is: B1, A2, B2, A1, B1….

For microcontroller, the command pulses for the driver are generated according to the power phase sequency.

Determination drivers command pulses was achieved using combinational logic [3]. They are comprised of basic logic gates whose operation is described by Boolean algebra.

TABLE I
TRUTH TABLE

A	B	C	Phase
1	1	1	B1
0	1	1	
1	0	1	A2
0	0	1	
1	1	0	B2
0	1	0	
1	0	0	A1
0	0	0	

where: A-is the output signal from the converter, B and C are signal A divided by 2 and 4. This is illustrated in Fig. 4.

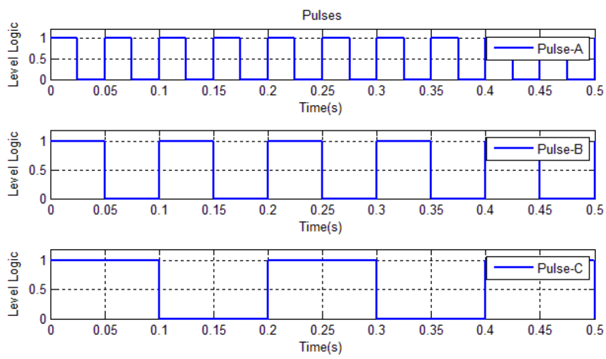

Fig. 4. Out signals A, B and C.

In practice this can be done easily using two D-type bistabiles or a count [9].

Minimization function was accomplished using the diagram Karnaugh [9-10]. Simulink Implementation of the minimized functions for the driver command pulses are illustrated in Fig. 5 and also in fig. 6. Is illustrates control signals for the driver full step sequence.

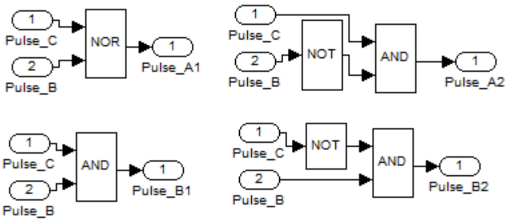

Fig. 5. Functions to minimize the driver command pulses.

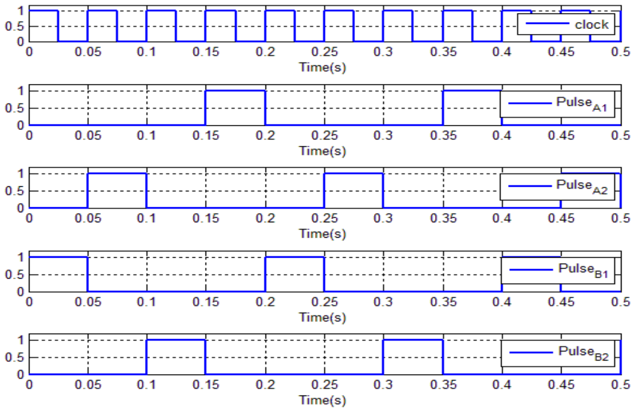

Fig. 6. Control signals for the driver full step sequence.

IV. The Driver

The HSM motor phases are supplied with alternating voltages. Bipolar voltage is obtained using two H-Bridge inverters [1][3-4]. As switching elements H-bridge inverters using bipolar, MOS-FET and IGBT transistors [1]. These switching elements are controlled by pulses from the controller driver.

Each H-Bridge has one bridge of four diodes, connected in reverse parallel with the switching transistors, provides the path for freewheeling currents. The freewheeling path includes the dc supply and therefore some of the energy stored in the phase winding inductance at turn-off is returned to the supply [4].

Supply voltage of phases is shown in Fig 7.

