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The utilization of the PWM inverter feeding in the asynchronous motor command

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In this paper, the acquisition of new control tools and the improvement of the PWM inverter feeding in the asynchronous motor command are considered. In the asynchronous machine, the directions flow and the electromagnetic torque are closely tied. The scalar command law allows to maintaining the flow and consequently the electromagnetic torque constant for high frequencies. However, this law is very insufficient at low frequencies, what leads us to proceed with the field-oriented asynchronous pulse-width modulation, for high-performance asynchronous machine drives operating at low frequency. The performances of this command are evaluated by using results of simulation realized by the MATLAB software under the SIMULINK environment. The obtained simulation results prove the efficiency of the PWM signal in the command and give excellent electrical magnitude performances of the system. With this easy model, the simulated system, constituted by the asynchronous machine and the two levels voltage inverter, is achieved in a very short time interval and the obtained results are interesting.

INTRODUCTION

Up to date, the numerical command of asynchronous machines remains of interest as shown in the most recent research works [1, 2]. In our paper, the acquisition of new control tools and the improvement of command are considered. During a varying speed drive (asynchronous machine – voltage inverter), the ideal command is to be able to find an adjustment characteristic of the electromagnetic torque identical to that the continuous current machine.

In this paper, we study the control of the electromagnetic torque while maintaining a constant flow [3]. Before any synthesis of numerical command laws, it is necessary to analyze the process to control, to establish an adapted modeling and to interpret its dynamics. The choice of the simulation program and the equations simplifications lead us to establish an information graph for the command. It indicates clearly the blocks articulation and the command meaning [4].

In an asynchronous machine, the directions flow and the electromagnetic torque are closely tied. It is necessary to be able to untie them in order to suitable choose the regulators parameters. On the other hand, the scalar command law $V/F = constant$ only allows to maintain the flow constant and consequently the electromagnetic torque constant for high frequencies. However, this law is very insufficient at low frequencies, what leads us to proceed with the vector command with the orientation of the flow. This allows to improve the performances of the system asynchronous machine-voltage inverter, either in the course the transient regime or in the course of the permanent regime despite the disturbances that are able to intervene while the system operates. As area of applications of the association "asynchronous machine-inverter" and for small powers less then 10 kW, one uses them in the electro-spits, centrifuge. As for average and high powers greater than 1 MW, they are used in pumps, ventilators, compressors, mixers, machines-tools [5].

1. PRINCIPLE

Electrical machines feed by static converters are used as rotary actuators in a many industrial equipments of varying speed. The actuator characteristics depend at the same time on the machine, its feeding and the command of the whole system [6]. These characteristics are:

- A torque with the minimum possible undulation;
- Controlled by the smallest variables number;
- A large range of varying speed;
- Small electrical and mechanical time constants.

The dynamic control of the asynchronous motor is a more delicate but recent works [2, 3] on the vector control have already shown its feasibility. Beside the used technology, one is always interested in the ratio quality/price, thus one tries realize the high performances of the most economical product. Because of the *PWM* structure of the variator, it presents a major disadvantage in the noise level that is very high. As its structure of command is entirely numerical, the *PWM* modulator of the variator is directly linked to the variator. The success of the variator speed has a good optimization of the *PWM* system. For that, it is necessary [2, 7, 8]:

- To make the good choice of the commutation elements;
- To have a good numerical structuring of its command allowing an adaptability of the *MATLAB* software under the *SIMULINK* environment.

2. BLOCK DECOMPOSITION OF THE SYSTEM

The principle is based on the decomposition of the system to study in blocks and in under blocks and to establish relationships between them [1, 3]. Then, the following formulae have been established, describing the operation of the system under study (see Fig. 1).

2.1. Asynchronous machine subsystem

The system to study is a not linear system [8]. Our objective is to render it a linear model for the purpose of facilitating the command techniques utilization. Because of the complexity of the asynchronous machine model, it is desirable to apply the PARK transformation so as to undertake a change of three phased axis (a, b, c) in a two phased referential (d, q) (see Fig. 2).

