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DC BRUSHLESS DRIVE SYSTEM SUITABLE FOR VEHICLE PROPULSION

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ABSTRACT

This paper analyses the dynamic performances of a VSI-DC brushless drive system suitable for an electrical vehicle propulsion. The main original part of the work is a computer simulator realized in Matlab-Simulink sofware package, based on the laboratory practical experiments. To monitorize and control the motor parameter variations and influences during the variable frequency motor dynamics, an evaluation board with DSP TMS320C31 based on the dSPACE system is used. With the simulator tool is possible also, to estimate the motor demagnetizing reaction during the starting conditions (at constant torque operation). To minimize the losses of VSI-DCBM drive, the following main goals are proposed: optimum PWM technique to reduce the inverter commutation losses, new fast isolated drivers for the IGBTs of inverter and new programming algorithms for the DSP controlling device.

Keywords: voltage source inverter, dc brushless motor, drive system, vehicle propulsion.

1. INTRODUCTION

During the recent years the performances of the DC Brushless Motors (DCBM) were enhanced by the technological progress and the power & control devices evolution. As a result, this motor type is finding an increasing application extending the traction ones. Since to their low inertia, dynamic response and a high power to weight ratio, there is a large interest to use of DCBM in electrical vehicle propulsion. Because of their flexibility and power density efficiency, these drives are quite suitable to provide constant torque operation below the base speed and constant power operation for a wide speed range between the base and maximum speed. Based on [2, 4], a DCBM with segmented magnets has been used in order to reduce the torque ripples. To reduce the IGBT inverter commutation losses, an optimum sinusoidal PWM technique was designed [1, 3].

2. DRIVE SYSTEM DESCRIPTION

The drive system consists in a voltage-source PWM inverter with IGBTs, fed an DCBM as load and a “logic unit” which main includes the drivers for the IGBT inverter and the DSP TMS320C31 based on the dSPACE system as control unit. The simplified structure of the systems is depicted in the Figure 1.

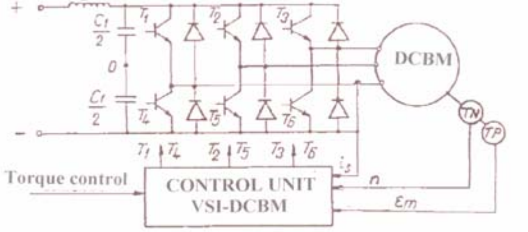


Figure 1. The VSI-DCBM drive system

Based on the motor d,q model, the general torque equation results as:

$$T = \frac{3}{2}\, p\, [\Psi_o\, i_q + (L_d - L_q)\, i_d\, i_q] , \tag{1}$$

where:
L_d , L_q – are the d,q axes stator inductances ;
Ψ_o – is the PM magnetic flux;
p – is the pole pairs number;
i_d , i_q – are the d,q axes armature currents.
To the equation (1) it must be associated the d,q axes stator voltage and current equations, as follows:

$$\underline{v}_S = v_d + jv_q , \qquad \underline{i}_S = i_d + ji_q . \tag{2}$$

At starting (see Figure 2), to provide a constant torque, the armature current $\underline{i}_S$ must have only the q axis $\underline{i}_S = ji_q$ component, with the following expression:

$$i_q = \frac{2}{3}\, p\, \frac{T}{\Psi_o + (L_d - L_q) i_d} . \tag{3}$$

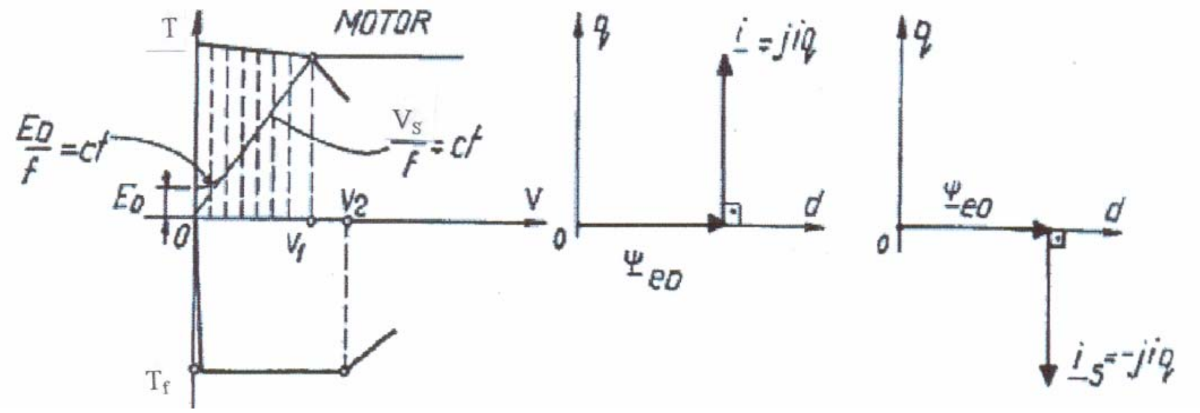


Figure 2. Characteristics and phasor diagrams at DCBM at constant torque operation

