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On delta modulation control of three-phase asynchronous motors

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Abstract – This work presents some considerations on a control method for a three-phase asynchronous motor. This control method uses the delta modulation principle to generate the command signals for a full bridge power inverter that drives three phase asynchronous motor. The operation principle and the simulation results are also presented to compare the performances of this control method versus a direct feed from mains. The system that is analysed in this work can be also useful in many other applications such as: uninterruptible power supply, solar energy conversion and so on.
Keywords: delta modulation, asynchronous motor

I. INTRODUCTION

Nowadays, there are a lot of command methods for mono-phase and three-phase asynchronous motors due to the fact that these electrical machines are used in a lot of industrial and home consumer applications. The main command methods for the power inverters, that are part of the electric drive of asynchronous motors, are: pulse width modulation (PWM), harmonic cancellation, sinusoidal pulse width modulation (SPWM) ^nd sp^ce 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 microcontrollers [1].

Despite of these advantages, there are many efforts to develop new control strategies to improve the p rf r f p w r v r r r d command asynchronous motors. For this reason the research in this field is not finished.

In this work is presen.ed a command me.hod o. 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 [2]. This principle is adapted in this work to the electric drive of an as nchronous motor.

I^n next ^ection of this work is bri.fly m.n.ion.d he princip e of delta modul i n nd s s l 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.

II. 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.

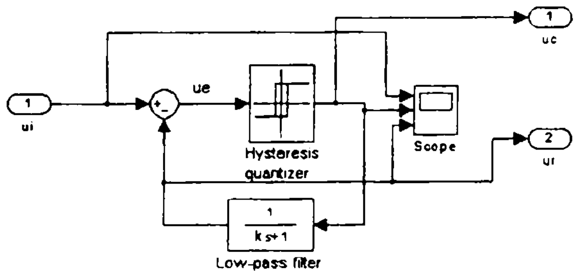

Fig.1 Block diagram of a delta modulator

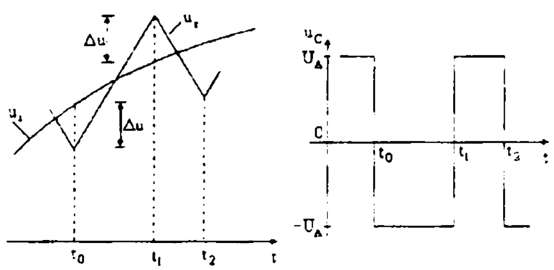

Fig.2 Typical waveforms that arise in a delta modulator circuit

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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.

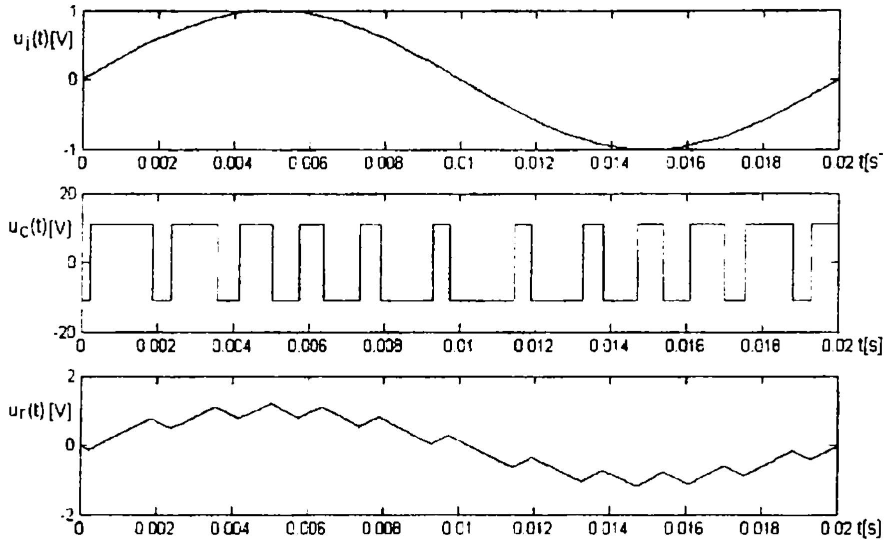

Fig.3. Waveforms for the delta modulator

III. INDUCTION MOTOR MODEL

The induction machine d-q model or its dynamic equivalent circuit is shown in Fig.4 - [3], [4], [5].