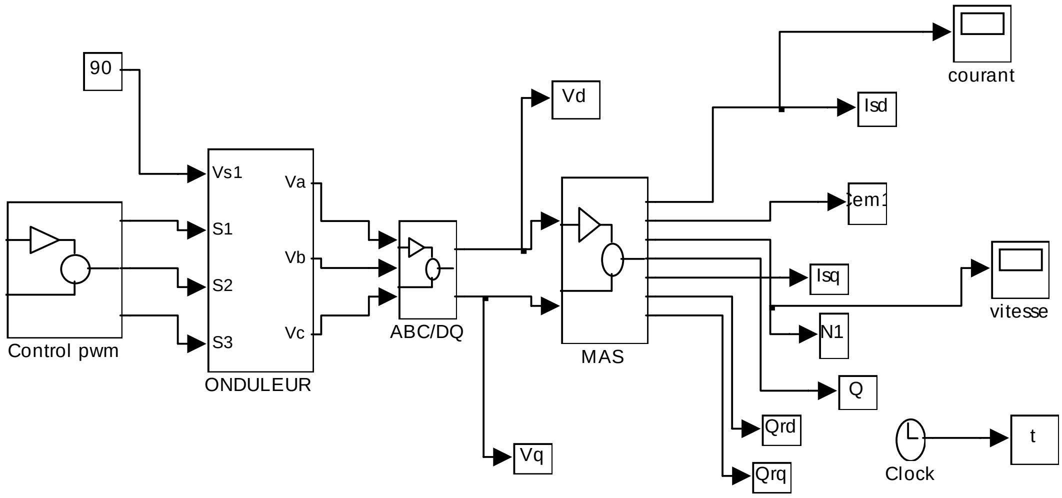

Figure 1. Command of the associated *PWM* inverter-asynchronous machine system voltage feed

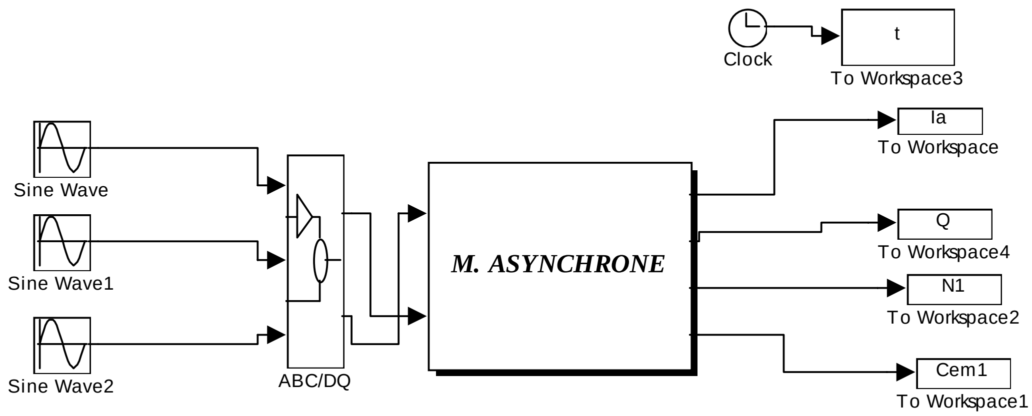

Figure 2. Asynchronous machine subsystem

The state vector is:

$\left[I_{sd};\ I_{sq};\ \Phi_{rd};\ \Phi_{rq};\ \omega_m\right]^T$.

We write I_{rd}, I_{rq}, Φ_{sd}, Φ_{sq} with the state variables chosen. Settlement form of the machine state equations:

$$I_{rd} = \frac{\Phi_{rd}}{L_r} - \frac{M}{L_r} I_{sd}\,; \tag{1}$$

$$I_{rq} = \frac{\Phi_{rq}}{L_r} - \frac{M}{L_r} I_{sq}\,; \tag{2}$$

$$\Phi_{sd} = I_{sd} L_s \sigma + \frac{M}{L_r} \Phi_{rd} ; \tag{3}$$

$$\Phi_{sq} = I_{sq} L_s \sigma + \frac{M}{L_r} \Phi_{rq} , \tag{4}$$

where Φ_{rd}, Φ_{rq} are the components torque of the rotor respectively to axis *d* and *q*; I_{sd}, I_{sq}, I_{rd}, I_{rd} are the components current of the stator and the rotor respectively of axis (*d*, *q*); σ is the dispersion coefficient:

