THE ENERGETIC ANALYSIS OF THE DRIVE SYSTEM WITH INDUCTION MOTOR CONSIDERING IRON LOSSES: PART 1 –SINUSOIDAL VOLTAGE SUPPLY

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REZUMAT. In acesta lucrare este prezentata analiza energetica a unui sistem de actionare cu motor asincron cu considerarea piederilor in fier. S-a considerat cazul in care motorul asincron este alimentat de la un sistem trifazat sinusoidal si simetric de tensiuni. Rezultatele obtinute corespund mai multor puncte statice de functionare, pentru diferite frecvente si valori ale cuplului static. In vederea obtinerii inductivitatii de magnetizare si rezistentei echivalente, s-a folosit un algoritm care presupune un calcul iterativ al acestor parametri.

Cuvinte cheie: analiza energetică, indicatori de calitate, sistem de actionare, motor asincron, pierderi în fier

ABSTRACT. This paper presents the energetic analysis of an induction motor drive system considering the iron losses. The induction motor was powered by a symmetrical, sinusoidal three-phase voltage system. The results are obtained for several static operating points corresponding to different frequency and torque values. In order to obtain the magnetizing inductance and resistance an iterative computation algorithm was proposed.

Keywords: energetic analysis, quality indicators, drive system, induction motor, iron losses

1. INTRODUCTION

In the electrical drive systems with induction motors, various static operating points can be obtained by using different command strategies. These suppose a correlation between voltage and frequency (U/f = ct or $U/\sqrt{f}$ = ct), or maintaining constant a quantity with respect to the motor operation (rotoric flux, statoric flux, rotoric frequency, etc.) [1].

Although, in the drive systems, the electric motor is supplied from a static converter, the energetic analysis of different control strategies can be made by considering the voltage source sinusoidal and symmetrical [1], [2]. This way, the results can be easily interpreted, avoiding the static converter influence over the control strategy.

The induction motor with squirrel cage rotor is taken into account in this paper [3], [4], [5].

The purpose of this paper is the determination of the induction motor energetic performances, considering the iron losses, for the sinusoidal symmetrical three-phase voltage system.

2. MATHEMATICAL MODEL OF THE INDUCTION MOTOR

The equivalent circuit of the induction motor considering iron losses is illustrated in figure 1. The shunt equivalent circuit consists of the magnetizing resistance (R_m) and reactance (X_m) [6], [7].

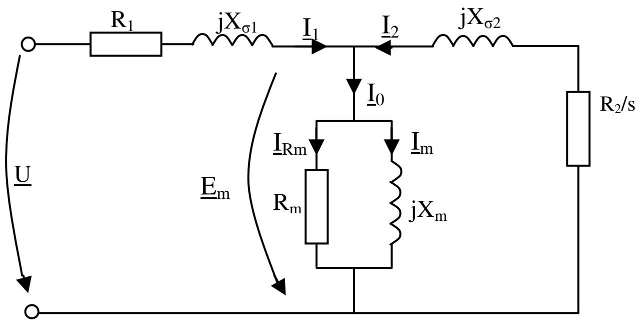

Fig. 1 The equivalent circuit of the induction motor considering iron losses

The used mathematical model of the induction motor takes into consideration the iron losses and it was obtained based on the set of equations in the stationary d-q frame [6], [8], [9]. For their simplification, it was considered that dynamic magnetizing inductance is equal to the static , but they are dependent on the magnetizing current.

The equations of the induction motor considering iron losses mathematical model contain the stator and rotor currents components d-q frame and was realized in MATLAB-Simulink environment.

3. IRON LOSSES COMPUTATION

Even though in most cases the iron losses are neglected, they achieve 40% of the total losses. This is why they are studied and different relations were proposed to approximate them [10], [11].

The iron losses were calculated using [4], [9].

$$P_{Fe} = kE^{\beta} f^{\alpha-\beta} \quad (1)$$

which depends on three parameters (k, α and β).

Using the experimental data, for both idle current and load current, six equation systems were formed. The resulted quantities were all positive, which means that (1) has physical meaning.

To obtain a steady value for k, α and β the average value was used for each parameter giving: k=0.079; α=0.714; β=2.846.

4.THE ENERGETICAL ANALYSIS

Imposing the supply and the load for the induction motor, the Simulink model of the drive system gave all the necessary quantities in order to analyze the energetic performances.

