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A design of a computer-based measuring system of a frequency converter drive

***Abstract**. The paper presents a computer-based system for measuring, registering and visualising selected electromechanical quantities of a drive with a frequency converter. The measuring system includes measuring converters, a measuring card and a computer with specialised software. The crucial parameters of the three-phase frequency converter have been characterised and principles of their configuration are presented. Measurements of the drive system have been carried out for the following operating conditions: start-up, reverse, and deceleration. The results of the tests are represented as curves of phase-to-phase voltage, phase current and rotational speed versus time.*

***Streszczenie.** W referacie przedstawiono komputerowy układ do pomiarów, rejestracji i wizualizacji wybranych wielkości elektromechanicznych napędu z przemiennikiem częstotliwości. Układ pomiarowy zrealizowano z wykorzystaniem przetworników pomiarowych, karty pomiarowej oraz komputera ze specjalistycznym oprogramowaniem. Scharakteryzowano podstawowe parametry trójfazowego przemiennika częstotliwości oraz zasady ich konfiguracji. Przeprowadzono badania pomiarowe układu napędowego dla następujących stanów pracy: rozruch, rewers oraz hamowanie. Rezultaty badań napędu z przemiennikiem częstotliwości przedstawiono w postaci przebiegów czasowych napięcia międzyfazowego, prądu fazowego oraz prędkości obrotowej. (**Koncepcja komputerowego układu pomiarowego napędu z przemiennikiem częstotliwości**).*

Keywords: induction motor, frequency converter, computer-based measuring system.
Słowa kluczowe: silnik indukcyjny, przemiennik częstotliwości, komputerowy układ pomiarowy.

Introduction

Frequency converters with an intermediate circuit for powering squirrel-cage AC motors are widely applied in industrial drives. Utilising semiconductor power instruments, such systems start, reverse, decelerate, and smoothly control the rotational speed of a drive. Besides, they are characterised by high energy efficiency and a large reliability coefficient, which is of great importance in the case of industrial drives operating continuously [1, 3, 5, 10].

Equally important are such parameters of the converter as the minimal and maximal frequency of the output voltage, time of voltage increase during the start-up, the value of the deceleration torque, deceleration time and the maximal output current. In the practice of designing drive systems it is often necessary to verify real parameters with respect to the prescribed parameters. In such cases a computer-based system proves to be indispensable for registering and visualising selected electromechanical values of the drive, such as rotational speed, phase current and phase-to-phase voltage [6, 9, 13].

AC frequency converter drive

The drive system under test consists of an asynchronous squirrel-cage motor and separately excited generator connected by means of a rigid shaft. The asynchronous motor is powered by means of a three-phase frequency converter of the series ACS 600 manufactured by ABB. The rotor of the AC motor is mechanically connected to a tachometric generator, enabling measurements of the rotational speed.

The converter of the ACS 600 series utilises the direct torque control (DTC) method [2]. This method offers advantages over the conventional pulse-width modulation (PWM) method with respect to regulation properties. In the DTC method, a control sequence switching semiconductor elements in the voltage inverter is determined on a cyclic basis depending on a current electromagnetic state of the AC motor. The instantaneous value of the electromagnetic torque of the asynchronous motor is proportional to the product of the stator-rotor flux linkage vectors [1, 8]:

$$T_e = c_m \cdot \left(\underline{\Psi_s} \times \underline{\Psi_r}\right) = c_m \cdot \Psi_s \cdot \Psi_r \cdot \sin \vartheta_\Psi \quad (1)$$

where: $\underline{\Psi}_s$, $\underline{\Psi}_r$ - stator-rotor flux linkage vectors, ϑ_Ψ – angle between stator-rotor flux linkage vectors, c_m - constant dependent on motor design parameters.

When ϑ_Ψ belongs to the interval (0, π), then the stator flux vector precedes the rotor flux vector and the drive torque direction is the same as that of rotational speed. With the reverse mutual alignment of the stator and rotor vectors, a decelerating torque occurs. The absolute value of the electromagnetic torque can be changed not only by changing the flux modules, but also by changing the angle between their vectors.

