# THE ENERGETIC ANALYSIS OF THE DRIVE SYSTEM WITH INDUCTION MOTOR CONSIDERING THE IRON LOSSES: PART 2 - FEEDING BY SINUSOIDAL PWM INVERTER

Eng. **Ileana-Anamaria MITRAN**, PhD student, Prof. Eng. **Alexandru BITOLEANU**, PhD

University of Craiova
Electrical Engineering Faculty,
Electromechanical, Environmental and Industrial Informatics Department, Craiova, Romania.

**REZUMAT. In aceasta lucrare s-a avut in vedere analiza energetica a sistemului de actionare cu motor asincron cu considerarea pierderilor in fier si convertor static cu modulatie sinusoidala. Modelul global al sistemului de acționare, realizat în mediul de programare MATLAB-Simulink, furnizează toate mărimile necesare pentru calcularea indicatorilor energetici. Pentru obtinerea acestora s-a simulat functionarea intr-un punct static de functionare. Algoritmul de calcul in vederea obtinerii analizei energetice parcurge si un proces iterativ pentru obtinerea valoriilor rezistentei si inductivitatii de magnetizare.**

**Cuvinte cheie:** analiza energetica, motor de inductie, modulatie PWM sinusoidala.

**ABSTRACT. This paper had in view the energetic analysis of the drive system with induction motor and static PWM sinusoidal converter, by taking into account the iron losses. The global model of the drive system was realized in MATLAB-Simulink software and gives all necessary facilities for calculate the quality indicators. To determining them, the operation of the system was simulated for each operating point. The calculation algorithm contains an iterative process for the magnetization resistance and inductance obtaining.**

**Keywords:** energetic analysis, induction motor, sinusoidal PWM modulation.

## 1. INTRODUCTION

The developing of pulse width modulation (PWM) techniques was favored by the technological advances in the field of semiconductor devices with reduced switching time and allowed, especially for the three-phase voltage source inverters (VSI) intended to AC motors supply, a much better control of both magnitude and frequency of the output voltage.

In all electrical drive systems that require speed or position adjustment, a static converter is required to connect the motor to the power supply. Currently, the electrical drives with induction motors are used increasingly more and they are more economical in terms of energy conversion, due to the spectacular development of power semiconductor devices, the technological processes in the related fields, as well as the vector and scalar control techniques.

As the induction motors supplied by PWM inverters are widely used in industrial applications [1], their energetic performance is of great importance. Indeed, given that the power quality is a current concern in both electrical energy generation and circulation, the choice of a control strategy requires, besides the well-known performance addressed in the literature, taking into account the associated energetic performance, particularly in the high power systems. It is significant that the dynamic performance is improved too, though the efficient use of the equipments in the power system.

The VSI PWM-based control strategies can be analyzed comparatively by taking into consideration two performance criteria, namely the magnitude of the fundamental output voltage and the total harmonic distortion factor (THD).

It is known that the PWM techniques allow obtaining better quality of the VSI output voltage which makes filtering much easier, because the harmonics in its spectrum are shifted to the high frequencies domain [2], [3], [4]. A good quality of the output voltage is provided when the desired reference waveform (modulating signal) is sinusoidal.

This paper aims to analyze the energetic performance of an induction motor fed by a VSI with sinusoidal modulation when the iron losses are taken into account.

## 2. THEORETICAL ASPECTS

In accordance with the pure sinusoidal modulation principle, the switching instants of the power electronic devices are determined by comparing a high-frequency triangular carrier signal ($u_r$) with a sinusoidal reference (modulating) signal ($u_c$) of the desired frequency (Fig. 1). Depending on whether $u_c$ is larger or smaller than $u_r$, either the top switch or the bottom switch of the VSI's branch is turned on [5].