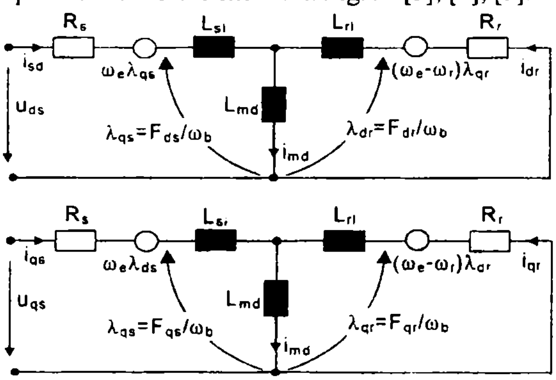

Fig 4 Dynamic or d-q equivalent circuit of an induction machine

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:

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

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:

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

We can write:

$$
\begin{aligned}
v_{qs} &= \frac{p}{\omega b} F_{qs} + \frac{\omega}{\omega b} F_{ds} + rs\, i_{qs} \\
v_{ds} &= \frac{p}{\omega b} F_{ds} - \frac{\omega}{\omega b} F_{qs} + rs\, i_{d} \\
v_{qr} &= \frac{p}{\omega b} F_{qr} + \frac{\omega - \omega r}{\omega b} F_{dr} + rr\, i_{qr} \\
v_{dr} &= \frac{p}{\omega b} F_{dr} + \frac{\omega - \omega r}{\omega b} F_{qr} + rr\, i_{dr} \\
T_{em} &= \frac{3}{2}\frac{P}{2\omega b}\left(F_{ds} i_{qs} - F_{qs} i_{ds}\right)
\end{aligned}
\tag{8}
$$

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

$$
\frac{dF_{qs}}{dt} = \omega b\left[v_{qs} - \frac{\omega}{\omega b} F_{qs} + \frac{rs}{xls}\left(\frac{x_M}{xlr} F_{qr} + \left(\frac{x_M}{xls} - 1\right) F_{qs}\right)\right]
$$

$$
\frac{dF_{ds}}{dt} = \omega b\left[v_{ds} + \frac{\omega}{\omega b} F_{qs} + \frac{rs}{xls}\left(\frac{x_M}{xlr} F_{dr} + \left(\frac{x_M}{xls} - 1\right) F_{ds}\right)\right]
$$

$$
\frac{dF_{qr}}{dt} = \omega b\left[-\frac{\omega - \omega r}{\omega b} F_{dr} + \frac{rr}{xlr}\left(\frac{x_M}{xls} F_{qs} + \left(\frac{x_M}{xlr} - 1\right) F_{qr}\right)\right]
$$

$$
\frac{dF_{dr}}{dt} = \omega b\left[\frac{\omega - \omega r}{\omega b} F_{qr} + \frac{rr}{xlr}\left(\frac{x_M}{xls} F_{ds} + \left(\frac{x_M}{xlr} - 1\right) F_{dr}\right)\right]
$$

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

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

where d: direct axis,
q: quadrature axis,
s: stator variable,
r: rotor variable,
r_r: rotor resistance,
r_s: stator resistance,
x_{ls}: stator leakage reactance,
x_{lr}: rotor leakage reactance,

$$
x_M: \; 1 \bigg/ \left(\frac{1}{x_m} + \frac{1}{x_{ls}} + \frac{1}{x_{lr}}\right)
$$

P: numbers of poles,
T_{em}: electrical output torque,
T_{mech}: load torque,
ω_e: stator angular electrical frequency,
ω_b: motor angular electrical base frequency,
ω_r: rotor angular electrical speed.
F_{ij} is the flux linkage ($i=d$ or q and $j=s$ or r),

IV. 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. 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. Parameters of the asynchronous motor are the same as in the model given in the Power Blockset.