The elements of the AC drive and of the measuring system together with the relevant parameters are specified in Table 1.

Table 1. The parameters of the drive system and the measuring system

Designation	Names and basic parameters
ACS 600	Frequency converter P_N = 4,0kW; I_N = 11,0A; U_{N1} = 380÷415V; f_1 = 48÷63Hz; U_{N2} = 0÷U_{N1}; f_2= 0÷300Hz; cosφ= 0,97; η_N= 98%
M	Asynchronous squirrel-cage motor P_N = 4,0kW; U_N = 220V/380V; I_N = 14,6A/8,5A; n_N = 1430 obr/min; cosφ = 0,85
G	Separately excited generator P_N = 5,5 kW; U_{tN} = 220V; I_{tN} = 28,0A; U_{wN} = 220V; I_{wN} = 0,91A; n_N = 1450 rpm
PT	Tachometer generator: 1000 rpm - 20V
PD	Diode rectifier: U_d = 250V; I_d = 2A
Atr	Autotransformer: U_{inp}= 230V; U_{out}= 0÷230V; I_N= 10A
R_L	Load resistance: R = 12Ω; I_{max} = 20A
LV25-P	LEM voltage transducers: measurement range 100V, 500V, measurement accuracy ± 0,8 %, linearity ± 0,2 %, response time 40 μs
LA55-P	LEM current transducers: measurement range 10A, measurement accuracy ± 0,65 %, linearity ± 0,15 %, response time 40 μs
V_a	Voltmeter: measurement range 300V, class 0.5
A_f	Ammeter: measurement range 20A, class 0.5
A_a	Ammeter: measurement range 2A, class 0.5

The measuring system and the AC drive are presented in the diagram shown in Fig. 1.

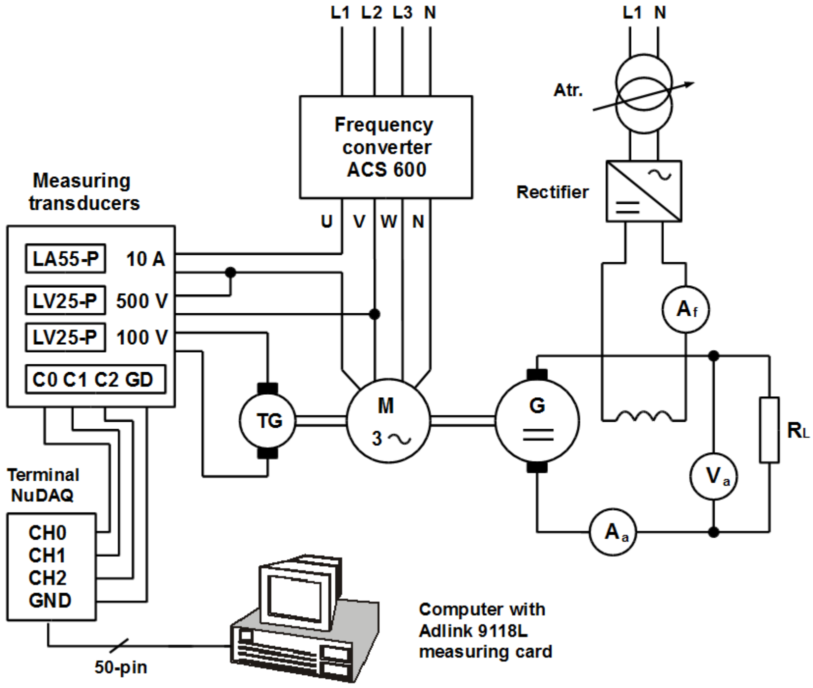

Fig. 1. Diagram representing connections in the AC frequency converter drive and the computer-based measuring system

The components of the current and voltage of an induction motor stator described in a coordinate system (d q) can be determined using the following relationships [3]:

$$i_d = \sqrt{\frac{2}{3}}\, i_a \; ; \qquad i_q = \frac{1}{\sqrt{2}}\left(i_b - i_c\right) \tag{2}$$

$$u_d = \sqrt{\frac{2}{3}}\, U_{DC}\left(S_1 - \frac{1}{2}\left(S_2 + S_3\right)\right) \tag{3}$$

$$u_q = \frac{1}{\sqrt{2}} U_{DC}\left(S_2 - S_3\right) \tag{4}$$

where: : i_d, i_q – components of the stator current, i_a, i_b, i_c – stator phase currents, u_d, u_q – components of the stator voltage, U_{DC} – the voltage in a DC intermediate circuit, S_1, S_2, S_3 – inverter control signals in the individual phases.