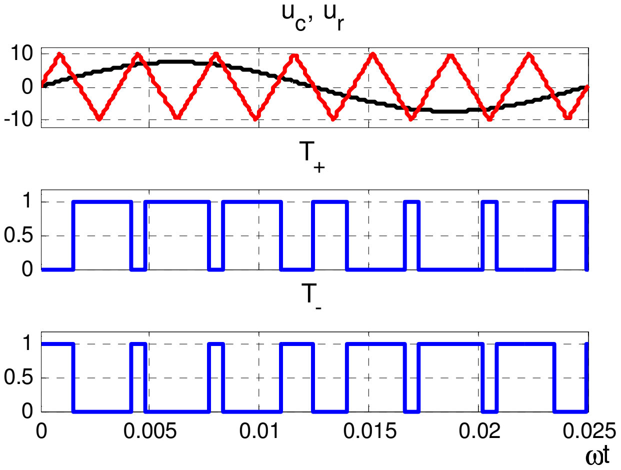

**Fig. 1.** Sine-Triangle Comparison in sinusoidal modulation and control signals of T+, T- transistors

In the case of the three-phase VSI, by considering the synchronous modulation, an odd value multiple of 3 for the frequency–modulation ratio and the optimal correlation between the reference and carrier signals (i.e. ur has a maximum or a minimum in the middle of each half wave of $u_c$), a single carrier signal can be used. Thus, the harmonic spectrum of the output voltage contains only the even harmonics. The output voltage frequency is equal with the modulating signal frequency and the RMS value of the output voltage is proportional to the amplitude of the modulating signal [6], [7]. Compared with the solid wave modulation, the sinusoidal modulation leads to a lower THD by reducing the low order harmonics amplitudes and increasing the harmonics order of significant amplitude [8].

## 3. THE STRUCTURE OF THE DRIVE SYSTEM

As shown in the block diagram (Fig. 2), the firing pulses to the three-phase VSI in the frequency static converter structure are generated by the PWM control block on the basis of information received from the Reference voltage calculation block. A specific block for energetic parameters calculation is added.

## 4. THE DRIVE SYSTEM MODEL

The energetic analysis of the electrical drive system with induction motor and frequency static converter with sinusoidal modulation was performed under MATLAB-Simulink environment [10]. Note that the iron losses were taken into consideration in the induction motor model.

After modeling the whole system, the operation under different steady state operation points was simulated.

The developed Simulink model provides all the quantities needed to calculate the following the energetic indicators: motor efficiency, power factor, iron losses, electrical losses and total losses.

In the Simulink model of the electrical drive system shown in Fig. 3, the frequency static converter consists of the single-phase uncontrolled bridge rectifier, the DC bus circuit and the sinusoidal controlled PWM inverter.

Based on the prescribed values of the frequency and the output voltage (f*, U*), a MATLAB script file is used to calculate the amplitude of the sinusoidal control voltage. Then, according to the sinusoidal modulation principle, six gating signals are generated for the six IGBTs.

A specific block for the induction motor modeling was created in order to take into consideration both the iron losses and the main flux saturation [9]. A lot of additional blocks are added to facilitate the energetic analysis.