The induction motor was supplied by a sinusoidal symmetric three-phase voltage system respecting the constant ratio between the voltage and the frequency.

The simulation results were obtained for three frequencies (10Hz, 25 Hz and 40 Hz) and different values for the load torque M_s=[0.05; 0.2; 0.4; 0.6; 0.8;1;1.2]M_N.

Computation algorithm

For the drive system simulation in a specific operating point, the magnetizing resistance and inductance must be known. Using specific motor parameters and starting from imposed values for the torque and for the supply voltage and frequency, the following algorithm is used:

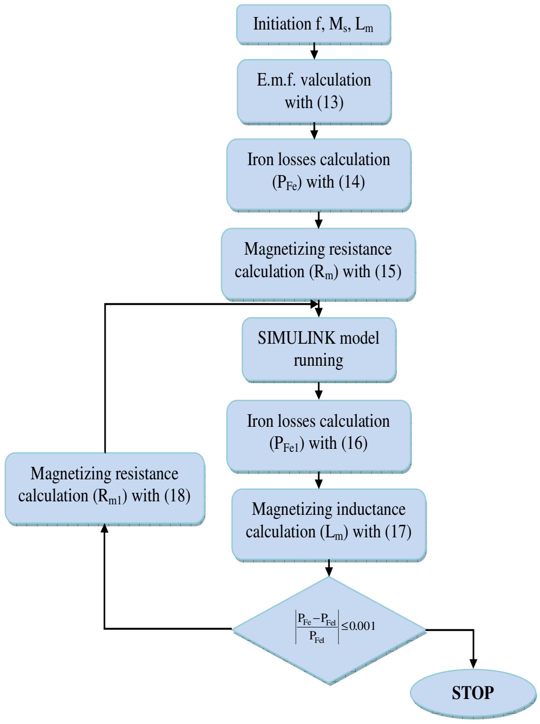

Fig.2 Computation algorithm

where:

- the e.m.f. : $E_m = 0.96 \cdot U$; (2)
- the iron losses $P_{Fe} = 3kE^{\beta} f^{\alpha-\beta}$; (3)
- based on the experimental data a fitting function was determined (4) necessary to calculate the magnetizing resistance from the computed iron losses. The magnetizing resistance variation versus the iron losses is illustrated in figure 3.

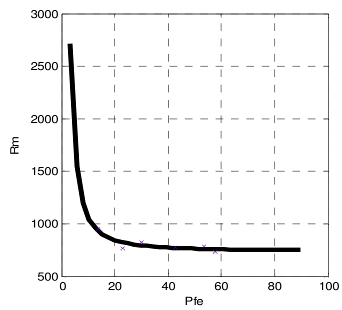

Fig. 3 The magnetizing resistance versus iron losses

$$R_m = a \cdot P_{Fe}^{b} + c \quad (4)$$

where, a, b, c are coefficients

- after Simulink model running was obtained I_{Rm}.
- the iron losses: $P_{Fe1} = 3R_m I_{Rm}^2$; (5)
- taking into account (6) it was calculated the magnetizing inductance,

$$L_{ms}=\begin{cases} a & pentru \quad i_m \le i_{m1} \\ bi_m^2+ci_m+d+e/i_m & pentru \; i_{m1}<i_m<i_{m2} \\ p+q/i_m & pentru \quad i_m \ge i_{m2} \end{cases} \quad (6)$$

where: $i_{m1} = 1,2543\ A$, $i_{m2} = 2,786\ A$;

- the magnetizing resistance $R_{m1} = \dfrac{1-(P_{Fe}-P_{Fe1})}{P_{Fe1}}$ (7)

The Simulink model of the drive system

Specific blocks were added to the Simulink model of the induction motor drive system powered from a sinusoidal voltage source (figure 4).

The corresponding parameters of the induction motor considering the iron losses are the following: the rated power - P_N = 2.6 kW; the rated voltage - U_N = 380 V; the rated frequency- f_N = 50 Hz; the rated load torque M_N = 16 Nm; stator resistance and inductance: R_1=1,6Ω; $L_{\sigma1}$=0,0093H; rotor resistance and inductance: R_2=1.76Ω; $L_{\sigma2}$=0,0173H; magnetizing inductance: L_m=0,2899 H.

