ENERGETICAL ANALYSIS OF INDUCTION MOTOR AND VOLTAGE INVERTER WITH SINUSOIDAL AND TRAPEZOIDAL PWM CONTROL

Eng. **Ileana – Anamaria MITRAN,** PhD Student, Prof. Eng. **Alexandru BIOTOLEANU,** PhD, Lecturer Eng. **Mihaita LINCA,** PhD

University of Craiova
Faculty of Electrical Engineering, Craiova, Romania

REZUMAT. Analiza energetică a sistemului de acționare a fost realizată în mediul de programare Matlab Simulink, în care s-a considerat alimentarea unui motor asincron de la un invertor de tensiune ,utilizând în partea de comandă, pe rând, modulația sinusoidală şi modulația trapezoidală. În urma simulării sistemului de acționare pentru cele două variante de comandă s-a realizat analiza energetică pe baza randamentelor, factorului de putere şi a pierderilor totale introduse de fiecare metodă de modulare.

Cuvinte cheie: analiza energetică, motor de inducție, PWM,modulație sinusoidală, modulație trapezoidală.

ABSTRACT. The energetic analysis of the system has been conducted in Matlab Simulink environment, in witch was consider an induction motor powered by a voltage inverter, using , in turn, sinusoidal and trapezoidal modulation, as command strategy. After the simulation of the drive system for both command methods (sinusoidal and trapezoidal modulation) an energetical analysis was performed, obtaining the effinciency, power factor and total losses, induced by each modulation method.

Keywords: energetical analysis, induction motor, PWM, sinusoidal modulation, trapezoidal modulation

1. INTRODUCTION

The development of pulse width modulation techniques was driven by technological advances in the field of semiconductor devices with reduced switching times and allowed, especially for three – phase voltage inverters for asynchronous and synchronous machines, a much better amplitude and frequency control of the output voltage.

Pulse width modulation (PWM) techniques udes today to control modern static converters such as high – power machine drives, strongly depend on switching frequency of the power semiconductor. Normally, voltage moves to discrete values, forcing the desing of machines with good isolation, and sometimes loads with inductances in excess of the required value. In other words, neither voltage nor current is as expected.[6]

The most modern drives use voltage and frequency static converters with an intermediate DC link, in front of the PWM voltage inverter.

The PWM inverters feeding induction motors are widely used in industrial applications.[3]

The electric drive systems with induction motor,various static operating points can be obtained by using various command strategies of the static converter. These assum respecting, specifically a correlation between voltage and frequency, $U/f=ct$ or $U/\sqrt{f}=ct$, or keeping a value that characterizes the constant operation of the motor.[5]

Because using the static inverters is an indispensable action, the command methods have been also evolved, in order to ameliorate certain parameters. Thus, begining with the amplitude modulation, lots of high performance PWM methods have appeared, to minimize winding losses, the electromagnatic torque ripple, etc., like the sinusoidal modulation, the pre – calculated time modulation, space – vector modulation, trapezoidal modulation etc. [4]

There is no definite answer to the question „Which modulation method is best?”. As for comparing performances, the criteria to be chosen of, can be from the following: the energetic performances of the motor, the energetic performances of the system, the commutation losses of the inverter, the system dynamics, and so on.

This aim of this paper is a comparative study of the energetic performances of the induction operating motor for both modulation strategies: sinusoidal and trapezoidal.

2. THEORETICAL ASPECTS

Sinusoidal modulation

One from the oldest methods, is the sinusoidal PWM modulation. The main principle of this method is to determine the switching time of the elements, by comparison a sinusoidal control signal u_c whose frequency is the feeding voltage frequency and ajustable amplitude, with a reference signal, usually triungular u_r, wich has constant amplitude and higher frequency that the control signal (fig.1.).

