NEW ASPECTS REGARDING THE ANALYSIS OF THE ASYNCHRONOUS MOTORS WITH DELTA MODULATION CONTROL

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Abstract: This work presents some considerations on a control method for a three-phase asynchronous motor and a time-frequency analysis of the proposed system. The control method uses the delta modulation principle to generate the command signals for a full bridge three phase power inverter that drives an asynchronous motor. The time-frequency analysis can bring useful information that could be used to develop new control strategies. The operation principle and the analysis and simulation results are also presented to compare the performances of this control method versus a direct feed from mains.

Keywords: delta modulation, asynchronous motor, time-frequency analysis

1. INTRODUCTION

Nowadays, there are a lot of command methods for asynchronous motors due to the fact that these electrical machines are used in many industrial and home consumer applications (Boldea and Nasar, 1992). The main command methods for the power inverters used to drive the asynchronous motors are: pulse width modulation (PWM), harmonic cancellation, sinusoidal pulse width modulation (SPWM) and space vector pulse width modulation (SVPWM). There are many advantages of the PWM command techniques of asynchronous motors such as: easy to use and easy implementation, no linearity degradation and compatibility with digital micro-controllers (Bose, 2001).

Despite of these advantages, there are many efforts to develop new control strategies to improve the performances of power converters that are used to command asynchronous motors. For this reason the research in this field is far away to be finished.

In the first part of this work is presented a command method of a full bridge power inverter used for electric drive of a three-phase asynchronous motor, which is based on the signals generated by delta modulators. Till now, there were reported some works that used the delta modulation principle especially for power rectifier (Rahman *et al.*, 1995). This principle is adapted in this work to the electric drive of an asynchronous motor.

In next section of this work is briefly mentioned the principle of delta modulation and some useful design relation. In section 3 is presented the electric drive of the three-phase asynchronous motor proposed in this work and realised by using the Simulink and Power Blockset of MATLAB programming environment. In section 4 is described the control system. This section is followed by the simulation results. The last part of the work presents new aspects regarding the time-frequency analysis of the proposed system. One can see that there are interesting information that can be used to develop new structures of feedback loop control.

2. DELTA MODULATION PRINCIPLE

A method to generate PWM form signals is presented in Fig.1. The waveforms of the signals used to predict the switching frequency of the modulator are presented in Fig.2. The voltage u_r from the output of a low-pass filter is compared with the input voltage u_i and the difference signal u_e is applied to a hysteresis quantizer. The window widths of the hysteresis quantizer can have same values but also different values. The output voltage of the hysteresis quantizer is applied to the input of the low-pass filter. This circuit generates a self-carrier signal u_c, delta modulated, that can be used to command the switches of a power inverter.

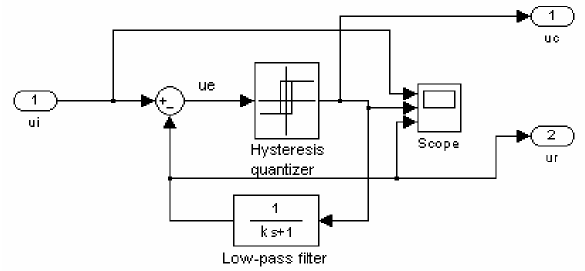

Fig.1 Block diagram of a delta modulator

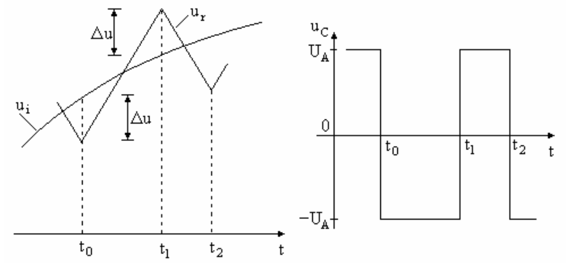

Fig.2 Typical waveforms that arise in a delta modulator circuit

Taking into consideration the waveforms presented in the Fig.2, one can determine the rising and falling edges time by means of next two relations:

$$t_1 - t_0 = \frac{2 \cdot \Delta u}{\frac{U_A}{T_i} - U_i \cdot \omega_i \cdot \cos\omega_i} \qquad (1)$$

$$t_2 - t_1 = \frac{2 \cdot \Delta u}{\frac{U_A}{T_i} + U_i \cdot \omega_i \cdot \cos\omega_i} \qquad (2)$$