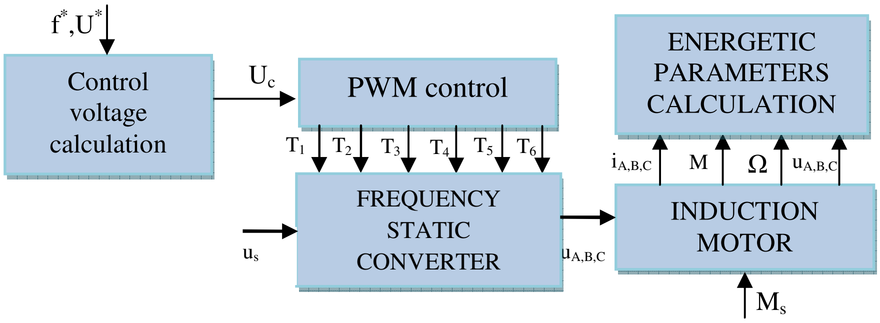

**Fig. 2** The structure of the drive system

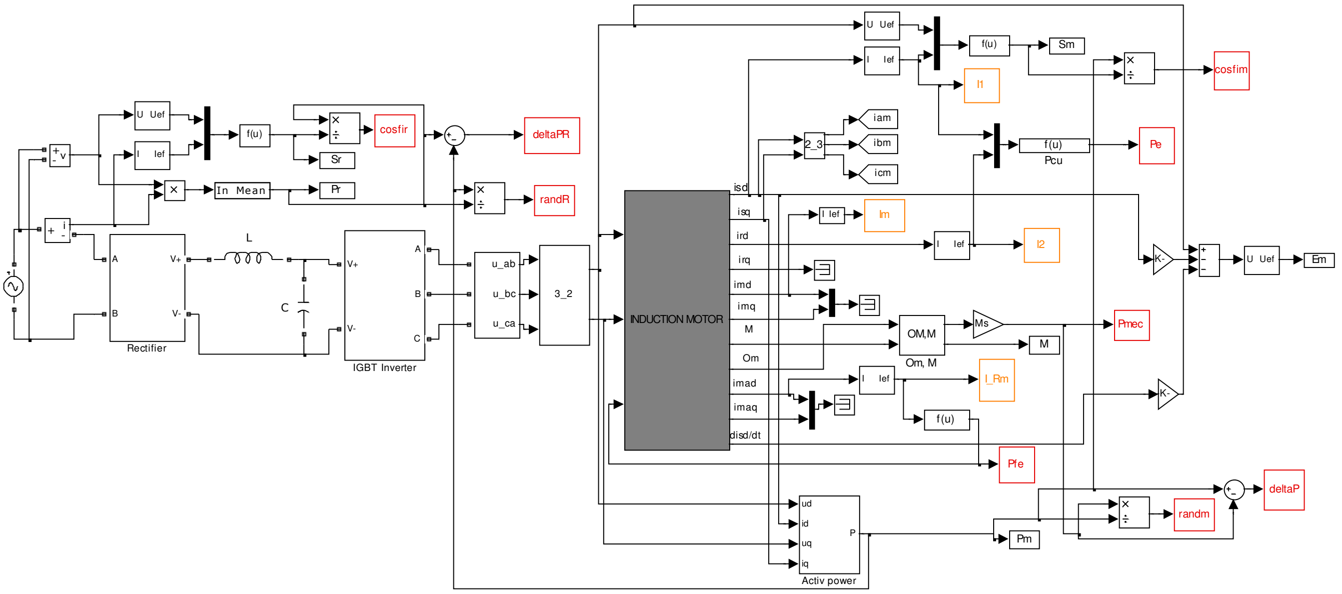

**Fig. 3** The Simulink model of the drive system

## 5. THE SIMULATION RESULTS AND THE ENERGETIC ANALYSIS

The parameters of the induction motor considering the iron losses are [9]:

- the rated values of the induction motor: $P_N$=2.6kW; $U_N$=380V; $I_N$=6A and $f_N$=50Hz;
- stator resistance and inductance: $R_s$=1.61Ω; $L_s$=0.0093H;
- rotor resistance and inductance: Rr=1.76Ω; $L_r$=0.0173H;
- magnetizing inductance: $L_m$=0.2899 H;
- rated speed: $n_N$=1500 rot/min.

The components of the DC intermediary circuit [11]:

- capacitor: C=2000 μF;
- inductance: L=1 mH.

The IGBT transistors and diodes characteristics [10]:

- saturation voltage: $I_C$ = 30A, $U_{CE}$ (sat) = 1.8 V (max.2.5V); threshold voltage for diode: $I_C$ = 15A, $U_{CE}$ = 2.5 V (max. 3.5V).

The frequencies taken into account for the energetic analysis are 10Hz, 20Hz, 30Hz and 40 Hz and the maximum load torque is 1,2$M_N$.

The energetic analysis is made on the basis of the motor efficiency, the iron losses, the electrical losses, the total losses and the power factor. All these indicators are represented in the form of their dependence on the load torque for different frequencies.

So, the efficiency dependence versus the load torque shows that (Fig. 4):

- ○ for all frequencies the efficiency curve retains its known shape; it increases with the load torque, has a maximum and then decreases slowly;
- ○ the efficiency at 40 Hz is higher than at 10 Hz;
- ○ the efficiency at 40 Hz is the highest having the minimum value of 0.59 at the minimum load, and a maximum value of about 0.8 at $M_s$=$M_N$;
- ○ the efficiency at 10 Hz is the lowest, with a maximum value of 0.542 at Ms=0.8$M_N$;
- ○ the maximum values of the efficiency for all frequencies are obtained nearly to 85% of the maximum load torque.
- ○ From the power factor dependence versus load torque the following remarks can be done (Fig. 5):