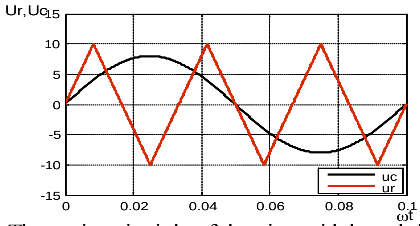

Fig.1. The main principle of the sinusoidal modulation

According to the principle of pure sinusoidal modulation, the easiest type of PWM , the elements T+ and T- found on the same phase of the inverter are fired on the intervals in which uc > ur and uc < ur, respectively.

Considering the synchronous control, odd index multiple of 3 modulation and the optimal correlation between the reference signal and command signal (ur must have a maximum or a minimum in the middle of each uc half wave) a single reference signal for the three-phase system can be used. So, the harmonic spectrum of output voltage contains only the even harmonics. The output voltage frequency is equal with the command signal voltage frequency and its RMS value is proportional with the command voltage amplitude. [1],[2]. The output voltage approximation with a sine wave is improving, as the reference voltage period is smaller in relation with command voltage period, respective as the frequency modulation factor is bigger. For the PWM modulation, comparative to the solid wave modulation, the THD factor becomes better by reducing the low order harmonic amplitudes and increasing harmonics order of significant amplitude in relation with the fundamental.

Trapezoidal modulation

The trapezoidal modulation in another method that is used to obtain the control signals for the semiconductor power devices, which are main components of the static inverter, this method being similar to the sinusoidal modulation.

The control voltage has been took as a isosceles trapezoid with corresponding to equal time intervals.

Thus, the command signals for the transistors situated on the inverter branches, will be obtained by comparing the trapezoidal command signal, with the triungular shaped reference signal, with a frequency greatly superior than the command frequency (fig.2).[7]

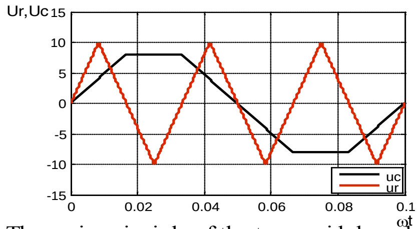

Fig. 2. The main principle of the trapezoidal modulation

3. MODELING THE DRIVE SYSTEM

Taking into account the structure of the drive system (fig.3) it was obtained the energetical parameters.

To calculate the voltage control has been obtained an m-file in matlab software and it were introduced the voltage and frequency reference input. Based on the principle of each method (comparing the control signal with the reference signal, where the reference signal uses for both modulation methods the same frequency referance value), were obtained six output signals of the transistors. The induction motor is feeding from the inverter. The inverter was obtaind with IGBT transistors and the parameters of the induction motor are:

- nominal power, voltage and frequency: P_N=2.6kW; U_N=380V; f_N=50Hz;
- stator resistance and inductance: R_s=1.61**Ω**; L_s=0.0085H;
- rotor resistance and inductance: R_r=1.52**Ω**; L_r=0.012H;
- mutual inductance: L_m=0.2456H;
- nominal current: I_N=6A;
- nominal speed: n_N=1442 rot/min;

The energetic analysis is based on the power quality indicators: the power factor (PF), the motor efficiency

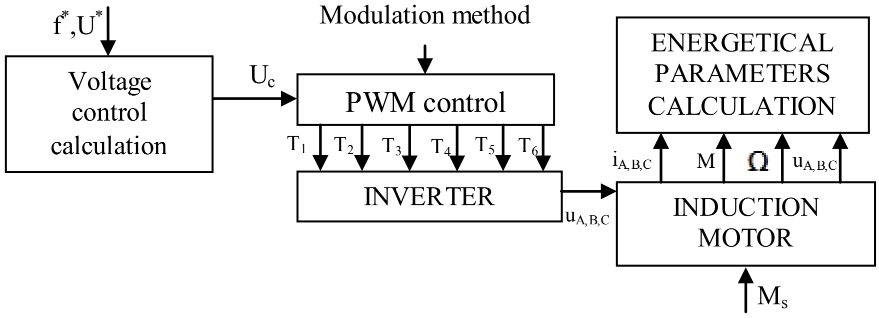

Fig.3 The structure of the drive system

(η) and the electrical losses (P_e) give by the sinusoidal modulation comparatice with trapezoidal modulation, defined as:

- the power factor:

$$\eta = \frac{P_m}{P_1} \tag{1}$$

- the motor efficiency:

$$PF = \frac{P_1}{3U_1 I_1} \tag{2}$$

- the electrical losses:

$$p_e = p_{Cu1} + p_{Cu2} \tag{3}$$

The shaft mechanical power is calculated as,

$$P_m = M_s \boldsymbol{\Omega} \tag{4}$$

where M_s is the load measured torque and **Ω** is the angular measured speed.

The total losses are calculated as,

$$\Delta p = P - P_m \tag{5}$$

4. NUMERICAL RESULTS

The frequency influence:

To better emphasize the influence of the fundamental frequency, the power factor and efficiency dependencies have been represented, according to frequency, for the same value of thestatic torque M_s=0.6M_N (fig.4,5).

When we look at figure 4, we can see, that up to 25Hz, the power factor values which correspond to the modulations methods are practically equal.

As a result, the power factor values that correspond to the trapezoidal modulation are higher than from the sinusoidal modulation. For instance, at 50 Hz for the trapezoidal modulation, it results the 0.88 value, compared to 0.67, coresponding to the sinusoidal modulation.

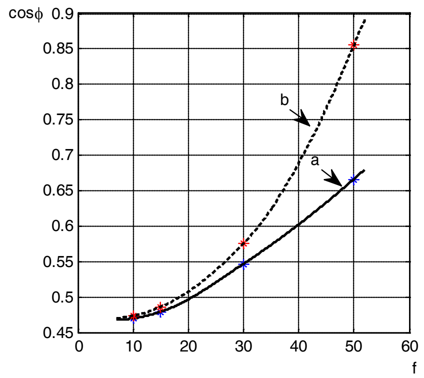

Fig. 4 The power factor versus frequency

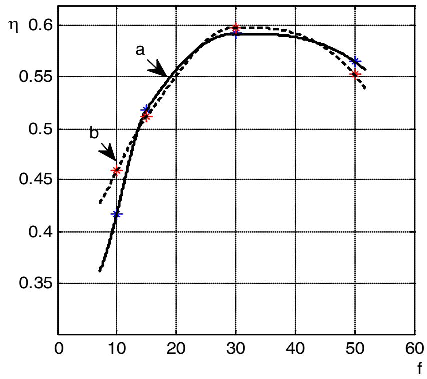

Fig. 5 The efficiency versus frequency

The drive system efficiency increases with the frequency. When the frequency is less, the efficiency has higher values for the trapezoidal modulation, and when the frequency is higher, the efficiency has higher values for the sinusoidal modulation, as shown in fig. 5.

For instance, at 10 Hz, for the trapezoidal modulation, it results the value of 0.47, compared to 0.43, which is obtained for the sinusoidal modulation and for the trapezoidal modulation, it results the value of 0.55, compared to 0.57, which results for the sinusoidal modulation

The energetic quality indicators of the performance

The power factor

The power factor dependencies for feeding the motor with different four frequencies (10 Hz, 15 Hz, 30 Hz, 50 Hz) are shown below:

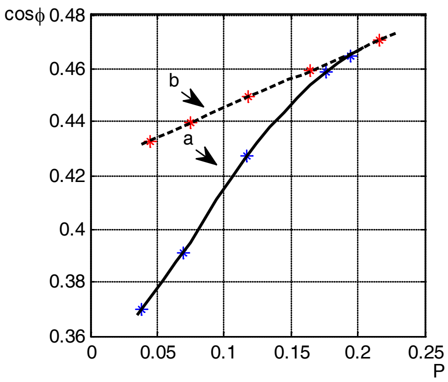

Fig. 6 The power factor versus mechanical power (10 Hz)

