A real-time monitoring instrument of induction machines for an integrated teaching test bench

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Abstract

The purpose of this paper is to present a real-time analogue monitoring instrument developed for an integrated test bench for teaching as well as for R&D activities, in power electronics and variable speed drives of induction machines. The instrument is based on electronic modules and has been developed for monitoring the stator, rotor and magnetizing fluxes space phasors, electromagnetic torque as well as active and reactive powers.

Keywords: monitoring instrument, induction machine, variable speed drives.

1. Introduction

The main goal of a school laboratory is to give the possibility to the students to put in practice the theory without spending too much time with details concerning to sophisticated hardware implementations, [1] being for the authors an interesting example, if possible avoiding high level and expensive development systems like the ones used in [2], to focus only on the monitoring, control and estimation schemes, by using simple, practical and low-cost solutions as suggested in [1]. In [3] the authors noticed the courses in electric machines have not changed in decades and the subject is considered as old-fashioned, staid and boring by the students and suggest that in the same course we can shift the focus from electric machines to electrical drives, allowing the introduction of this subject in the context of exciting new applications. The purpose of this paper is to present a real-time monitoring instrument to work with an integrated low-cost test bench, for teaching and R&D activities, in variable speed drives of induction machines. This project is a different solution but has globally the same objectives as [1] and [3] and is intended to be an important contribution to stimulate the student's interest in electric machines and power electronics as well as to provide them with practical experience in electronic design. The developed monitoring instrument enables the students to be in experimental contact with the issues surrounding the context of electric machines controlled by electrical drives, namely, the consequences of the switching pattern as, for instance, voltage and current harmonics, noise, electromagnetic interferences, torque ripple, instantaneous fluxes space phasors, active and reactive powers, and so forth, as a part of a multidisciplinary technology integrating many areas as for example: modelling, simulation, control and identification theories, signal processing and power electronics besides the electric machines themselves.

2. The integrated test bench

To reach the objectives described in the previous section, a modular electronic system described in [4] has been developed to capture, isolate, filter and process the stator voltages and currents space phasors, as well as rotor speed and position calculation, for an induction machine controlled by a voltage inverter. By using the *AD2S100* analogue vector processor from *Analog Devices*, the equivalent orthogonal *dq* components of stator voltages and currents are available in both stator and rotor reference frames in the range of ±10V, isolated and further filtered by a set of active elliptic low-pass filters, *MAX7411*, from *MAXIM*. All signals are available, the three-phase systems of voltages and currents and the equivalent two-phase orthogonal systems, before and after anti-aliasing filtering, as well as before and after coordinate rotation by using the vector processor. The global system consists of an integrated test bench as follows. An electronic unit was developed for conditioning and processing of stator voltages and currents, as well as rotor speed and position calculation for coordinate transformations [4]. Then, the new instrument was implemented and integrated for monitoring the stator, rotor and magnetizing fluxes space phasors, electromagnetic torque and active and reactive powers. This is an additional contribution of the authors after [4-6]. The *IRMDAC3* reference design kit for 3-phase 3HP AC motor drives from *International Rectifier* has been used to feed the induction machine. An opto-coupler interface board was created to connect the inverter kit to a command board which processes the logic signals, dead-time, faults detection and measurements and then this board is connected to a controller board which consists of a simple analogue scalar control for the purposes described in the introduction section. The mechanical system includes a squirrel-cage induction motor with an incremental encoder loaded by a powder brake. A tachometer generator and torque sensors are also available as well as a mechanical measurement and control module that is used to control the load torque imposed by the powder brake.

3. The real-time monitoring instrument

From [7] and taking into account the voltage and current *dq* components in the stator reference frame, as well as rotor speed, provided by the electronic system [4] we can obtain the set of equations that are suitable for monitoring all the estimated signals as follows:

$$\phi_{sd}^{s}(t)=\int (u_{sd}^{s}(t)-R_s i_{sd}^{s}(t))\,dt \quad \text{and} \quad \phi_{sq}^{s}(t)=\int (u_{sq}^{s}(t)-R_s i_{sq}^{s}(t))\,dt \tag{1}$$

$$\phi_{md}^{s}(t)=\phi_{sd}^{s}(t)-\phi_{sld}^{s}(t) \quad \text{and} \quad \phi_{mq}^{s}(t)=\phi_{sq}^{s}(t)-\phi_{slq}^{s}(t) \quad \text{where} \quad \phi_{sld,q}^{s}(t)=L_{sl} i_{sd,q}^{s}(t) \tag{2}$$

