Energetical Performances of Phasorial Modulation for the Induction Motor and Voltage Inverter System: Experimental Approach

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***Abstract* – The electric drive is a main component of industrial equipment designed for small or large complexity, because the achievement of finished goods implies the adjustable mechanical energy available at the output of the drive system. Because the static converters are needful in such a system, the evolution of the converter's command sub-systems was also needful, to improve their performance. The aim of this paper is the energetic analysis of the drive system and it had been performed on an experimental platform for different static operation points. It was considered feeding the asynchronous motor from an indirect voltage source static converter using the space-vector modulation as command strategy. Two cases had been taken into consideration: feeding the motor with the same RMS voltages and achieving the same static torque. We use space-vector modulation to reach the nominal torque at different frequencies. For each static point, read data and recorded the waves form needed in calculate all the energetic parameters at the outputs of rectifier, inverter and static converter. The frequency considered for the energetic analyses are 20Hz, 30H and 50Hz, and the load was adjusted up to the nominal value. For the measured quantities, a Fluke power quality analyzer was used at the power grid side, precision ammeter and voltmeter were used in the dc-link, and in order to compute the power quality indicators at the inverter output, a digital oscilloscope was used to record the waveforms of voltage and current, later used to calculate the electric power.**

Keywords - *electric drive, static converter, induction motor, quality indicators, sinusoidal PWM modulation*

I. INTRODUCTION

Starting from the square-wave modulation, the space-vector modulation appeared and improved to minimize copper losses, torque ripple, etc. Space-vector modulation techniques used today to control the modern static converters as part of high–power machine drives strongly depend on switching frequency of the power semiconductors.

The electromechanical drive is an essential component of technical equipments for industrial activities of high or low complexity, because obtaining the final product necessitate mechanical energy available the output of the drive system.

II. THEORETICAL ASPECTS

A. The operated equipment

The experimental platform contains a Leybold type stand was used [9], which includes the following components (Fig. 1, Fig. 2):

- A single-phase fully controlled bridge rectifier;
- The DC link circuit of the voltage inverter;
- The three-phase voltage inverter with IGBTs and its control modulus;
- Squirrel cage motor;
- The mechanical load (asynchronous motor of special construction and its torque control modulus);
- Measurement and recording equipment (Fluke 41b analyzer, Metrix OX 7042 – M oscilloscope, voltmeter and ammeter).

The power system components have the rated values indicated below:

Motor: P_N=370W; U_N = 230V; I_N = 2.1A;
cos φ = 0.76; n_N = 1380 rot/min.

Inverter: U_N = 230V; I_N = 10A.

Load: P_N=250W; U_N =230V; M_N=2Nm.

To obtain the experimental data required to determine the energetic performances of the drive system based on the space-vector modulation we made a modification in the dc-link of static converter: before the capacitor, we mounted an ammeter to read the current and a voltmeter for the voltage.

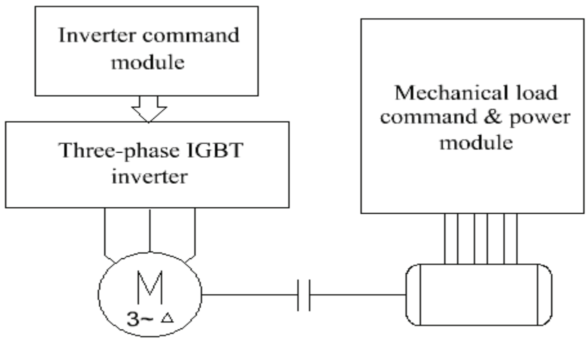

Fig. 1 The drive system block diagram

Fig. 2 The experimental workbench

The power quality indicators of the power grid were read with Fluke 41b and the corresponding indicators at the motor terminals had been calculated based on the recorded waveforms of the voltage and current using a simulation model in Matlab Simulink.

B. The space-vector modulation

Dealing with the space-vector modulation it can be started from the idea that in order for an inverter to provide sinusoidal phase voltages, the associated space phasor must rotate continuously. If the imposed frequency and amplitude of the sinusoidal voltages are constant, the locus of the peak of the phasor is a circle.

Because the operation of the inverter includes only eight possible configurations due to the "on" and "off" functioning of semiconductor devices, the voltage vector can only have eight distinct positions, including 6 non-zero ($\underline{u}_1$, $\underline{u}_2$, $\underline{u}_3$, $\underline{u}_4$, $\underline{u}_5$, $\underline{u}_6$) which correspond to the vertexes of a regular hexagon and the other two ($\underline{u}_7$, $\underline{u}_8$) which are null and corresponds to the middle of the hexagon- [4],[8].