The components of the stator flux in a coordinate system (d-q) are defined by equations [3, 13]:

$$\underline{\psi}_d = \int_0^{\Delta t} (\underline{u}_d - R_s \underline{i}_d) dt \tag{5}$$

$$\underline{\psi}_q = \int_0^{\Delta t} (\underline{u}_q - R_s \underline{i}_q) dt \tag{6}$$

where: $\underline{\Psi}_d$, $\underline{\Psi}_q$, – vectors of flux components, R_s – resistance of the stator phase, t - time period for which the flux components are calculated.

Computer-based measuring system

The measuring system used in the tests consisted of a desktop computer equipped with the specialised software DasyLab and a measuring card Adlink 9118L with a 12-bit A/C transducer of a maximal sampling frequency of 100 kHz. The measuring card simultaneously registers and visualises voltage signals at up to eight bipolar channels. Since it was necessary to ensure galvanic isolation of the voltage and current circuits of the converter drive from the measuring system, transducers manufactured by LEM with appropriate ranges were used. In the measuring circuits of the line-to-line voltage and rotational speed voltage transducers LV25-P were applied, and in the phase current circuit a current transducer LA55-P were applied [4, 7, 11].

The proposed system for visualisation and recording of selected waveforms of the drive is presented in Fig. 2.

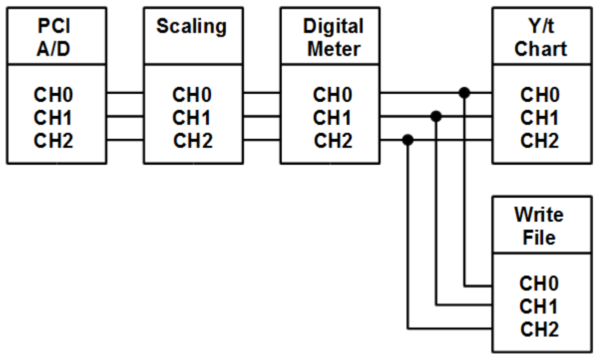

Fig. 2. Block diagram of the system for registering and visualising the time curves of voltage, current and rotational speed of the AC drive

The line-to-line voltage, phase current and rotational speed voltage of the AC drive were recorded by means of the software DASYLab. Measuring signals are read by three channels of the card Adlink 9118L and subsequently introduced to a scaling module in order to be reconverted into real values occurring in the drive system.

Then, the scaled signals are directed to the digital gauge module, where RMS values are determined with respect to the line-to-line voltage and the phase current, and for the rotational speed a mean value in a time interval is obtained. At a final stage, the waveforms obtained are represented graphically and saved on the disc in a file, in accordance with the DASYLab standard [4, 7, 12].

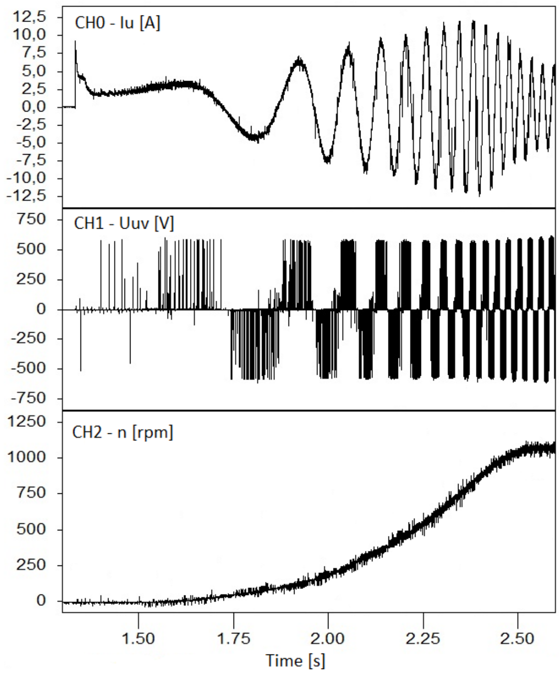

Fig. 3. Time characteristics of the phase current, phase-to-phase voltage and rotational speed at start-up