To have maximum torque, at starting, the following condition must be accomplished:

$$E_o / f_p = V_1 / f_1 = V_2 / f_2 = \ldots = V_n / f_n = ct., \tag{4}$$

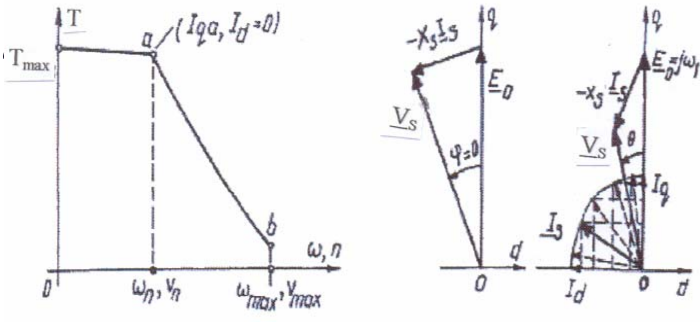
where:
E_o – is the PM electromotive force;
V_1, V_2, ..., V_n – are the armature voltage values, at the variable frequencies f_1, f_2, ..., f_n.
The ***constant power operation*** (see Figure 3) deals with the equations and the phasor diagram as follows:

$$\underline{V}_S = (R_S + j\,\omega_1 L_S)\, \underline{I}_S + j\,\omega_1\, \underline{\Psi}_o , \tag{5}$$

where the DCBM armature current is

$$\underline{I}_S = I_d + j\, I_q , \tag{6}$$

and have a circle as geometric loci.



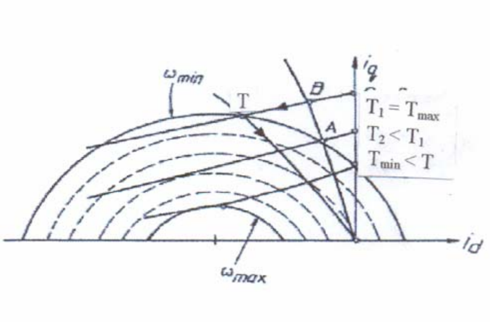


Figure 3. Traction characteristic and phasor diagram

Figure 4. Loci for i_d and i_q currents

During the constant power operation within the range a-b with the frequency and speed increasing, the all operating motor points must respecting as geometric loci some elipsoidal tracking curves as shown in the Figure 4 and in accordance with the following equation:

$$\left(\frac{V_{So}}{X_q}\right)^2 = i_q^2 + \left(\frac{X_d}{X_q}\right)^2 \left(i_d + \frac{\Psi_o}{X_d}\right)^2 \qquad (7)$$

where:
V_{S0} – is the fundamental of the armature voltage,
Ψ_0 – is the flux of the permanent magnet,
X_d , X_q – are the DCBM d,q axis reactances.

3. PRACTICAL RESULTS

Based on this theory, an experimental laboratory model has been developed, as follows:

- **DCBM**: armature voltage 196V, current 9,3A, maximum speed 6000 r/min, torque 2,2/2,9Nm, p=3; PM (Nd-B-Fe, B_r=1,25T, H_c=860kA/m).
- **VSI IGBT** inverter: power range maximum 30kW (U=200V, I=15A), max. frequency 500Hz [3].
- **Experimental traction curves** (see the Figure 5):