The energetic analysis of the drive system for different static operating points involves the calculation of various quantities, as follows:

- the active power based on the instantaneous complex power theory [14], [15].

$$P_1 = \frac{1}{T}\int_{t-T}^{t} p dt \; ; \quad (8)$$

- iron losses (5);
- stator winding losses, $p_{Cu1} = 3R_1 I_1^2$ (9)
- rotor winding losses, $p_{Cu2} = 3R_2 I_2^2$ (10)
- electrical losses, $p_e = p_{Cu1} + p_{Cu2}$ (11)
- mechanical power, $P_m = M_s \Omega$ (12)
- total losses, $\Delta P = P_1 - P_m$ (13)
- efficiency, $\eta = \dfrac{P_{mec}}{P_1}$ (14)
- power factor, $PF = \dfrac{P_1}{3U_1 I_1}$ (15)

5.NUMERICAL RESULTS

The efficiency

Analyzing the figure 5 the following aspects can be drawn:

- the efficiency variations are not different from the typical shapes;
- over the rated torque the efficiency rise remains visible only for 10 Hz and 40 Hz;
- the efficiency reaches the highest value at 40 Hz and the lowest at 10 Hz;
- the frequency influence over efficiency is higher at lower frequencies as follows: at 80% of the rated torque a frequency drop of 15 Hz from 25 Hz leads to a efficiency drop of about 30 %, meanwhile a frequency rise of 15 Hz leads to a efficiency rise of about 8 %.

The power factor

From figure 6 the following aspects can be observed:

- the power factor increases with the load, having typical shape for 25 Hz and 40 Hz, and almost linear variation in case of 10 Hz;

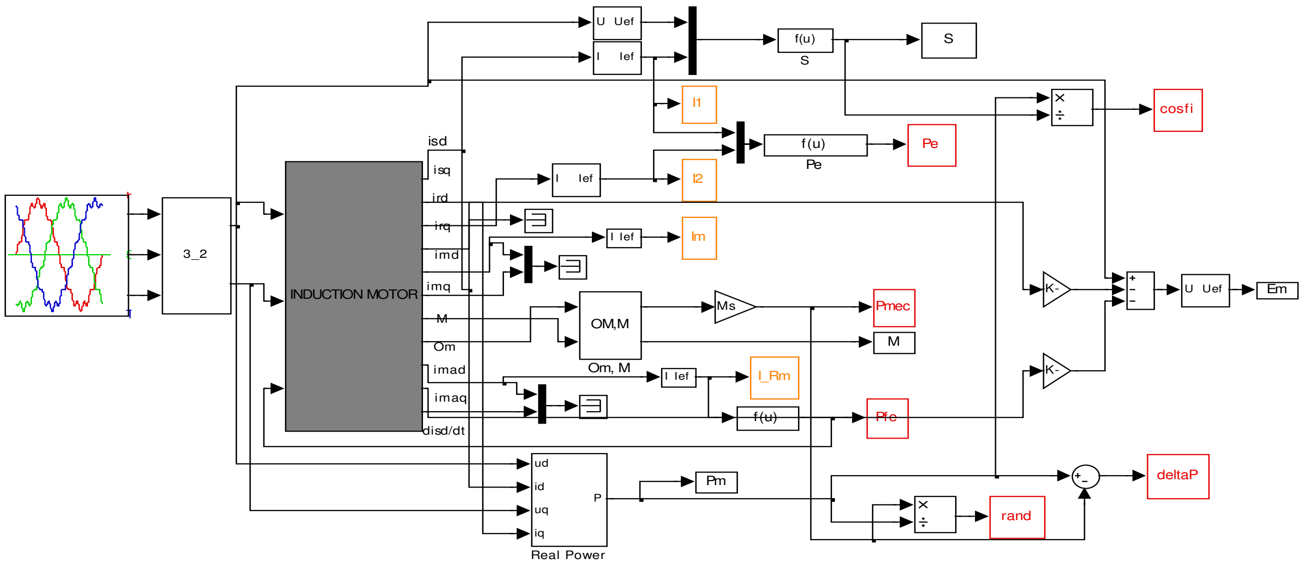

Fig. 4 The Simulink model of the drive system

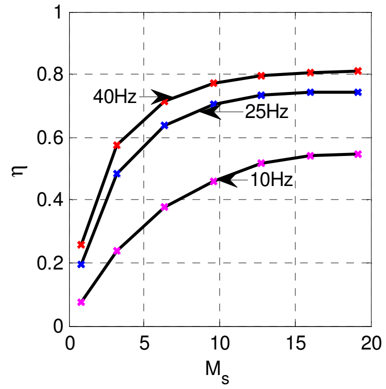

Fig. 5 The efficiency versus the load torque

- at 5% of the rated torque the power factor value is maximum for frequency of 10 Hz and minimum at 40 Hz;
- the power factor values are very close, at 25 Hz and 40 Hz, for the whole interval;