The time T_C during two successive rising or falling edges of the feedback voltage depending of the circuit parameters can be derived from (1) and (2).

$$T_C = t_2 - t_0 = \frac{4 \cdot \Delta u \frac{U_A}{T_i}}{\left(\frac{U_A}{T_i}\right)^2 - U_i^2 \cdot \omega_i^2 \cdot \cos^2\omega_i} \qquad (3)$$

In Fig.3. are presented the simulations results of a delta modulator obtained by the help of MATLAB programming environment. One can see that the control voltage u_c look like a pulse width modulated signal.

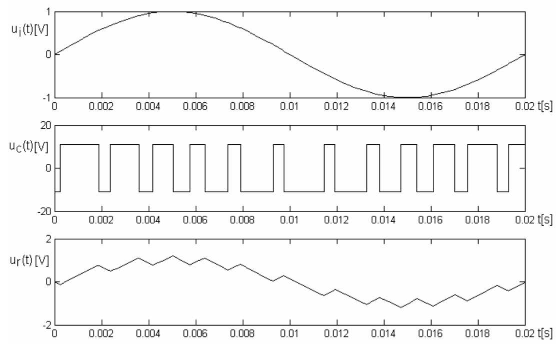

Fig.3. Waveforms for the delta modulator

3. INDUCTION MOTOR MODEL

The induction machine d-q model or its dynamic equivalent circuit is shown in Fig.4 - (Boldea and Naser, 1992).

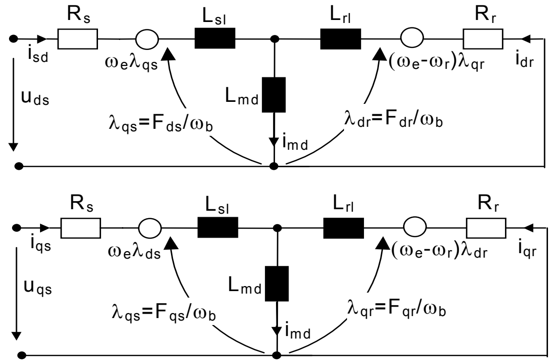

Fig.4 Dynamic or d-q equivalent circuit of an induction machine

Voltage equations for the induction machines in the arbitrary rotating reference frame are described by the help of the next equation system:

$$\begin{aligned} v_{qs} &= r_s i_{qs} + \frac{d}{dt}\lambda_{qs} + \omega\lambda_{ds} \\ v_{ds} &= r_s i_{ds} + \frac{d}{dt}\lambda_{ds} - \omega\lambda_{qs} \\ v_{qr} &= r_r i_{qr} \frac{d}{dt}\lambda_{qr} + (\omega - \omega_r)\lambda_{dr} \\ v_{dr} &= r_r i_{dr} + \frac{d}{dt}\lambda_{dr} + (\omega - \omega_r)\lambda_{qr} \end{aligned} \qquad (4)$$

The flux linkage expressions in terms of the currents can be written from Fig.4 as follows:

$$\lambda_s = L_s \underline{i}_s + L_m \underline{i}_r \qquad L_s = L_{ls} + L_m \qquad (5)$$
$$\lambda_r = L_r \underline{i}_r + L_m \underline{i}_s \qquad L_r = L_{lr} + L_m$$

Torque expression is:

$$T_{em} = \frac{3}{2}\frac{P}{2}\left(\lambda_{ds} i_{qs} - \lambda_{qs} i_{ds}\right) \qquad (6)$$