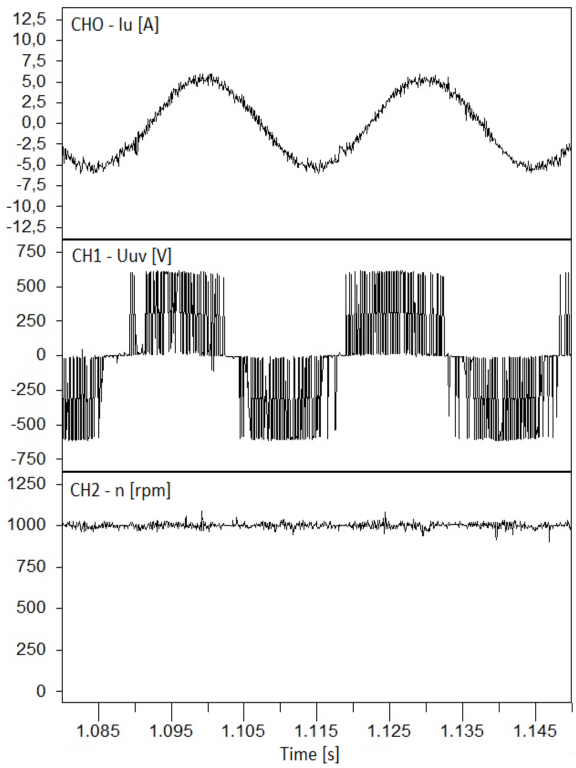

Fig. 4. Time characteristics of the phase current, phase-to-phase voltage and rotational speed for steady-state conditions

Measurement tests of the AC drive

The main element of the drive system under test is a three-phase frequency converter of the ACS 600 series. The high-current part of the converter consists of a rectifier, a DC intermediate circuit with a set of capacitors and an inverter. The intermediate circuit is connected to the decelerating circuit with an additional external resistor. Due to the presence of an inverter, direct voltage can be transformed into alternating voltage powering the asynchronous motor. During the decelerating stage, the inverter offers a possibility of the energy flowing to the resistor to be further dissipated as heat [10].

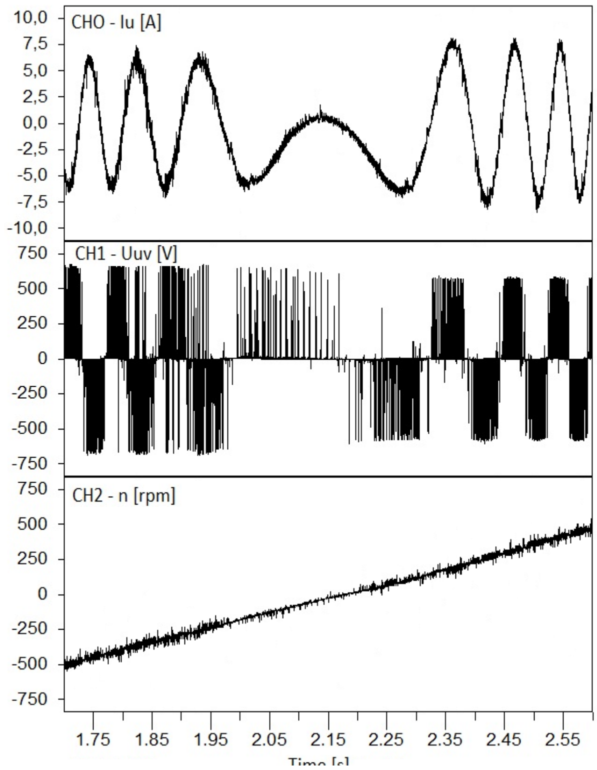

Fig. 5. Time characteristics of the phase current, phase-to-phase voltage and rotational speed at the reverse of the drive system