C. Power quality indicators

In the completed studies, for computing the active and the reactive power, the complex apparent power theory [1] (p-q theory) was used. According to the p-q theory, the instantaneous complex apparent power is defined as the product of the voltage phasor ($\underline{u}$) and the complex conjugate of the current vector ($\underline{i}^*$) [2]:

$$\begin{aligned}\underline{s} &= p + jq = \frac{3}{2}\underline{u}\cdot\underline{i}^* = \\ &= \frac{3}{2}\left[u_d i_d + u_q i_q + j\left(-u_d i_q + u_q i_d\right)\right]\end{aligned} \tag{1}$$

The real and the imaginary components of complex apparent power are:

$$p = \frac{3}{2}\left(u_d i_d + u_q i_q\right) \tag{2}$$

$$q = \frac{3}{2}\left(-u_d i_q + u_q i_d\right) \tag{3}$$

Is widely accepted that the average value of the real part p, over one period of the voltages and currents (T) gives exactly the active power P:

$$P = \frac{1}{T}\int_{t-T}^{t} p\,dt \tag{4}$$

It's also widely accepted that that the average value of the imaginary part q, over one period of the voltages and currents (T) gives the reactive power Q:

$$Q = \frac{1}{T}\int_{t-T}^{t} q\,dt \tag{5}$$

Starting from the instantaneous complex apparent power, the apparent power can be defined [5], [7], keeping true Bucholtz's formula [3]. Thus:

$$S_f = \sqrt{\frac{1}{T}\int_{t-T}^{t}\frac{U^2}{\left|\underline{u}\right|^2}\left|\underline{s}\right|^2 dt} \tag{6}$$

Where $\underline{\boldsymbol{U}}^2$ is the square RMS value of the voltage phasor modulus,

$$U^2 = \frac{1}{T}\int_{t-T}^{t}\left|\underline{u}\right|^2 dt \tag{7}$$

So, the apparent power is given by:

$$S_f = \sqrt{\frac{1}{T}\int_{t-T}^{t}\frac{U^2}{\left|\underline{u}\right|^2}\frac{9}{4}\left|\underline{u}\right|^2\left|\underline{i}\right|^2 dt} = \frac{3}{2}UI \tag{8}$$

Considering the quadrature relationship between powers, the distortion power is defined as

$$D_f^2 = S_f^2 - P^2 - Q^2 \tag{9}$$

The power quality analysis is based on the power quality indicators [6] specified below: the power factor, the drive motor efficiency and the electrical losses.

III. THE EXPERIMENTAL PROTOCOL

With the help of a Matlab / Simulink model, the power quality indicators were calculated at the motor input terminals. For the simulation protocol it was considered feeding the asynchronous motor from an indirect voltage source static converter with space-vector modulation.

Through the experimental protocol, the quantities needed to be measured in order to determine the energetic performances of the drive system had been recorded at the motor input terminals, on the static converter dc-link and at the power grid side.

The waveforms recorded at the motor input terminals where processed using a Matlab Simulink model (Fig. 3) in order to obtain the parameters at the motor input terminals.