Oftentimes, machine equations are expressed in terms of the flux linkages per second, F's, and reactances, x's, instead λ's and L's. These are related by the base or rated value of angular frequency ω_b, that is:

$$F = \omega_b \lambda; \; x = \omega_b L \qquad (7)$$

One can write:

$$\begin{aligned} v_{qs} &= \frac{p}{\omega_b} F_{qs} + \frac{\omega}{\omega_b} F_{ds} + r_s i_{qs} \\ v_{ds} &= \frac{p}{\omega_b} F_{ds} - \frac{\omega}{\omega_b} F_{qs} + r_s i_d \\ v_{qr} &= \frac{p}{\omega_b} F_{qr} + \frac{\omega - \omega_r}{\omega_b} F_{dr} + r_r i_{qr} \\ v_{dr} &= \frac{p}{\omega_b} F_{dr} + \frac{\omega - \omega_r}{\omega_b} F_{qr} + r_r i_{dr} \\ T_{em} &= \frac{3}{2}\frac{P}{2\omega_b}\left(F_{ds} i_{qs} - F_{qs} i_{ds}\right) \end{aligned} \qquad (8)$$

The modelling equations of a squirell cage induction motor in state space is (9):

$$\frac{dF_{qs}}{dt} = \omega_b \left[v_{qs} - \frac{\omega}{\omega_b} F_{qs} + \frac{r_s}{x_{ls}} \left(\frac{x_M}{x_{lr}} F_{qr} + \left(\frac{x_M}{x_{ls}} - 1 \right) F_{qs} \right) \right]$$

$$\frac{dF_{ds}}{dt} = \omega_b \left[v_{ds} + \frac{\omega}{\omega_b} F_{qs} + \frac{r_s}{x_{ls}} \left(\frac{x_M}{x_{lr}} F_{dr} + \left(\frac{x_M}{x_{ls}} - 1 \right) F_{ds} \right) \right]$$

$$\frac{dF_{qr}}{dt} = \omega_b \left[- \frac{\omega - \omega_r}{\omega_b} F_{dr} + \frac{r_r}{x_{lr}} \left(\frac{x_M}{x_{ls}} F_{qs} + \left(\frac{x_M}{x_{lr}} - 1 \right) F_{qr} \right) \right]$$

$$\frac{dF_{dr}}{dt} = \omega_b \left[\frac{\omega - \omega_r}{\omega_b} F_{qr} + \frac{r_r}{x_{lr}} \left(\frac{x_M}{x_{ls}} F_{ds} + \left(\frac{x_M}{x_{lr}} - 1 \right) F_{dr} \right) \right]$$

$$\frac{d\omega_r}{dt} = \frac{P}{2J} \left(T_{em} - T_{mech} \right)$$

$$T_{em} = \frac{3}{2} \frac{P}{2\omega_b} \left(F_{ds} i_{qs} - F_{qs} i_{ds} \right)$$

where d and q are direct axis and quadrature axis, s and r are stator and rotor variable, r_r and r_s rotor and stator resistances, x_{ls} and x_{lr} are stator and rotor leakage reactances, P represents the numbers of poles, T_{em} and T_{mech} are electrical output and load torques, ω_e is stator angular electrical frequency, ω_b is motor angular electrical base frequency, ω_r is rotor angular electrical speed and finally, F_{ij} is the flux linkage ($i=d$ or q and $j=s$ or r). In the last relations x_M is given by

$$x_M = \left(\frac{1}{x_m} + \frac{1}{x_{ls}} + \frac{1}{x_{lr}} \right)^{-1}.$$

4. ELECTRIC DRIVE OF THE THREE-PHASE ASYNCHRONOUS MOTOR

The block diagram of the proposed system is presented in the Fig.5. One can see one 50 or 60Hz sinusoidal waveform signal to the input of each delta modulator.