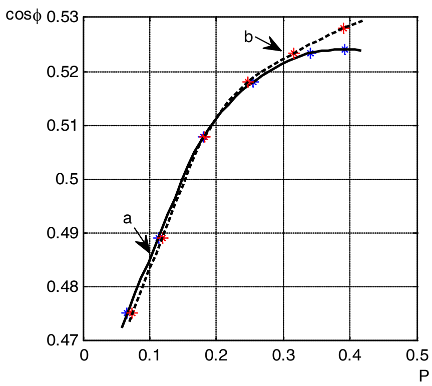

Fig. 7 The power factor versus mechanical power (15 Hz)

It can observe:

- the maximum power that motor develops increases with the frequency and is higher for trapezoidal modulation;
- the power factor is increasing with the mechanical power, looking different than that the induction motor feeding by sinusoidal PWM modulation;
- the power factor is higher in case of the trapezoidal modulation, for all four frequency;
- for both 30 and 50 Hz frequencies, the values of the power factor are practically equal, for both modulation methods.

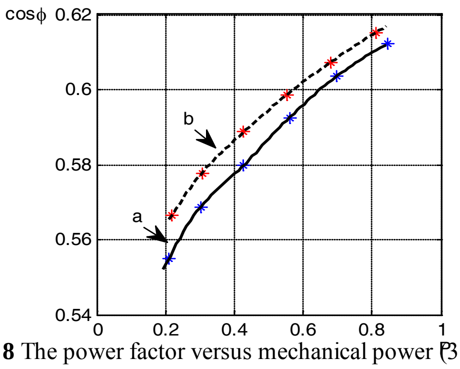

Fig. 8 The power factor versus mechanical power (30 Hz)

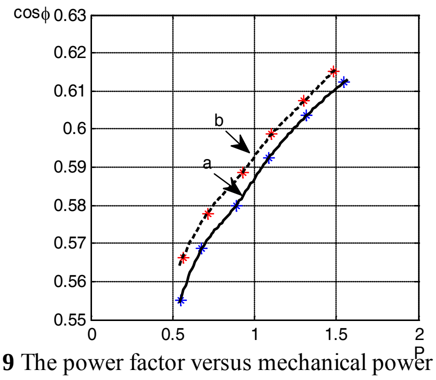

Fig. 9 The power factor versus mechanical power (50 Hz)

The efficiency

The efficiency dependencies are shown in figure 10, 11, 12, 13 and emphasize the following aspect:

- it has a maximum only for frequencies of 10 and 15 Hz (figures 10 and 11);
- at 30 Hz, it decreases and has a different shape than that an induction motor feeding by sinusoidal voltage (figure 12);

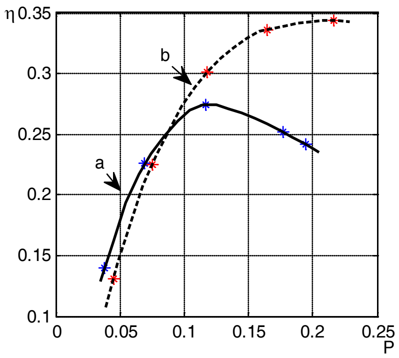

Fig. 10 The efficiency versus mechanical power (10 Hz)

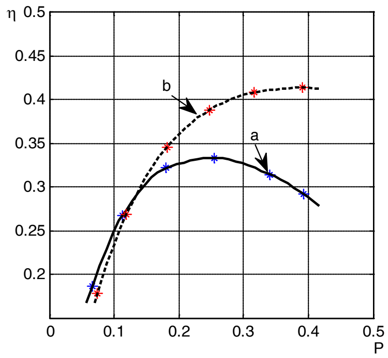

Fig. 11 The efficiency versus mechanical power (15 Hz)

- for small loads, the efficiency is higher than for the sinusoidal modulation method, for frequencies of 10 and 15 Hz;