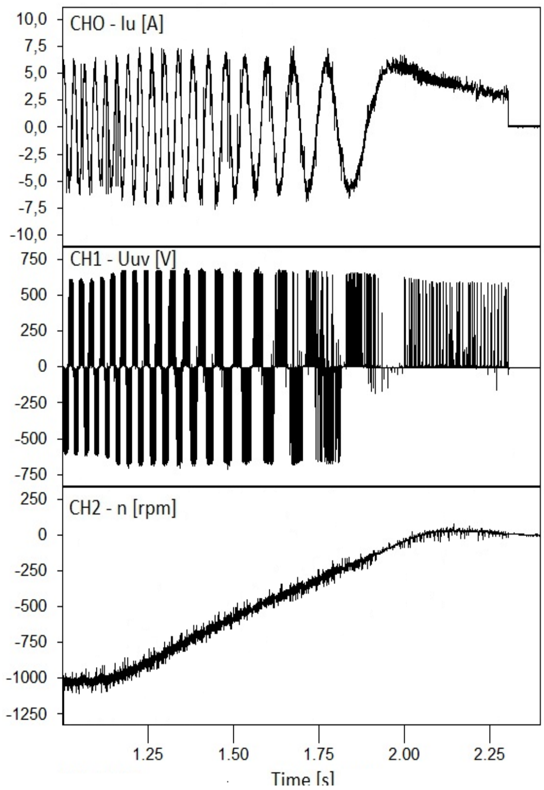

Fig. 6. Time characteristics of the phase current, phase-to-phase voltage and rotational speed at deceleration of the drive system

The frequency convertor under scrutiny offers access to information on the current values of selected physical quantities [2]. A set of those is given in Table 2.

Table 2. A set of current quantities for a series ACS 600 converter

Actual Signal	Range/Unit	Description
01 PROCESS VARIABLE	0 … 100000/ user units	Process variable based on settings in parameters
02 SPEED	rpm	Calculated speed of motor
03 FREQUENCY	Hz	Calculated motor frequency
04 CURRENT	A	Measured motor current
05 TORQUE	%	Calculated motor torque in % nominal motor torque
06 POWER	%	Motor power in %
07 DC BUS VOLTAGE	V	Measured Intermediate circuit voltage.

The measurements of the drive system were carried out for the following working conditions: start-up, reverse and deceleration at a constant load torque. Selected results concerning time waveforms of the rotational velocity, line-to-line voltage and phase current are presented in Figures 3-6.

Conclusions

The computer-based system for carrying out measurements, registration and visualisation of electromechanical quantities of an asynchronous drive powered by a DTC three-phase frequency converter is a useful tool for a precise analysis of line-to-line voltage variation, phase current and rotational speed. By selecting appropriate parameters of the frequency converter, it is possible to carry out a soft start of the drive system under load at the same time limiting the starting current to the level of the rated current of the asynchronous motor. An example of this kind of soft start is presented in Fig. 3, with the time scale selected in such a way that the full speed variation is presented from zero to the prescribed value.

The shape of the line-to-line voltage, which consists of pulses of variable width, is responsible for the occurrence of a variable component in the current waveform, with the frequency corresponding to the switching of the semiconductor elements in the converter. This is a detrimental phenomenon, but in modern converters the amplitude of the variable component is relatively small in comparison to the amplitude of the current sine component. This phenomenon is illustrated for the constant speed of the drive in Fig. 4.

A DTC frequency converter is highly useful at reverse conditions under load as well. The rotational speed waveform varies almost linearly from the initial to final speed and the current varies smoothly at very low frequencies of the sine component, as can be seen in Fig. 5. The frequency converter can be also used for decelerating the drive system. The energy obtained during deceleration is emitted as heat on the additional external resistor included in the system. The waveforms for the drive deceleration are presented in Fig. 6.

All in all, the computer-based measuring system developed in the study is a suitable tool for testing the frequency converter powering an asynchronous motor under start-up, deceleration, reverse and rotational speed regulation. The results obtained can be used for verifying the real parameters of the drive system with respect to prescribed ones.

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