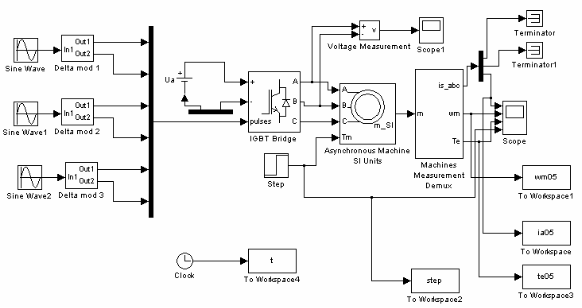

Fig.5. Block diagram of the control system

The phase shift between these signals is 120^0. Due to the operation principle of the delta modulator, PWM command signals will result. These signals are used to command the full bridge of a three phase power inverter. The load of the power inverter is in this case a three phase asynchronous motor. The motor speed can be modified if the parameters of the delta modulator blocks or the inverter's supply voltage are changed. In the Fig.6 are presented the simulation results of the control system during start transition time and at a load variation encountered after 1s: i_a - stator current, ω_m - rotor speed, t_{em} - electromagnetic torque and T - load torque. Parameters of the asynchronous motor are the same as in the model given in the Power Blockset.

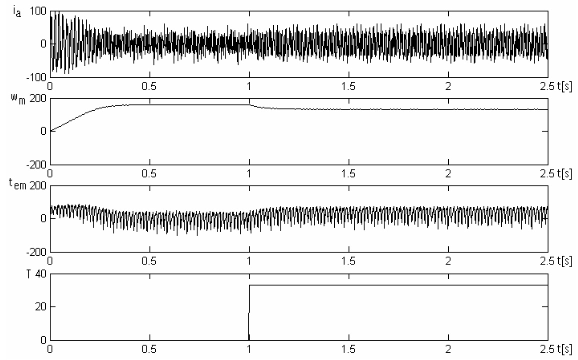

Fig.6 Simulation results for the control system

5. TIME-FREQUENCY ANALYSIS

The analysis of non-stationary signals is of interest in many fields but also in power electronics.

The study of these phenomena typically implies the use of a time-frequency (TF) analysis (Isar and Naforniță, 1998; Cohen, 1995), because it can give an overall view of the behaviour of non-stationary signals by means of the so-called time-varying spectrum $P(t, f)$ (or $P(t, u)$). This spectrum is defined in the time-frequency plane (t-f), and represents the evolution of signal power as a function of both time and frequency. In the case of time-frequency analysis, the main problem is that of obtaining a good frequency resolution and 'readability' of the spectrum, together with the possibility of highlighting its evolution over time.

The time-frequency representations as the Short-Time Fourier, Gabor, Wigner-Ville, Choi-Williams and "wavelet" transforms of a signal contain very important information concerning the regions from the time-frequency plane where the signal's energy is maximum. It was demonstrated that the ridges of the module of any time-frequency representation correspond to the maximum values of the signal's energy, which form the skeleton of the analysed transform. These maxims are localised around the instantaneous frequency (IF) of the signal, which means that the detection of the ridges offers the possibility to estimate the.

The importance of the instantaneous frequency concept stems from the fact that in many applications the signal analyst is confronted with the task of processing signals whose spectral characteristics (in particular the frequency of the spectral peaks) are varying with time. These signals are often referred to as "nonstationary". For these signals, the ridge is an important characteristic, because it is a time-varying parameter that defines the location of the signal's spectral peak as it varies with time.

In our analysis we used the Gabor time-frequency representation, because it has the best behaviour and it presents a reduced amount of interference terms.

The analysed signals were stator current, rotor speed and electromagnetic torque. These are non-stationary signals because some of their spectral components are varying in time. The rotor speed signal presents a sudden amplitude modification that can be observed when a load torque is applied.

The time-frequency representation of the signal shows that the frequency content remains unchanged in time. So, there aren't new spectral components that appear. The only parameter that changes is the amplitude of the spectral components, as can be observed in Fig. 7.