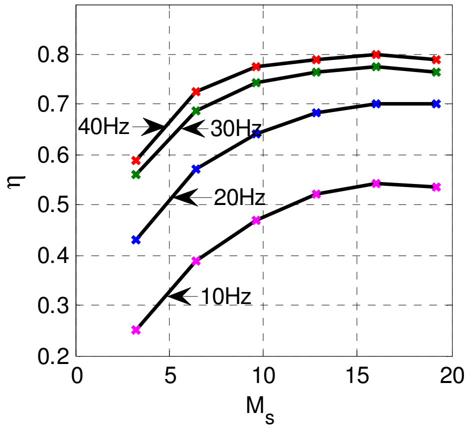

**Fig. 4** The motor efficiency versus load torque

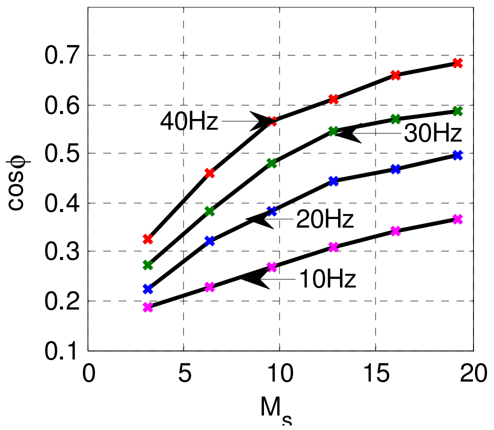

**Fig. 5** The power factor versus load torque

○ the power factor increases with frequency and load torque;

○ compared with other frequencies, the power factor at 10 Hz has almost a linear shape;

○ at minimum load, the power factor has a maximum value of 0.33 obtained at 40 Hz and a minimum value of 0.19 at 10 Hz;

○ at full load, the power factor at 40 Hz, has the maximum value of 0.68, and the minimum of 0.186 at 10 Hz;

The iron losses are illustrated in figure 6 which shows the following:

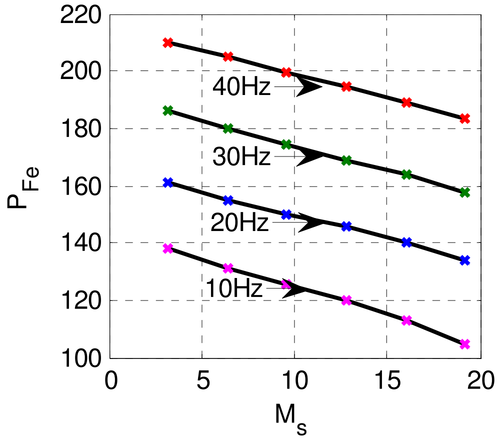

**Fig. 6** The iron losses versus load torque

○ the iron losses obtained for the four frequencies (10Hz, 20Hz, 30Hz and 40Hz) decrease monotonically while the load torque increases; the explanation is that, with increasing the load torque, the motor demagnetization occurs and the magnetic flux decreases;

○ at minimum load, the iron losses have a maximum value (209.6 W) corresponding to the frequency of 40 Hz and a minimum value of 138 W obtained at 10 Hz;

○ at full load, the higher value of the iron losses is 183.2W at 40 Hz and the minimum value corresponds to the frequency of 10 Hz and it is 104.23 W;

○ the iron losses at 10 Hz are up to 50% lower than the values associated to 40 Hz.

The electrical losses have an increasing dependence (Fig. 7) and it can be seen that:

○ the biggest electrical losses, are obtained at 10 Hz; thus, a value of 148.8 W is obtained at the minimum load, and 326.35 W is obtained at full load;

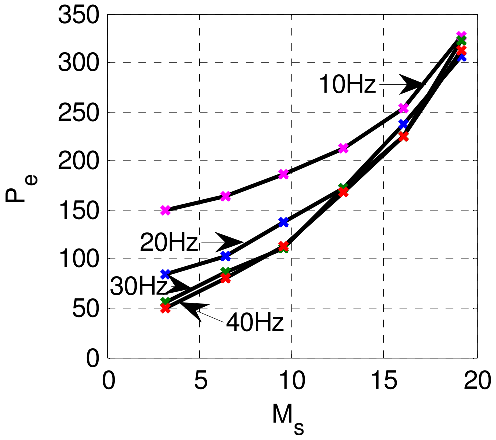

**Fig. 7** The electrical losses versus load torque

○ the lowest value of electrical losses obtained at low load is 57.48 W and it corresponds to the frequency of 40 Hz;

○ the lowest electrical losses at high load are obtained at 20 Hz (305.22 W);

○ for the higher load (over 85% of full load), the electrical losses for different frequencies become close;

○ at the load torque Ms = 0.8 $M_N$, the electrical losses for 20 Hz and 30 Hz are equal.