$$\frac{di_{mrd,q}^{s}(t)}{dt}+\frac{1}{\tau_r} i_{mrd,q}^{s}(t)=\frac{1}{\tau_r}\left(i_{sd,q}^{s}(t)-\omega_{ele}\tau_r i_{mrq,d}^{s}(t)\right) \tag{3}$$

$$\phi_{rd}^{s}(t)=L_m i_{mrd}^{s}(t) \quad \text{and} \quad \phi_{rq}^{s}(t)=L_m i_{mrq}^{s}(t) \tag{4}$$

$$T_e(t)=3/2p\left(\phi_{sd}^{s}(t) i_{sq}^{s}(t)-\phi_{sq}^{s}(t) i_{sd}^{s}(t)\right) \quad \text{or} \quad T_e(t)=3/2p\left(\phi_{md}^{s}(t) i_{sq}^{s}(t)-\phi_{mq}^{s}(t) i_{sd}^{s}(t)\right) \tag{5}$$

$$p(t) = 3/2\,p\left(u_{sd}^{s}(t) i_{sd}^{s}(t) + u_{sq}^{s}(t) i_{sq}^{s}(t)\right) \tag{6}$$

$$q(t) = 3/2\,p\left(u_{sq}^{s}(t) i_{sd}^{s}(t) - u_{sd}^{s}(t) i_{sq}^{s}(t)\right) \tag{7}$$

From (1) to (7) we have, respectively, the two-axis components of stator flux space phasor, the two-axis components of magnetizing flux space phasor, the two-axis components of magnetizing rotor current space phasor, the two-axis components of rotor flux space phasor, electromagnetic torque, active and reactive powers. Figure 1 shows the diagram of the implemented monitoring circuits of the instrument where integrations and multiplications of signals are present. Figures 2 and 3 show the electronic circuits for monitoring the stator flux and rotor flux space phasors, respectively.

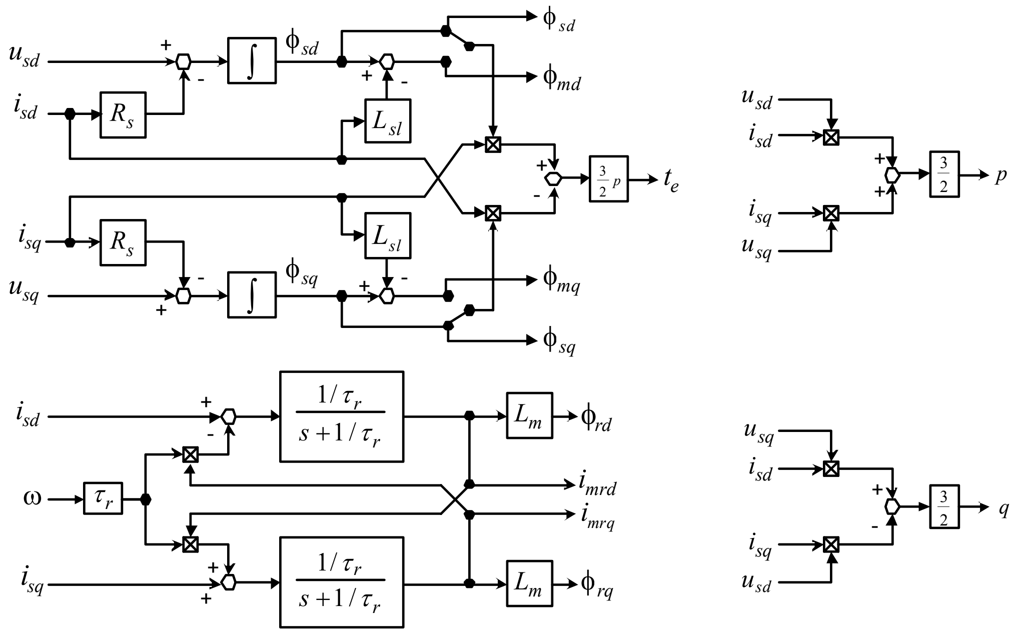

Fig. 1 – Diagram of implemented monitoring circuits.