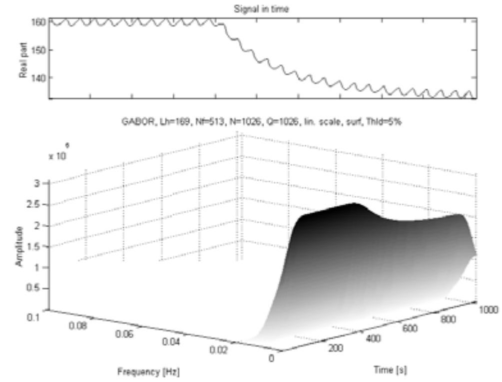

Fig. 7 Gabor representation of the rotor speed signal.

The modification of the signal's amplitude is obvious. The next signal was stator current.

In this case, at the moment when the load torque is applied, a new spectral component appear, as can be observed in Fig. 8.

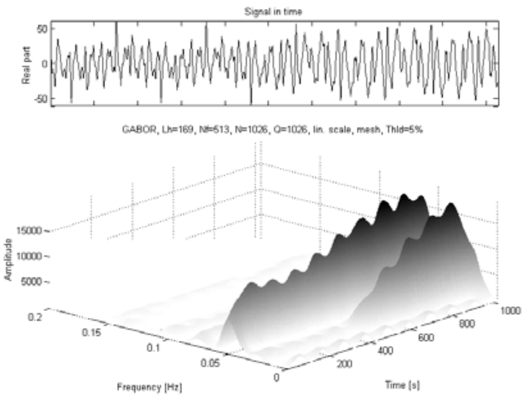

Fig.8 Gabor representation of the stator current.

From the 3D representation of the signal's Gabor transform we can obtain information not only about the various spectral components of the signal, but also about the moments of time when these components occur.

In the case of the electromagnetic torque signal, when the load torque is applied, a new low-frequency spectral component appear, as can be observed in Fig. 9.

In conclusion using time-frequency representations for processing these signals we can obtain useful information about the behaviour of the proposed system. In the future, taking into account the simulation results shown in the previous figures, time-frequency representations as the Short Time Fourier, Gabor, Wigner-Ville and the Wavelet transform could have a good contribution in the field of power electronics and can be used especially to develop feedback loops control.

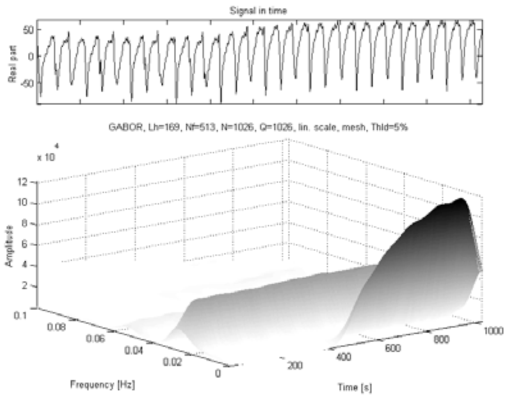

Fig.9 Gabor representation of the electromagnetic torque.

6. CONCLUSIONS

In this work are presented some consideration on a delta modulated inverter for an electric drive of a three-phase asynchronous motor. A delta modulator, used for each inverter leg, is presented together with its wave forms of the signal that describe the operation mode. The time between two successive rising or falling edges was also derived. This time is used to predict the switching frequency of the converter or to choose the parameters of the three delta modulators. The model and the parameters of the asynchronous motor were maintained like in the Power Blockset toolbox. The control of the motor speed is done by an asymetrical change of the windows width Δu of the hysteresis quantizer. At the implementation of the power inverters were took into consideration some aspects presented in valuable research works such as (Dudrik and Ondera, 1994; Popescu, 1998). In the last part of the work were presented a time-frequency analysis for the main signals in the proposed system that can describe its operation mode. All the simulations were obtained by the help of MATLAB and its toolboxes

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