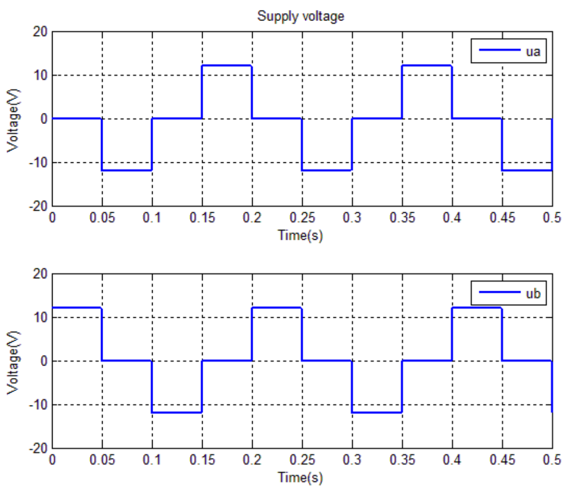

Fig. 7. Spply voltage of phases.

V. Simulation Result

The HSM used has the following parameters (described in [3]): L_a=L_{b}=12 mH, R_a=R_b=11 Ω, B=0.025 Nm/rad/s, Nr=50, J=1.125×10^{-4} kgm^2, k_m=0.22 Nm/A, Mr=0.07 N, k_d=0.022 Nm.

Performance simulation was done at different input voltages (input voltage frequency converter is HSM speed). Below are presented the experimental results of the motor with a frequency of 20Hz.

Fig. 8. illustrates the waveforms of the current through the motor phases. From Fig. 8. it can seen that the current has the same form as the supply voltage.

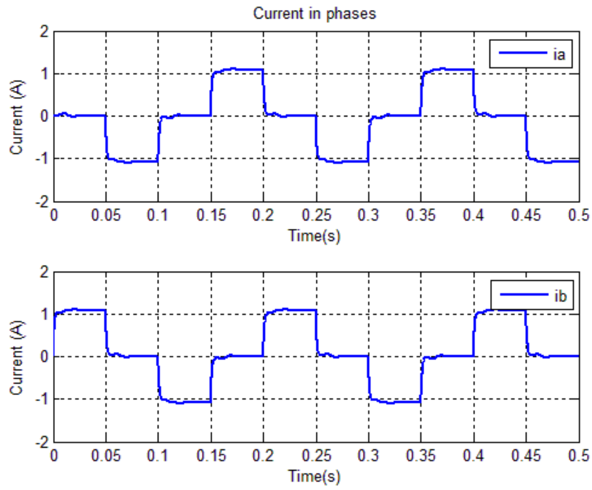

Fig. 8. Current in phases.

Motor speed varies at each step executed by the HSM. Evolution rotor speed is shown in Fig. 9. Rotor speed increases, reaching a maximum value and then decreases. The speed takes the value zero when the rotor reach steady state.

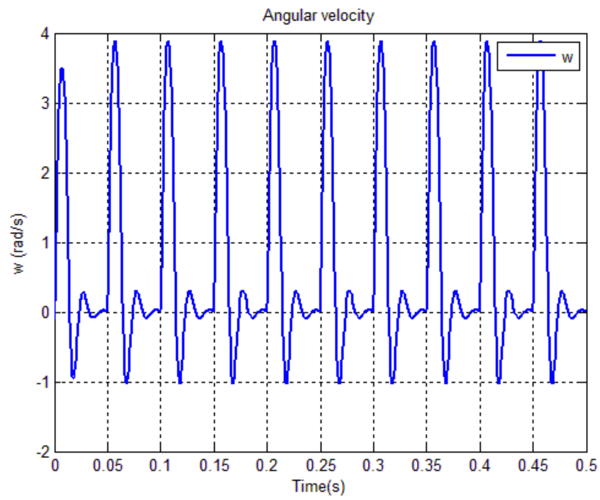

Fig. 9. Angular velocity of the rotor.

Torque developed by HSM is dependent on the rotor position, this is illustrated in Fig. 10. From the figure we can see that the motor develops high torque at low speeds compared to other motors. Also, the motor torque is higher than the resistent torque.