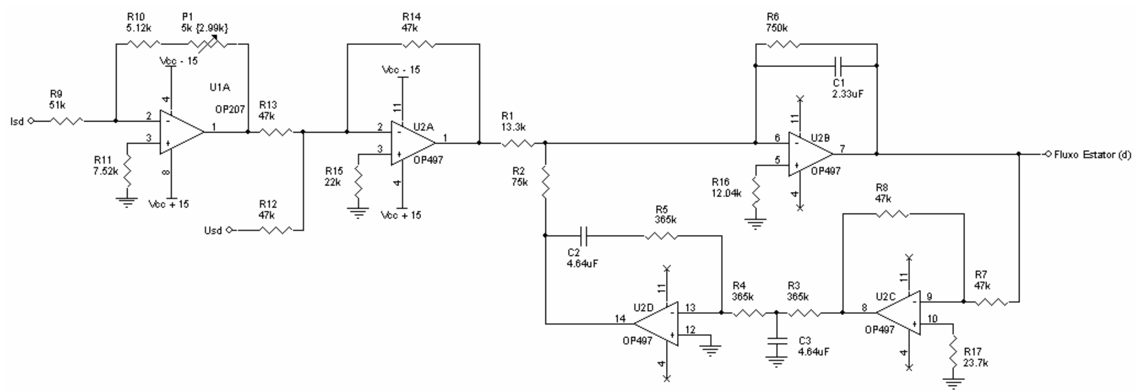

Fig. 2 – Electronic circuit for stator flux space phasor monitoring.

The signals are processed through the electronic circuit in the range of ±10V. Therefore, the signals and the electrical parameters of the machine have been carefully jointly scaled in order to preserve the physical relationships of the induction motor model. Signal processing at very low magnitude was also avoided due to the strong noisy interference fields of electrical drives. A practical design of an analogue integrator was implemented and optimised for low frequencies and rejection of DC component, being a basilar block of the global circuit. The practical integrator has a feedback loop constituted by an inverter circuit, a low-pass filter and a PI controller as can be seen on the right-hand side of the circuit in above fig. 2.

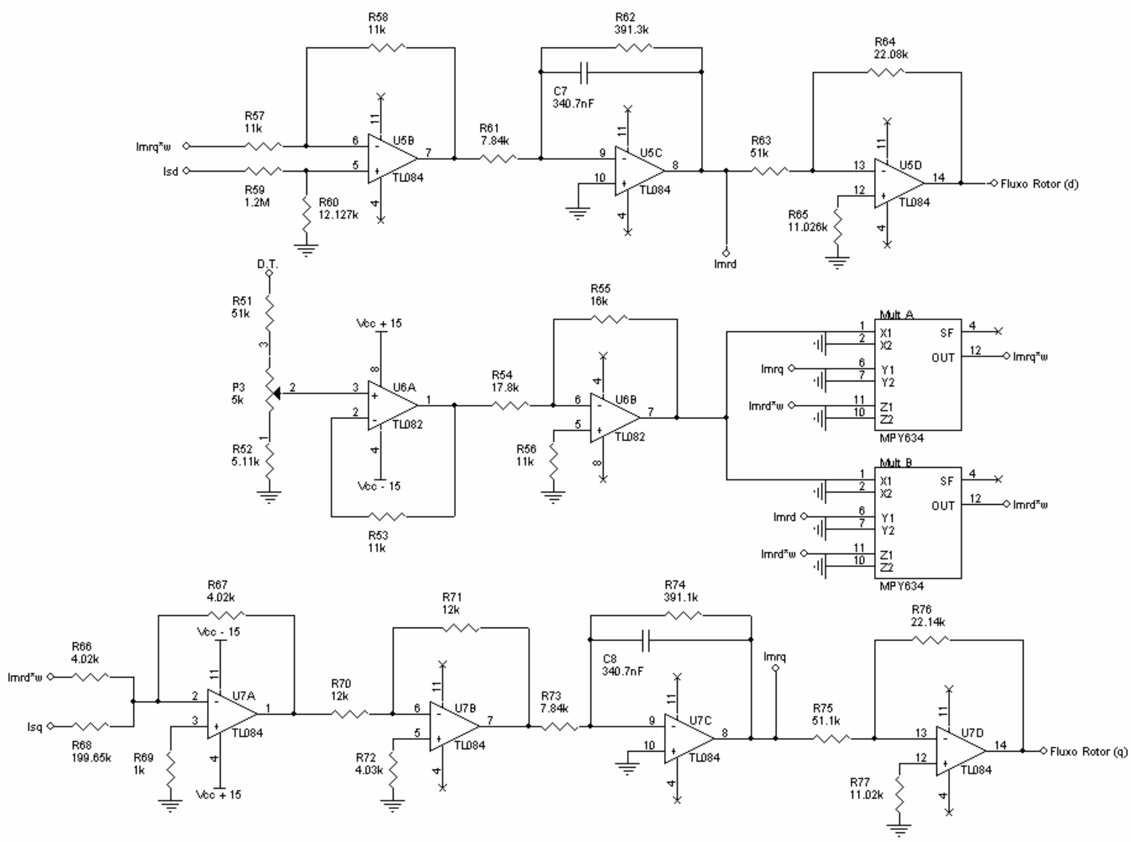

Fig. 3 – Electronic circuit for rotor flux space phasor monitoring.