The iron losses

- Analyzing the obtained iron losses variation some conclusions can be outlined:
- for all the considered frequencies the iron losses drop while the load increases;
- for both minimum and maximum load the highest value of the iron losses is obtained at 40 Hz, and the lowest value of them resulted in case of 10 Hz

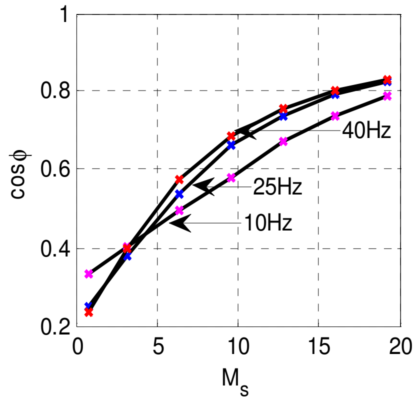

Fig. 6 The power factor versus the load torque

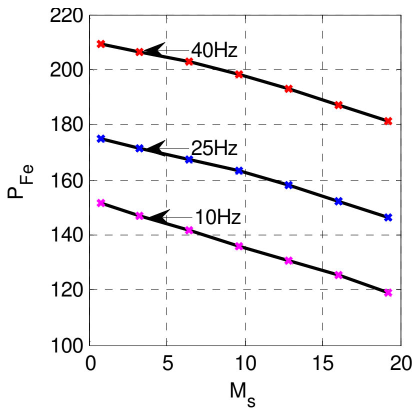

Fig. 7 The iron losses versus the load torque

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- considering all the studied load torques it can be seen that the lowest iron losses resulted at the frequency of 10 Hz, comparing with the frequency of 40 Hz in which these are up to 55% higher;

The electric losses

From graphical representation (Figure 8) can be seen:

- the electrical losses grow while the load torque increases;
- over 60% of the rated torque the electrical losses values at 25 Hz and 40 Hz are almost equal;
- for a wide range of load variation, the electrical losses are higher at 10 Hz, comparing with the frequencies of 25 Hz and 40 Hz in which they are lower.

The total losses

Out of the dependence of total losses versus load torque can be remark:

- the total losses increasing while the load increases;
- the total losses shape is the same, at 40Hz and 25 Hz for the whole interval;

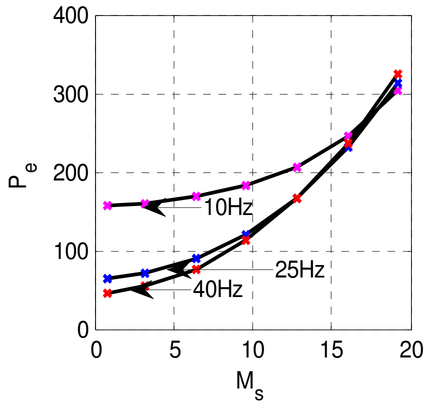

Fig. 8 The electrical losses versus the load torque

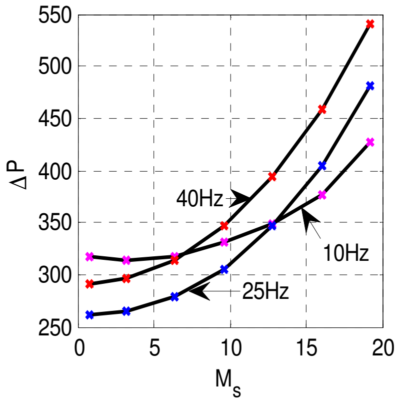

Fig. 9 The total losses versus the load torque

- for low values of load torque (under 6 Nm) the highest value of the power losses is obtained at 10 Hz;
- the lowest values of total loses correspond to 25Hz, for load torque under 12,5 Nm;

the difference of total losses is influenced by the power system frequency, voltage and load torque

6. CONCLUSIONS

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

✓ The higher values of the efficiency were obtained at 40Hz, and the lowest at 10Hz

✓ For all frequencies, the efficiency retains shape known in specialized literature;

✓ Regardless of the power system frequencies, the electrical losses corresponding to the maximum load are almost equal

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 Sectorial Operational Programme Human Resources Development 2007 – 2013.

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