$$\sigma = 1 - M^2 / L_s L_r . \tag{5}$$

The mathematical model is:

$$\frac{dI_{sd}}{dt} = \frac{1}{\sigma L_s}\left(-\left(R_s + \frac{M^2}{L_r T_r} \right) I_{sd} + \sigma \omega_s L_s L_{sq} + \frac{M}{L_r T_r} \Phi_{rd} + \frac{M}{L_r} \omega_m \Phi_{rd} + V_{sd} \right); \tag{6}$$

$$\frac{dI_{sq}}{dt} = \frac{1}{\sigma L_s}\left(-\left(R_s + \frac{M^2}{L_r T_r} \right) I_{sq} - \sigma \omega_s L_s L_{sd} + \frac{M}{L_r T_r} \Phi_{rq} - \frac{M}{L_r} \omega_m \Phi_{rd} + V_{sq} \right); \tag{7}$$

$$\frac{d\Phi_{rd}}{dt} = \frac{MI_{sd}}{T_r} - \frac{\Phi_{rd}}{T_r} + (\omega_s - \omega_m)\Phi_{rq} ; \tag{8}$$

$$\frac{d\Phi_{rq}}{dt} = \frac{MI_{sq}}{T_r} - \frac{\Phi_{rq}}{T_r} + (\omega_s - \omega_m)\Phi_{rd} , \tag{9}$$

where V_{rd}, V_{rq} are the components voltage of the rotor of axis *d* and *q* respectively and V_{sd}, V_{sq} are the components voltage of the stator of axis *d* and *q* respectively; R_s, R_r are the stator and the rotor resistance and L_s, L_r are the stator and the rotor self-induction; ω_s is the pulsating of the stator field; M is the mutual of the self-induction; T_s, T_r are the time constant to stator and rotor respectively.

The mechanical equation of the induction machine is:

$$\frac{d\omega_m}{dt} = \frac{p M^2}{JL_r}\left(\Phi_{rd} I_{sq} - \Phi_{rq} I_{sd} \right) - \frac{pL_r}{J} - \frac{K\omega_m}{J} , \tag{10}$$

where ω_m is the pulsating of the rotor field.
The equation of electromagnetic torque is:

$$C_e = p \frac{M}{L_r}\left(\Phi_{rd} I_{sq} - \Phi_{rq} I_{sd} \right),$$

where C_e is the electromagnetic torque and p is the number of pair pole.

This modeling has shown a strong coupling between the flow and the electromagnetic torque. It is therefore interesting to use the indirect vector command of rotor flow orientation so as to improve their performances in dynamic regime [5, 10].

2.2. Inverter Sub-System

It is composed a three phased bridge of six power switches, essentially thyristors (see Fig. 4). Its main role is to deliver a power signal as close as possible to the command signal coming from the regulation and command sub-block. [9]. Before any synthesis of command laws, it is necessary to analyze the process to control, to establish a adequate modeling and to interpret its proper dynamics. The digital algorithmic command envisaged to operate the converter, necessitates the sampling and the quantification of magnitudes [3, 5, 9]. Others constraints are present as for example, the imperfection of the source, the sampling of the converter, the delay due to the opening time and closing time of the thyristors. To each switch K_{ci} corresponds a connection function f_{ci} [3, 4] with:

$$f_{ci} = 0 \;\Rightarrow K_{ci} \; open\,, \tag{11}$$

$$f_{ci} = 1 \;\Rightarrow K_{ci} \; closed\,. \tag{12}$$

One defines the connection function as follows:

$$f_{c1} + f_{c2} = 1\,. \tag{13}$$

Each inverter arm is formed of two complementary switches in such away that that it realizes the connection function [4] (see Fig. 3). The following equations for *PWM* inverter feeding: (phased-neuter voltage/axis (*a*, *b*, *c*)) [5, 9]:

$$v_{an} = \frac{u}{2}\left(\frac{2v_a - v_b - v_c}{3}\right)\;; \tag{14}$$

$$v_{bn} = \frac{u}{2}\left(\frac{-v_a + 2v_b + v_c}{3}\right); \tag{15}$$

$$v_{cn} = \frac{u}{2}\left(\frac{-v_a - v_b + 2v_c}{3}\right) \tag{16}$$

and following the referential (α, β):

$$v_{s\alpha} = v_{an}\,; \tag{17}$$

$$v_{s\beta} = \frac{v_{cn} - v_{bn}}{\sqrt{3}}\,, \tag{18}$$

where $v_{s\alpha}, v_{s\beta}$ are the components voltage of the stator to follow the axis (α, β).
Following the referential (d, q):

$$v_{sq} = v_{an}\,; \tag{19}$$

$$v_{sd} = \sqrt{\frac{2}{3}}\,(v_{cn} - v_{bn})\,, \tag{20}$$

where v_{sq} ; v_{sd} are the components voltage respectively of the stator to follow to axis (*d*, *q*).

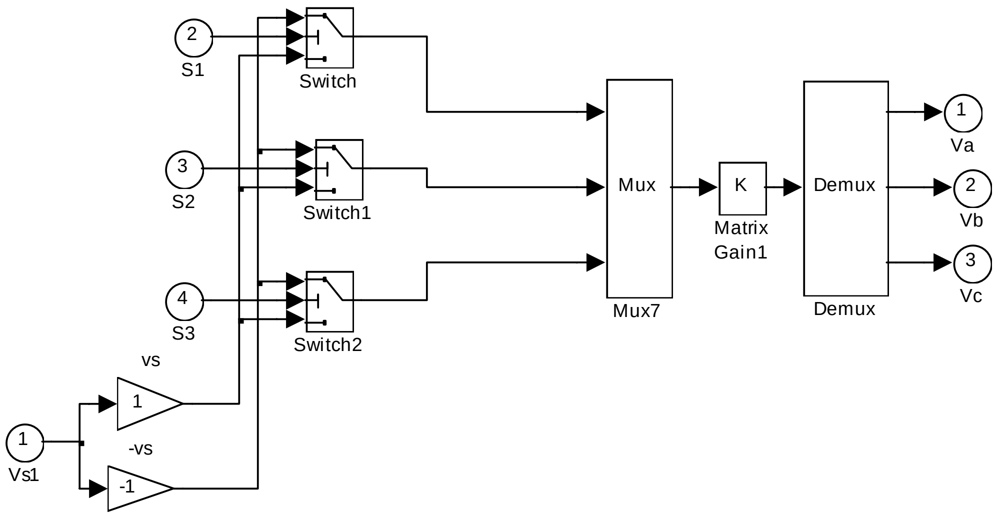

Figure 3. PWM inverter feeding

2.3. Rectifier sub-block

The rectifier sub-block is a three phased bridge formed of six diodes placed at the output of the alternative three phased network, its role is to deliver a waved rectified continuous voltage that will be (*L*, *C*) filtered.

2.4. Input filter and output filter sub-block

The input filter plays an essential role in the power under block of the inverter. Its role is to filter the waved continuous voltage to the rectifier output.

2.5. Auxiliary power feeding sub-block

The sub-block of the auxiliary power feeding is under the form of a transformer to multiple secondary.

2.6. Regulation and command sub-block

The regulation and command sub-block is formed by (see Fig. 4):

- Measures and collector system;
- Modulation systems;
- Algorithmic command;
- User interface.

The *PWM* command block is composed at: [3, 5, 9]:

- Carrier block;
- Reference block;
- Compared digital block;
- Digital command block.