3. Experimental results

Figure 4 shows the two-axis components of stator voltage and current space phasors, in the stator reference frame, with a cutoff frequency of the low-pass filters adjusted to 500Hz as well as the monitored signals by using the monitoring instrument. The signals were acquired directly from the digital oscilloscope *HP54601B*.

In the complete lack of an equivalent piece of equipment, the authors decided to do a computational verification of the results, based on real signals, that works as a preliminary validation. Therefore, the monitored signals were compared with the corresponding signals computed by simulation in the *Simulink* environment using real stator voltages, stator currents and rotor speed, acquired by means of a data acquisition system that consists of the 16 bits *PCI-6035E* data acquisition board, the *SC-2040* module with 8 SSH channels for simultaneous acquisition and *LabVIEW*, all from *National Instruments*, which is further described in [6]. These signals jointly with the measured rotor speed were used to perform the same functions of the diagrams in fig. 1. To achieve these comparisons the monitored signals provided by the monitoring instrument were also simultaneously acquired for subsequent comparison and the results are shown in fig. 5, showing a good agreement.

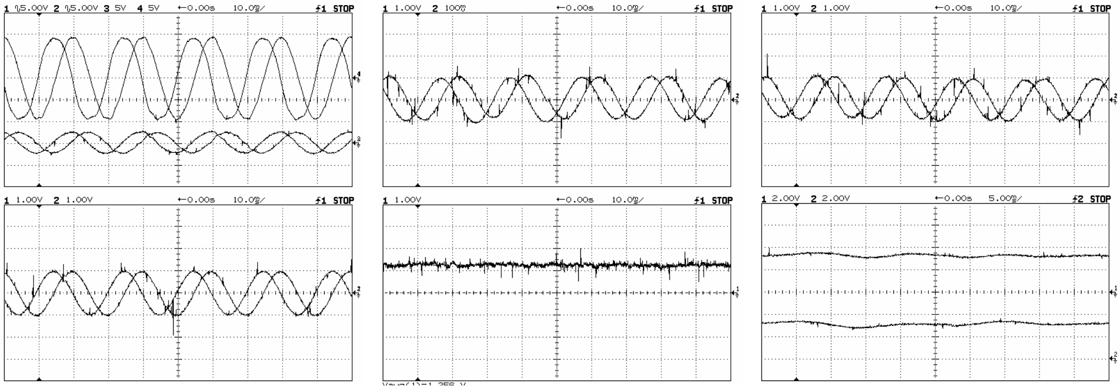

Fig. 4 – From top left to bottom right along rows: the two-axis components of stator voltage and current space phasors, the two-axis components of monitored stator flux space phasor, the two-axis components of monitored magnetizing flux space phasor, the two-axis components of monitored rotor flux space phasor, monitored electromagnetic torque of 12Nm and, finally, the active and reactive powers