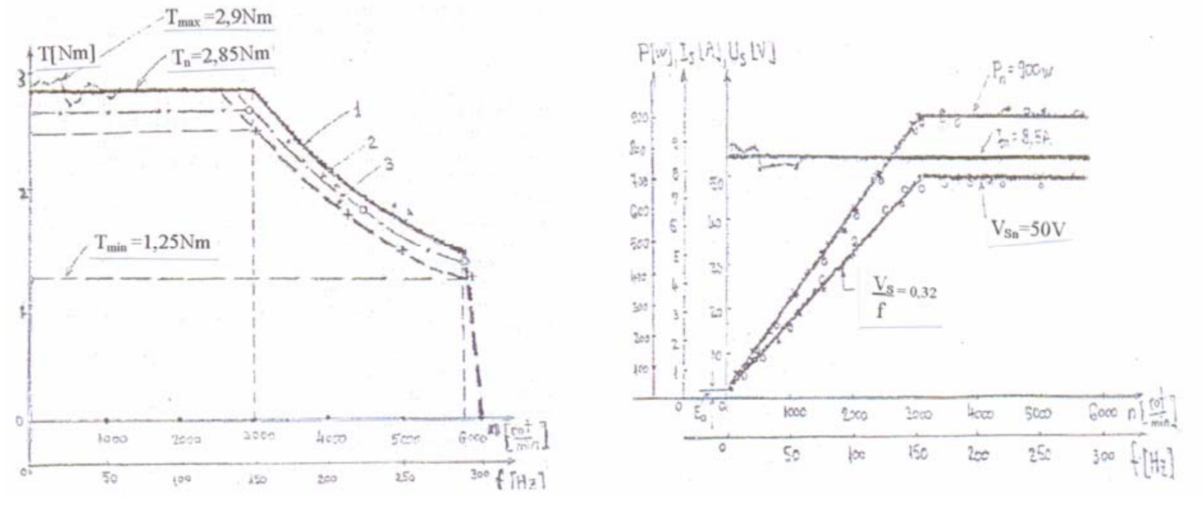


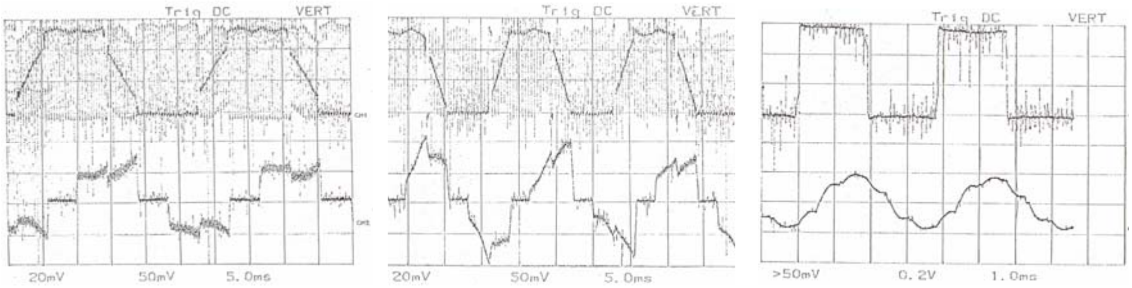
Figure 5. Experimental traction curves

- **Experimental PWM and maximum speed curves**

The experimental curves has been considered in the following three cases, as shown in the Figure 6:

- PWM at 37Hz and 710 r/min (Figure 5, a),

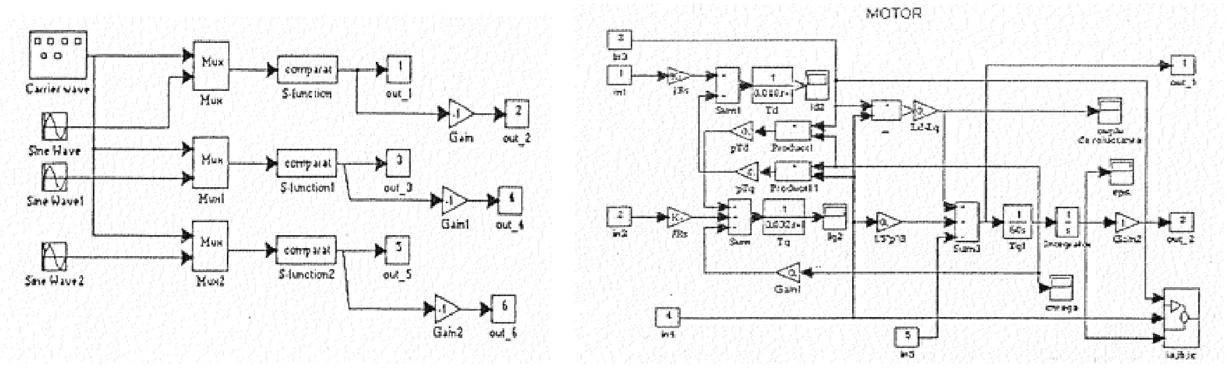
- end of PWM at 59Hz and 1130r/min (Figure 5, b),
- maximum speed at 260Hz and 5100r/min (Figure 5, c).



a) b) c)

Figure 5. Experimental PWM and maximum speed curves

- **MATLAB-Simulink simulations** (see the Figure 6):



Model of the PWM generator *DCBM model*

Figure 6. MATLAB - Simulink simulations

4. CONCLUSIONS

The author present a modern solution to control a VSI-DCBM drive system suitable for vehicle propulsion, taking into account the parameter variations and influences with the frequency control. The main goals has been to develop an experimental laboratory model and after, based on it, to design a software simulator which can be used also as teaching tool one (as original goal).

5. REFERENCES

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