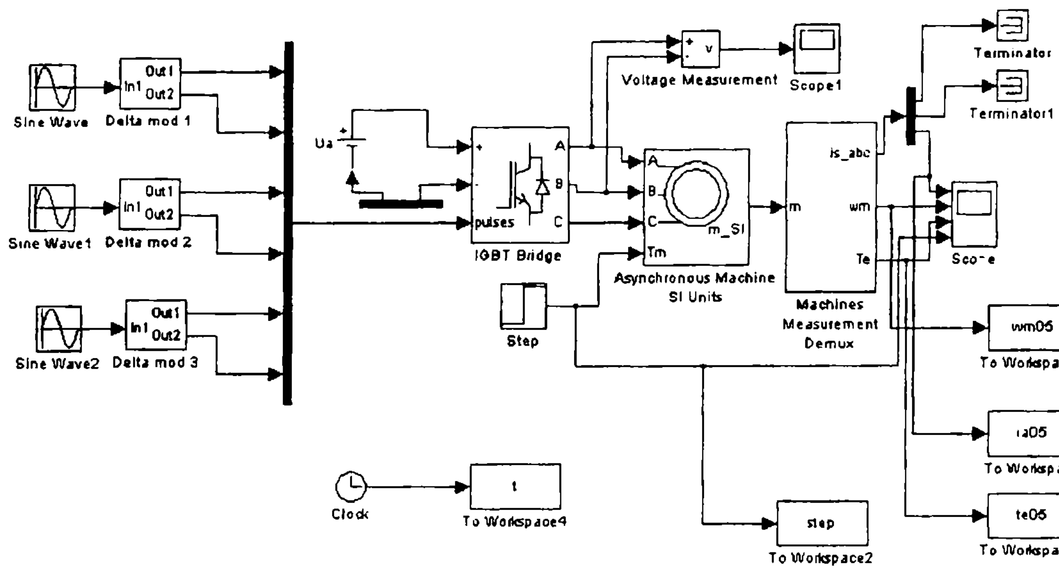

Fig.5. Block diagram of the control system

V. 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 simulations were obtained by the help of the Simulink and Power Blockset toolbox of MATLAB programming environment. The model and the parameters of the asynchronous motor were maintained like in the Power Blockset toolbox [5],[6].

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 [7] and [8].

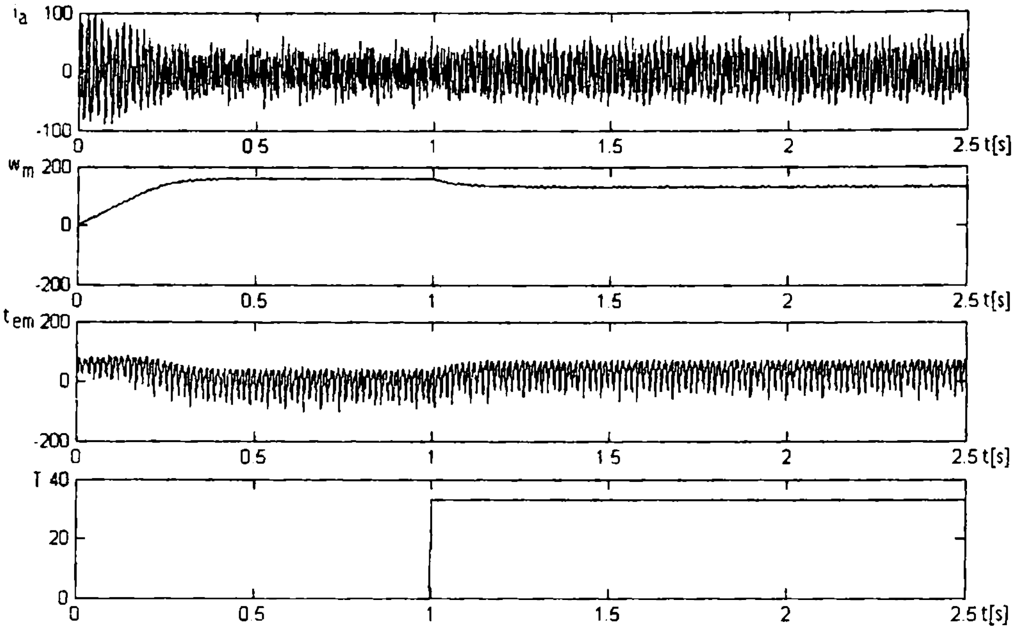

Fig.6 Simulation results for the control system

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