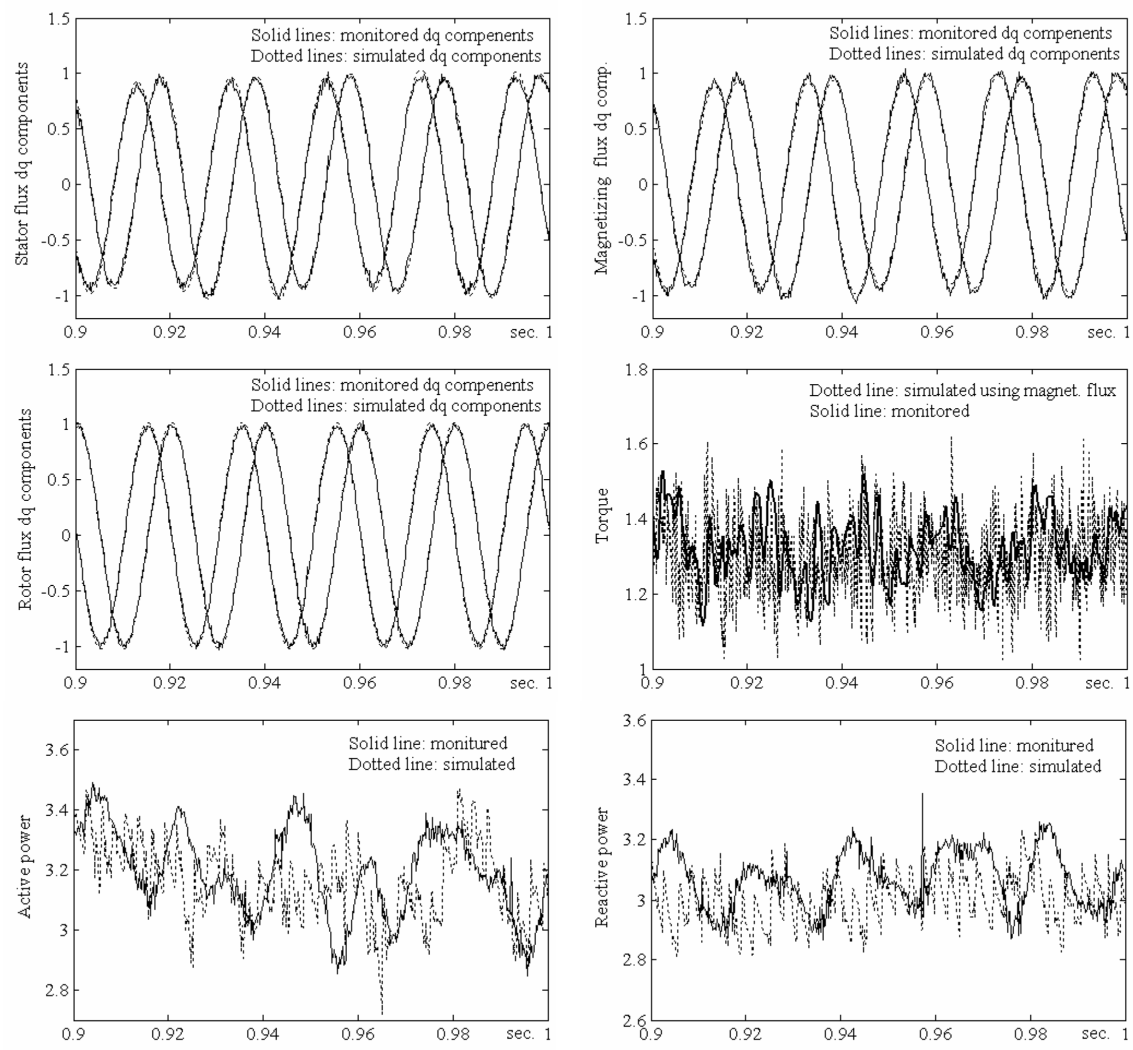

Fig. 5 – Performance of the real time monitoring instrument. From top left to bottom right along rows: simulated and monitored components of stator flux space phasor; simulated and monitored components of magnetizing flux space phasor; simulated and monitored components of rotor flux space phasor; simulated and monitored electromagnetic torque based on both monitored magnetizing flux; simulated and monitored active power; the same for reactive power.

4. Conclusions

The implementation of an electronic instrument for monitoring stator and rotor fluxes, magnetizing flux, electromagnetic torque and active and reactive powers has just been presented in this paper. It is based on the two-axis components of the stator voltage and current space phasors, as well as on rotor speed. This analogue instrument for monitoring the main electromagnetic signals of an induction motor controlled by frequency converters has the advantage of being a real time and very low cost solution. Hence, besides not involving sophisticated and expensive electronic circuits the monitored signals can be displayed on any oscilloscope screen.

When compared with virtual instrumentation systems this solution is not so flexible and, furthermore, using a software framework as for instance Simulink or LabVIEW the virtual instruments themselves can be constructed like in [6] providing that a good knowledge of the software is available. Any solution is time-consuming and any one should not be an alternative to the other one. On the other hand, they should be complementary in a school laboratory and the recent trend that uses more and more software ought to be complemented with as much electronic design skills as possible.

The monitoring instrument was integrated within an electronic system being part of an integrated teaching test bench that has been used for teaching and research activities in adjustable speed drives of induction machines.

The real time instrument works as a monitoring unit but can have other important applications as for instance, fault condition detection. For example, whenever the instantaneous power is monitored on-line, it is possible to use this for monitoring the condition of induction machines. Since in our case a squirrel-cage induction motor is used then it is possible to detect interturn short-circuits in the stator windings, short-circuits in the motor wiring, stator phase failures, and so on.

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