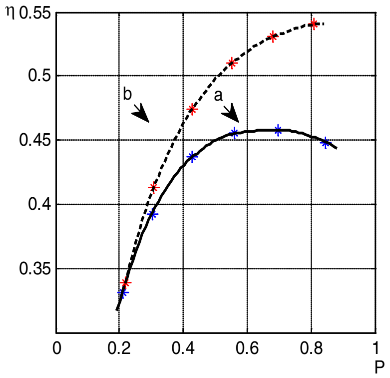

Fig. 12 The efficiency versus mechanical power (30 Hz)

The total losses

The total losses increasing with the mechanical power, having a different shape that for the induction motor feeding by the sinusoidal modulation.

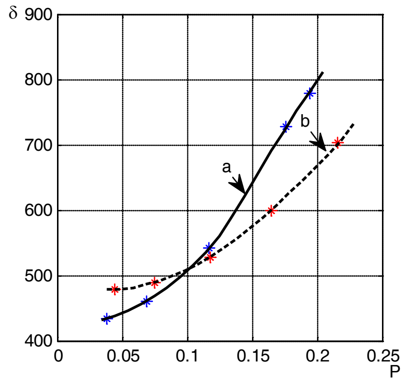

Fig. 14 The total losses versus mechanical power (10 Hz)

As the frequency decreases, the total losses are also decreasing.

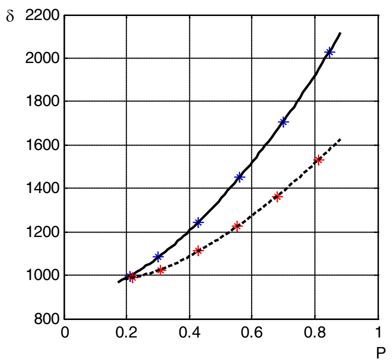

Fig. 16 The total losses versus mechanical power (30 Hz)

- at 30 Hz, the corresponding efficiency values are practically equal, for both methods.

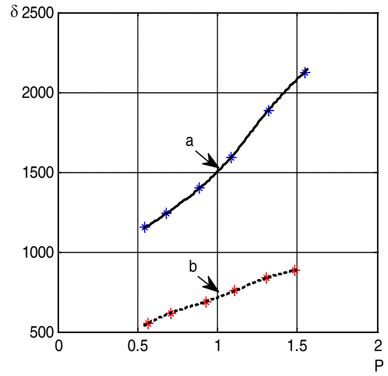

Fig. 13 The efficiency versus mechanical power (50 Hz)

As for the two quality indicators has been obtained the dependencies of the total losses versus mechanical power (fig. 14, 15, 16, 17).

The maximum power produced by the motor

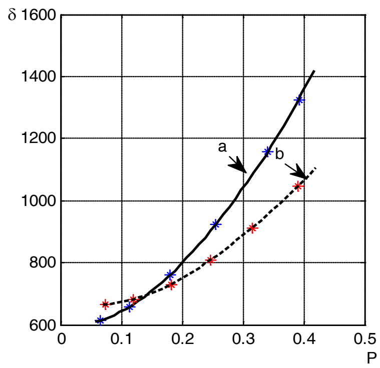

Fig. 15 The total losses versus mechanical power (15 Hz)

increases once the frequency is increasing and is higher for the trapzoidal modulation that for the sinusoidal modulation.

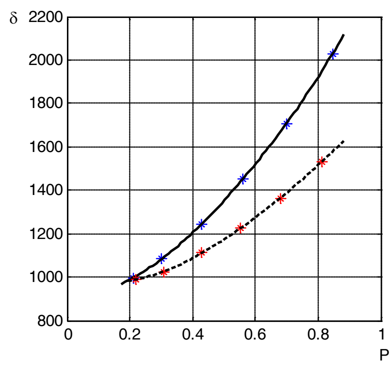

Fig. 17 The total losses versus mechanical power (50 Hz)

5. COCLUZIONS

✓ The eleborated algorithm is useful for selecting a modulation method, depending on the particularities of the motor load, especially at high power values.