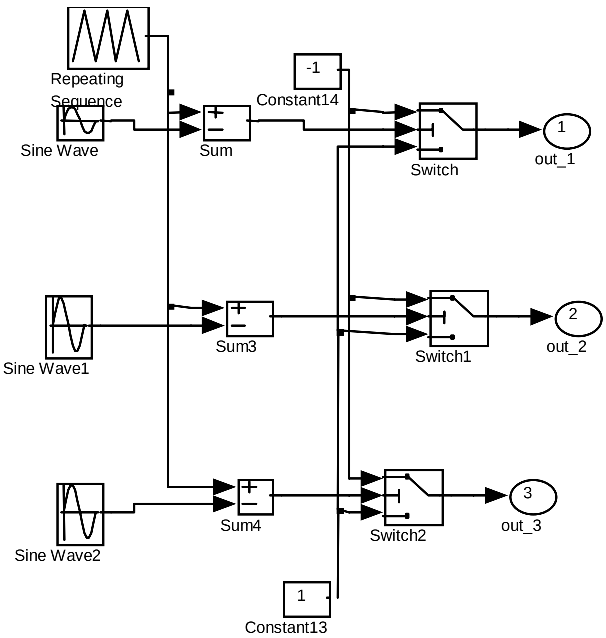

Figure 4. PMW command

The signal of carrier wave has amplitude u_p and frequency f_p, so the equations system are:

$$X_1 = -3u_p + 4\frac{u_p}{T_p}t; \tag{21}$$

$$X_2 = +u_p - 4\frac{u_p}{T_p}t; \tag{22}$$

$$T_p = \frac{1}{f_p}. \tag{23}$$

The reference signal has amplitude u_m and frequency f_m:

$$u_{m1} = u_m \sin \omega t; \tag{24}$$

$$u_{m2} = u_m \sin(\omega t - 2\pi/3); \tag{25}$$

$$u_{m3} = u_m \sin(\omega t - 4\pi/3); \tag{26}$$

$\omega = 2\pi f_m$ is the pulsating of the reference signal. (27)

3. SIMULATION RESULTS

The performances of this command are evaluated by using results of simulation realized by the *MATLAB* software. The figures below evaluate the obtained results quality in either open loop or closed loop. In the indirect vector command of the inverter–asynchronous motor system voltage feed, the obtained results quality shows the decoupling efficiency between the flow and the torque:

- In the open loop, the control between the flow and the electromagnetic torque is perfectly realized. Curves show that the decoupling affects weakly the flow where controlled magnitudes are i_{sd} and i_{sq} (see Fig. 6);
- In the closed loop, the speed response time is really reduced comparing with the preceding case. Despite the abrupt variations of the torque, the flow components Φ_{rd} and Φ_{rq} remain constant which shows the perfect decoupling between the flow and the torque (see Fig. 7).

By following the comparative test of the main control laws, one observes that the speed evolution is better which is to the benefit of the indirect command law in low and averages speed.

CONCLUSIONS

The simplicity of the used model in the simulation of the system constituted of the asynchronous machine and the two levels voltage inverter to *PWM* has allowed us to realize simulations in a very short time interval. The obtained simulation results prove the efficiency of *PWM* signal in the command and give excellent electrical magnitude performances of the system. In the open loop, the simulations results show that the torque responses are highly corrupted with noise and are weak of amplitude namely at low speeds. In closed loop the simulation shows high performances. Our current results concern the improvement of results obtained during the simulation in order to make the control of the speed and of the position more reliable at very low frequencies.