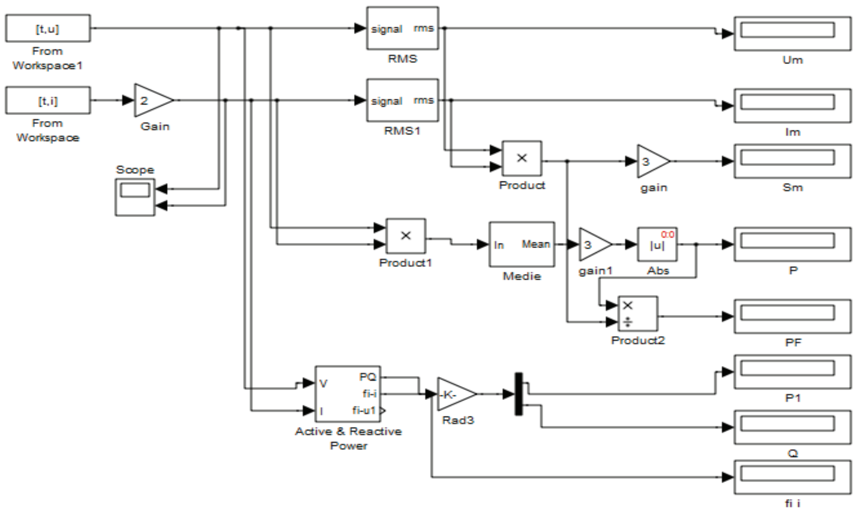

Fig. 3 The Simulink model used for energetic parameters computation

The measured or calculated parameters in the considered cases are: the phase voltage and line current (the motor is in the delta connection); the active and reactive power at the motor terminals and at the grid side, and the apparent power, respectively, also, the total power factor and efficiency of the drive system when feeding the motor at constant frequency (20, 30, and 50 Hz) and for different values of the load torque (0; 0.1 ;0.2; 0.3; 0.4;0.5;0.6;0.7;0.8;0.9; 1;1.1) TN. Taking into account the experimental protocol and starting from measured data for a static operating point, the other quantities needed to determine the energetic performances were calculated and the comparative analysis had been achieved. For each operating point the waveforms of voltage and current had been recorded, and also, the following quantities measured: the RMS values of voltage and current, the active power, rotor speed, and torque, respectively. The recorded data processing was done in Matlab (Simulink). It should be noted that the power quality computing was made based on the recorded waveforms, torque and rotor speed, using Matlab Simulink models developed by the authors [8].

IV. EXPERIMENTAL RESULTS

The energetic performances were analyzed based on the Simulink model results, for the same frequency (20, 30 and 50 Hz) and are based on the graphical representations for the most significant power quality indicators. The rectifier is having the highest efficiency because the space-vector modulation is a pulse width modulation and the rectifier is uncontrolled.

The inverter efficiency is smaller than that of the rectifier because it uses forced switching, followed by the static converter overall efficiency and the motor and global efficiency which is the lowest in relation to the other at both command frequencies.

The motor reaches the maximum efficiency at 1.5Nm for 20Hz command frequency.

The network electric power is higher than that from the dc-link and higher than that at the motor terminals for 20Hz command frequencies.

The global efficiency is the smallest efficiency because is the efficiency of the entire drives system and is the relation between the electric power at the motor terminals and the electric power at the network terminals.

The efficiency of the rectifier is the best efficiency because the rectifier is uncontrolled.

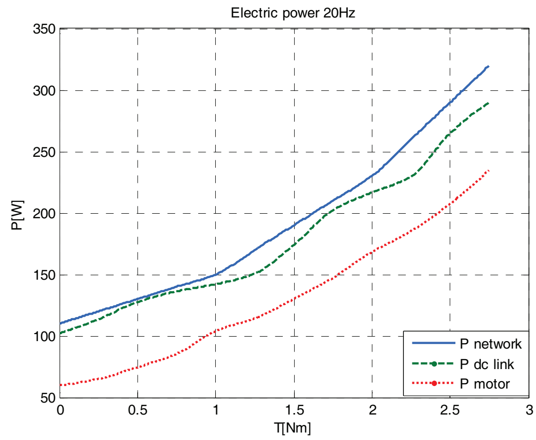

Fig. 4 Electric power depending on the torque for drive system with space-vector modulation for 20Hz command frequencies

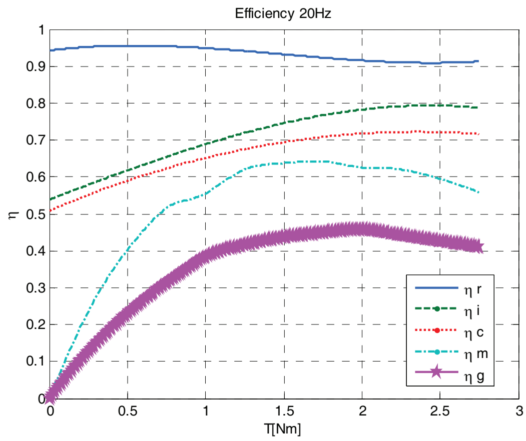

Fig. 5 Efficiency depending on the torque for drive system with space-vector modulation for 20Hz command frequencies