✓ As expected, the two modulation methods analyzed have different results, for different frequencies and load torques.

✓ The trapezoidal modulation brings several advantages, especially when it comes to efficincy.

✓ The research can and has to be further conducted with reference to:

- differentiating the losses inducted by each modulation method in the motor, compared to powering the system with a sinusoidal voltage;
- a separate analysis of the energetic performances of the inverter and the motor;
- experimental verifications.

Acknowledgments

„This work was partially supported by the strategic grant POSDRU/88/1.5/S/49516, Project ID 49516 (2009), co-financed by the European Social Fund – Investing in People, within the Sectoral Operational

BIBLIOGRAPHY

[1] Bitoleanu, A., Ivanov, S., Popescu Mihaela, *Convertoare statice***,** Ed. Infomed, Craiova, 1997, pp. 314 – 330.

[2] **Bitoleanu, A., Popescu Mihaela, Constantinescu, C., Mihai, D.,** *Convertoare statice si structure de comanda performante***,** Ed. SITECH, Craiova 2000, pp.48 – 70

[3] J.M.D. Murphy and Egen, *A Comparasion of PWM strategies for Inverter Fed Induction Motors,* IEEE, Trans. On Ind.Appl., vol, IA- 19, No 3, May, June.

[4] **Mehrizi-Sani, A., Filizadeh, S., WILSON, P.L.,** *Harmonic and loss analysis of space-vector modulated converters*, Int. Conf. on Power Systems Transients (IPST 07), Lyon, France, Jun. 2007.

[5] **Popescu Mihaela, Bitoleanu, Al.,** *Energetica sistemelor de actionare cu motor asincron si convertoare statice indirecte,.* Ed. Mediamaria, Cluj – Napoca 2004.

[6] **Rotella Mauricio, Peñailillo Gonzalo, Pereda Javier, and Dixon Juan**,*PWM Method to Eliminate Power Sources in a Nonredundant 27-Level Inverter for Machine Drive Application***,** IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, VOL. 56, NO. 1, JANUARY 2009.

[7] **Taniguchi, K., Irie, H.,** *Trapezoidal Modulating Signal for Three – Phase PWM Inverter,* IEEE Trans. on Industrial Electronics, Vol. IE – 33, No. 2, May 1986, pp 193-200

About the authors

Eng. **Ileana – Anamaria MITRAN,** PhD Student
University of Craiova
email: mi_ana_maria@yahoo.com

Graduated the Faculty of Electromechanical, Environmental and Industrial Informatics Engineering, and also obtained the Master Degree in Electrical Engineering at the University of Craiova. Since 2009 she joined the PhD School of Electrical Engineering Sciences at the University of Craiova and she is starting the 2nd stage of her thesis title: The losses of induction motor and voltage inverter driving system.

Prof. Eng. **Alexandru BITOLEANU**, PhD.
University of Craiova
email: alex.bitoleanu@em.ucv.ro

He received Electrical Engineering degree at University of Craiova in 1975, and PhD in 1989. He works at University of Craiova, Electromechanical Faculty, Electric Drives and Power Electronics Department, since 1978. Now, he is professor and the vicedean of Faculty for Electromechanical, Environmental and Industrial Informatics Engineering. His main research fields are Active Filter, Static Converters for Electric Drives Systems and Power Quality in Electric Drives Systems. He has published 6 books and more than 100 articles and papers.

Lecturer Eng. **Mihaita LINCA,** PhD.
University of Craiova
email: mlinca@em.ucv.ro

He graduated the Faculty of Electrotechnics and also obtained the Master Degree in Electrical Engineering at the University of Craiova, he obtained the PhD degree in 2010 and he is lecturer at the Faculty of Energetical Engineering, University of Craiova.