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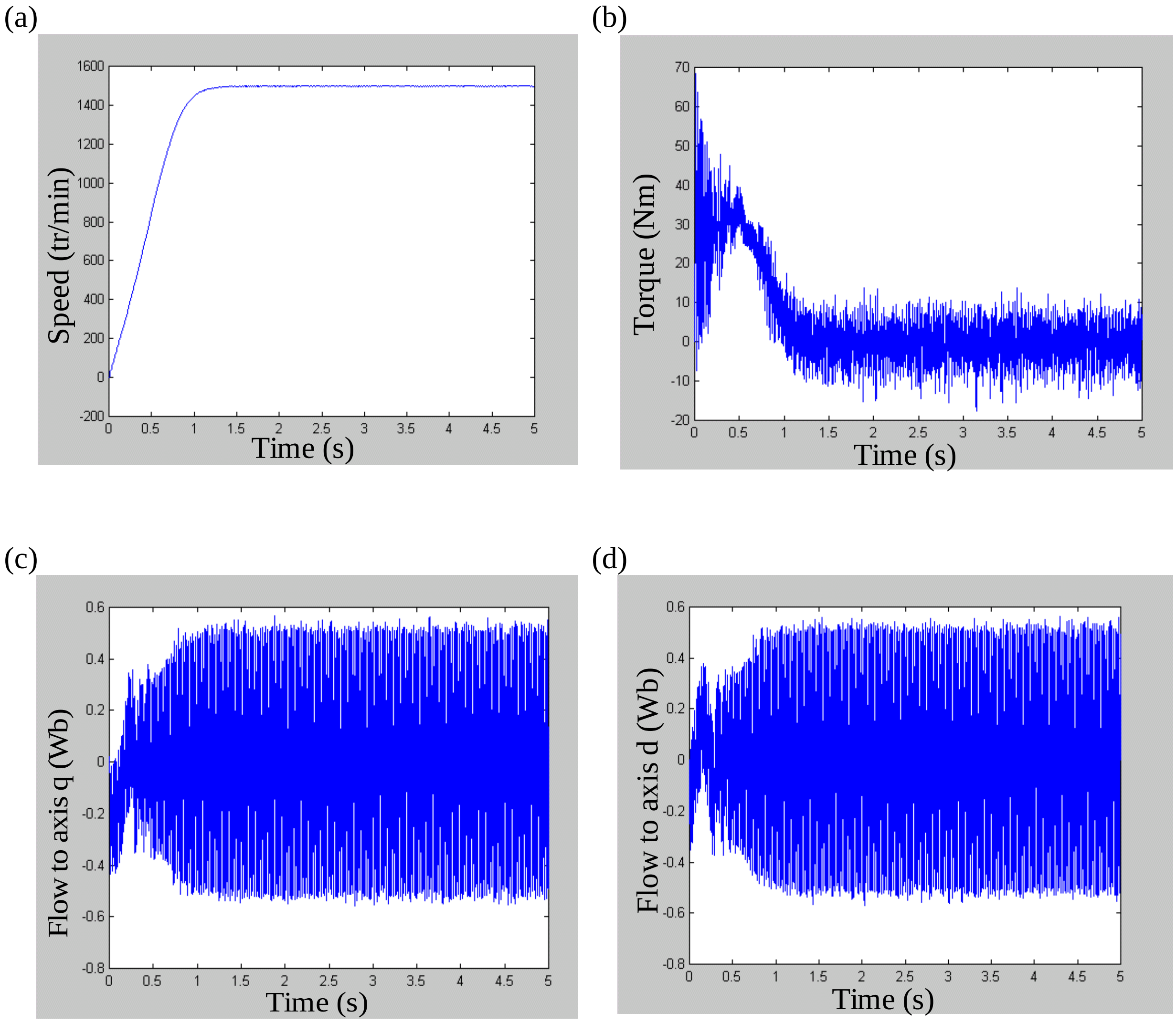

Figure 6. Electrical and mechanical values of the system (open loop):
speed (a); electromagnetic torque (b); component of the flow to axis *q* (c);
component of the flow to axis *d* (d)