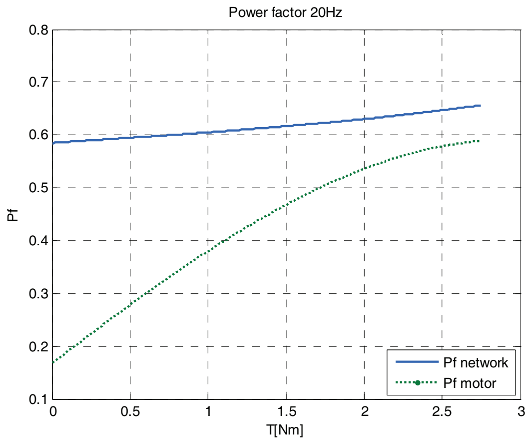

Fig. 6 Power factor depending on the torque for drive system with space-vector modulation for 20Hz command frequencies

The motor reaches its maximum efficiency at 2Nm for the 30Hz command frequency. The global efficiency depends especially on the efficiency of the inverter and the efficiency of the motor. The efficiency is better at 30 Hz command frequency than at 20 Hz command frequency so we can say that with the increase of the frequency the efficiency increases also.

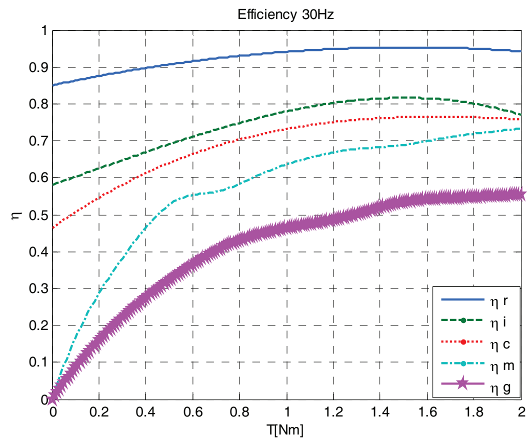

Fig. 7 Efficiency depending on the torque for drive system with space-vector modulation for 30Hz command frequencies

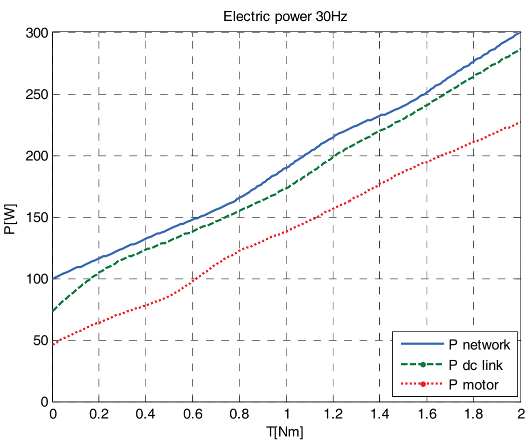

Fig. 8 Electrical power depending on the torque for drive system with space-vector modulation for 30Hz command frequencies

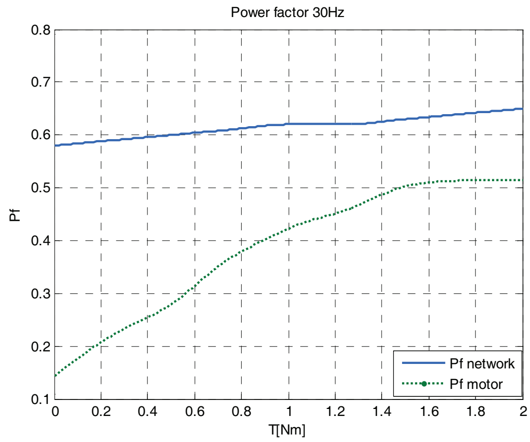

Fig. 9 Power factor depending on the torque for drive system with space-vector modulation for 30Hz command frequencies

With the increase of the command frequency the electrical power at the grid side, dc link and at the terminals of the motors increases also].

The efficiency of the rectifier, inverter and the entire static converter has some oscillations because the static converter is a voltage source converter and the power in the DC link is affected by the filtering capacitor.