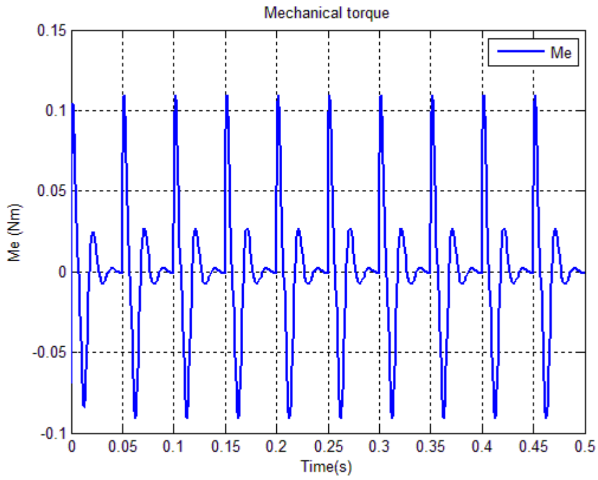

Fig. 10. Mechanical torque.

Each transition from low to high of command pulses (V/F converter) cause the rotor to move one step, as illustrated in Fig. 11. We see that the control pulses are synchronous with steps.

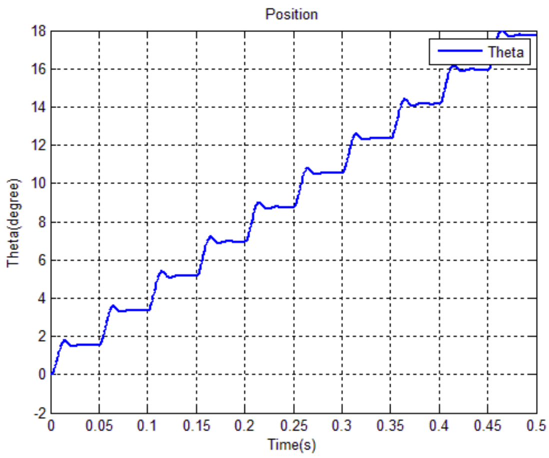

Fig. 11. Steps executed by HSM.

VI. Conclusions

This paper presented the HSM control with full step sequence using combinational logic in Matlab-Simulink.

Also, can be implemented and control half-step and one-phase-two-phase-one-phase-on.

Using the model in Matlab-Simulink, the maximum frequency command can be verified experimentally in the steady state of the HSM. In addition, it can illustrate the variation of current, speed and torque for each step.

Proposed system is easy to implement and has a practical low cost. It can be used for teaching and for understanding the hybrid stepper motor operation by students.

Hybrid stepper motor operation in this mode has the following disadvantages:

- torque developed by the motor shows ripple;

-engine speed has high oscillations;

-executed step motor is not sufficiently amortized;

The system can be implemented on closed-loop, in this case the voltage control is given by a Controller (eg PID, Fuzzy Controller).

References

[1] Q. S. AL-Sabbagh, A. S. Mahdi, *PULSE WIDTH MODULATION HIGH PERFORMANCE HYBRID STEPPER MOTOR*, Journal of Engineering, Number 4, Volume 16 December 2010.

[2] A. Kelemen, M. Crivii, *Motoare electrice pas cu pas*, Editura Tehnica, Bucuresti,1975.

[3] A. Morar, *Comanda inteligentă a acționărilor electrice cu motoare pas cu pas*, Editura Mediamira, Cluj Napoca, 2007.

[4] P. Acarnley, *Stepping Motors - A guide to theory and practice*, 4th Edition, The Institution of Electrical Engineers, London, 2002.

[5] M. Zribi, J. Chiasson, *Position Control of a PM Stepper Motor by Exact Linearization*, IEEE TRANSACTIONS ON AUTOMATIC CONTROL, Vol 36, NO 5, MAY 1991.

[6] LM 331 V-F Converter (www.fairchildsemi.com)

[7] S.D. Anghel, *Amplificatoare Operaționale în sistemele de masură*.

[8] S.D. Anghel, *Bazele electronicii analogice si digitale*.

[9] Z. F. Baruch, *Arhitectura calculatoarelor*, Editura TODESCO, Cluj-Napoca, 2000, ISBN 973-99780-7-x (pp. 56 – 64, 117 – 125).

[10] D. O. Overfield, United States Patent, Patent number: 4417189, Nov. 22.1983 (www.google.com/patents/US4417189).