The total losses have an increasing dependence too, but they have few particularities (Fig. 8):

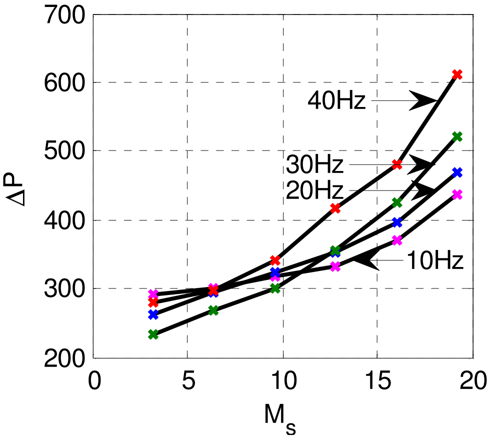

**Fig. 8** The total losses versus load torque

○ the total losses have a minimum value of 233.86W to 30 Hz and a maximum value of 293 W to 10 Hz, corresponding to the load torque Ms = 0.2$M_N$;

○ for a load torque over 39% of the maximum load, the total losses corresponding to the frequency of 40 Hz are the highest; so, at the load torque Ms = $1.2M_N$ is the highest value is 610.32 W;

- for load torque higher that 0.6 $M_N$, the total losses corresponding to the frequency at 10 Hz are the lowest compared to other frequencies.

## 6. CONCLUSIONS

✓ The iron losses of the induction motor must be taken into consideration because their weight in total losses is important. So, for our motor, at the operation frequency of 20 Hz, they represent about 60% at low load and 30% at high load.

✓ The developed model is useful for energetic analyses of any modulation method.

✓ The developed model is useful for benchmarking energy performance of the modulation methods.

✓ The obtained results do not contradict the physical phenomenon, but experimental verification is necessary.

## BIBLIOGRAPHY

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

[2] **Bitoleanu A., Popescu Mihaela, Ivanov S.** *The performances of an Induction Motor and Tension Fed Inverter Driving System*, Symposium on Automatic Control and Computer Science, Polytechnic Institute of Iaşi, October 29-30, 1993.

[3] **Bitoleanu A., Popescu Mihaela**, *New Power Optimization Possibilities of Static Converter and Asynchronous Motor Driving Systems*, CNAE'2002 Proceedings, Editura Fundației Universitare "Dunărea de Jos", Galați, octombrie 2002, pp. 19-26.

[4] **Holtz J.**, *Pulsewidth modulation-a survey*, IEEE Trans. Ind. Electron., Vol. 39, No. 5, , Oct. 1992, pp. 410–420.

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

[6] **Popescu Mihaela, Bitoleanu A.**, *Energetica sistemelor de acționare cu motoare asincrone şi convertoare statice indirecte*, Ed. Mediamira Cluj-Napoca, 2004.

[7] **Mohan N., Underland M.T., Robins P.W.,** *Power Electronics, Convertors, Applications and Design,* John Willey&Sons, New York, 1995.

[8] **Ileana – Anamaria Mitran, Alexandru Bitoleanu, Mihaita Linca,** *Energetical analysis of induction motor and voltage inverter with sinusoidal and trapezoidal PWM control*, Buletinul AGIR, Editura AGIR, Romania, nr. 2, aprilie-iunie 2012, 9th WORLD ENERGY SYSTEM CONFERENCE, WESC 2012, Suceava, Romania, iunie, 2012, pag. 379-385

[9] **Ileana – Anamaria Mitran, Alexandru Bitoleanu, Mihaita Linca,** *The mathematical model of the induction motor considering iron losses in enegetic analyze*, ICATE, Craiova, 2012

[10] *SIMULINK. Model-Based and System-Based Design*, The MathWorks Inc., 2007.

[11] **Günther Frhr. v. Schlotheim**, *Drive Technology, TPS 12.4.4. Frequency Converter Technology, Drives,*Germany

## 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 Programme Human Resources Development 2007 – 2013.

## 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

Alexandru Bitoleanu was born in Romania on November 9, 1947. He received Electrical Engineering degree at University of Craiova in 1975, and PhD in 1989. He works at University of Craiova, Electrical Engineering Faculty, Electromechanical, Environmental and Industrial Informatics Department, since 1978. Now, he is professor and the scientific coordinator of doctoral theses. 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, more than 120 articles and papers and coordinated eleven doctoral theses in electrical engineering