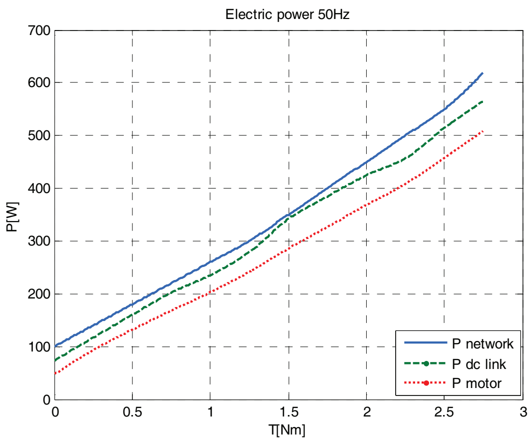

Fig. 10 Electrical power depending on the torque for drive system with space-vector modulation for 50Hz command frequencies

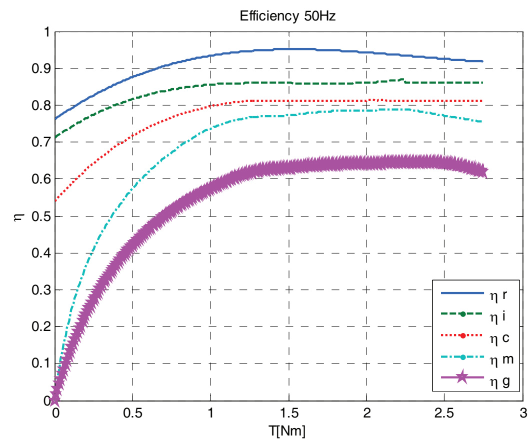

Fig. 11 Efficiency depending on the torque for drive system with space-vector modulation for two command frequencies

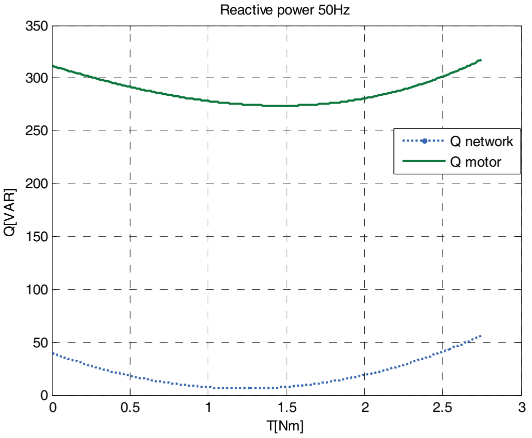

Fig. 12 The reactive power dependence on the torque for 50Hz command frequencies

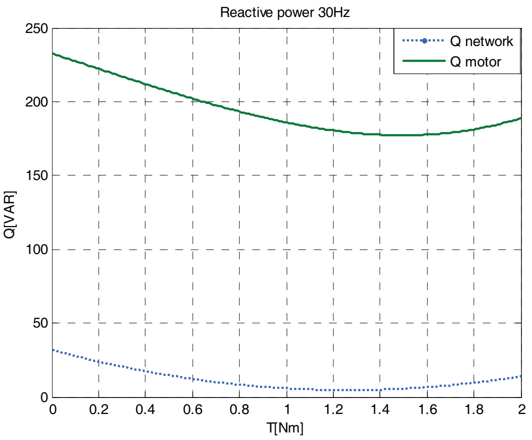

Fig. 13 The reactive power dependence on the torque for 30Hz command frequencies

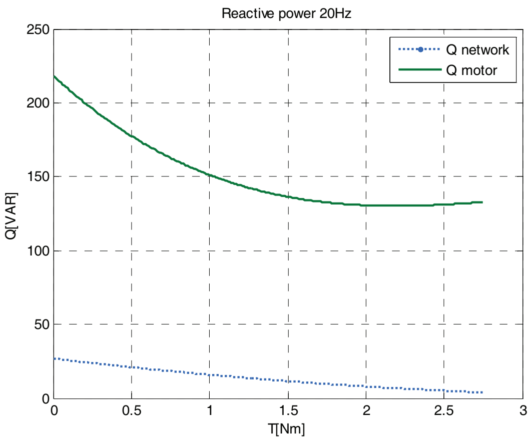

Fig. 14 The reactive power dependence on the torque for 20Hz command frequencies

At 50Hz and 30Hz the nominal electric power of the motor is reached at a 2Nm and not at the nominal torque value because the space-vector modulation forces the motor.

The reactive power is higher at the power grid terminals than the reactive power at the terminals of the motor. The reactive power on the network side increases with the increase of the command frequency.

V. CONCLUSIONS

The energetic performances were analyzed at the same frequencies (20, 30 and 50 Hz) based on the graphical representations for the most significant power quality indicators. The global efficiency depends especially on the efficiency of the inverter and of the motor, the rectifier and DC-Link efficiency influence in the overall efficiency is reduced.

Because a low power motor was used, at the nominal frequency the efficiency does not exceed the value of 65%.

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