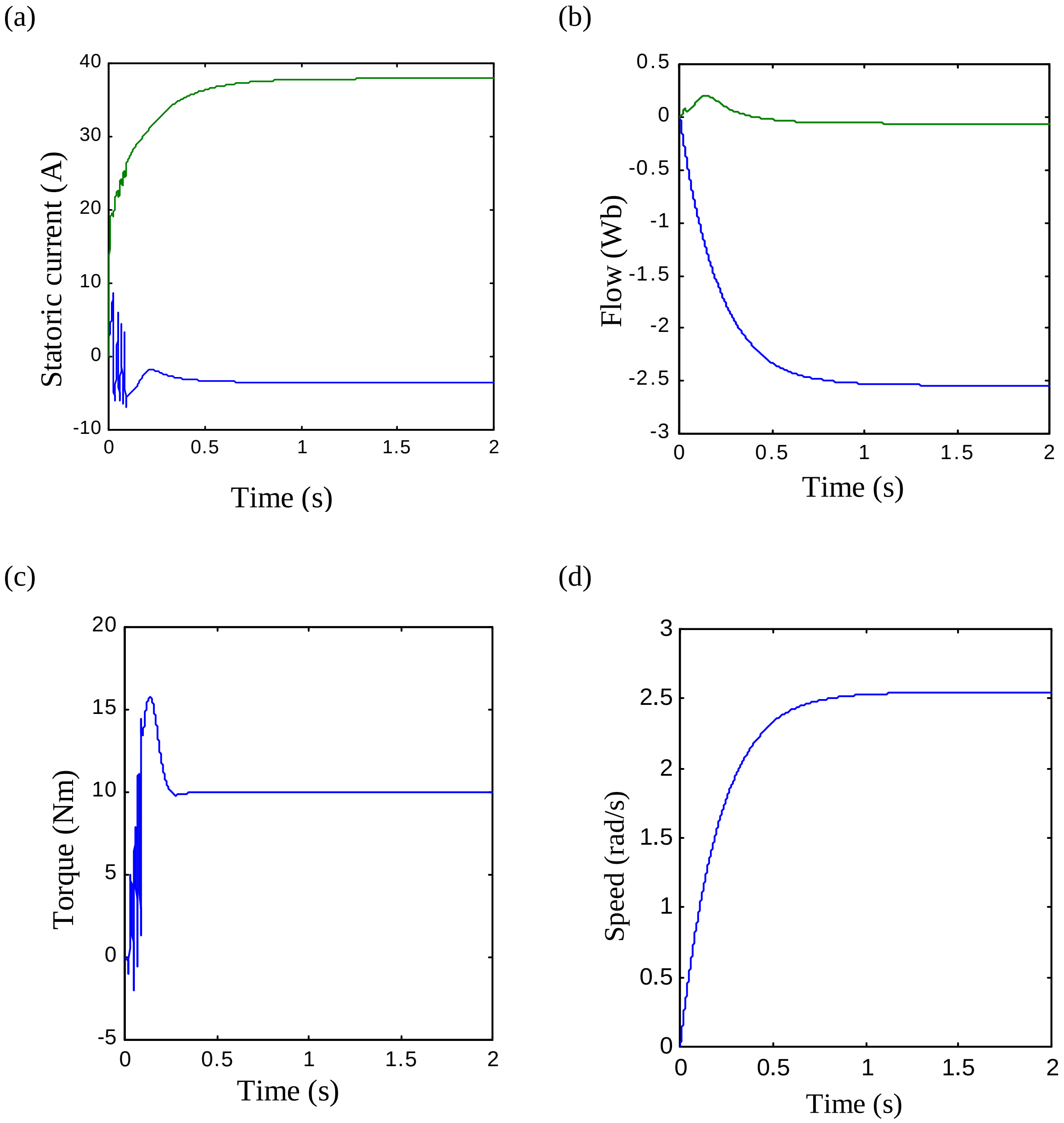

Figure 7. Electrics and mechanics values of system (in closed loop): plot of components current to axes *d* and *q* (a); plot of the flow (b); plot of the torque (c); plot of speed (d)

APPENDIX

SYMBOLS AND NOTATIONS

Φ_s, Φ_r	Flow respectively to stator and rotor
Φ_{sd}, Φ_{sq}	Components flow of the stator respectively to axis *d* and *q*
Φ_{rd}, Φ_{rq}	Components flow of the rotor respectively to axis *d* and *q*
V_s, V_r	Voltage respectively of the Stator and the rotor
V_{rd}, V_{rq}	Components voltage of the rotor respectively of axis *d* and *q*
V_{sd}, V_{sq} :	Components voltage of the stator respectively of axis *d* and *q*
I_s, I_r	Current respectively of the Stator and the rotor
I_{sd}, I_{sq}	Components current of the stator respectively of axis *d* and *q*
I_{rd}, I_{rq}	Components current of the rotor respectively of axis *d* and *q*
R_s, R_r	Resistance of the stator and the rotor
L_s, L_r	Self-induction respectively of the stator and the rotor
T_s, T_r	Time constant respectively to stator and rotor
C_e	Electromagnetic torque