RELUCTANCE SYNCHRONOUS MACHINE BASED COMPACT VARIABLE SPEED DRIVE SYSTEM

Ioan-Adrian VIOREL – Loránd SZABÓ – Radu-Cristian CIORBA – Vasile BARZ
Technical University of Cluj, Department of Electrical Machines
3400 CLUJ, Daicoviciu 15, Romania
Phone: +40 264 195 699 / Fax: +40 264 192 055
e-mail: Ioan.Adrian.Viorel@mae.utcluj.ro

Abstract: The increase of energy costs underlines the need to use more efficient electric drive systems. One of the best solutions to reduce energy costs is the use of variable speed drives. They can easily match motor torque and speed to the load, saving energy when load requirements are reduced. In almost all the cases in a variable speed drive system the motor is fed by a variable frequency electronic power converter. In the last years a tendency of integrating the motor and the frequency converter into a single unit could be observed. A prototype of such a compact variable drive system with a synchronous reluctance motor (SynRM or SyncRM) will be presented in this paper.

1. INTRODUCTION

Electric motors consume over 60-80% of all electricity used by industry [1]. Due to such statistics a major focus on energy efficiency programs in this field is inevitable today, when the quest for efficient use of power takes on great importance.

There are several ways to increase the efficiency of a drive system. The so-called energy-efficient motors can replace the old electric motors. These are higher quality products that embody more and higher-grade electric materials, and are more precisely manufactured than a standard motor [2, 3].

An other way to reduce energy costs is by using variable speed motor drives, which can save about half of the energy used by an electric motor when compared with electromechanical controls. The variable speed drives match motor torque and speed to the load, saving energy when load requirements are reduced. The best way to vary the speed of an electric motor is by feeding it from a variable frequency electronic power converter.

Recent market studies estimate that the current market for the integrated (compact) drive systems is expected to more than double over the next years. This is available both for induction motor based compact drive systems having the power converter mounted on the motor [4], and for servo or stepper motors that have positioning electronics incorporated into their housing [5]. This means that the relatively new technology of coupling together the motor and its power electronics is viable and has a sure future in the electric drive's market.

Converter fed synchronous reluctance motor is one of the future alternatives for high efficiency induction motor in variable speed drives because of its possibility to cheaper production costs (no rotor cage), better controllability especially at low speed and because of its possibility to have a higher efficiency [6].

There were not found any reports on coupling synchronous reluctance motors with power converters into a single drive unit. Therefore a prototype of such a compact drive system should be of interest.

2. THE RELUCTANCE SYNCHRONOUS MOTOR

The reluctance synchronous machine usually is obtained by replacing the rotor of a conventional induction machine with a rotor having different inductances along its d and q axes (L_d and L_q). In its simplest salient pole form, it is similar to the classical synchronous machine without a field winding. However, unlike the synchronous machine, it can only operate at lagging power factor, since all the excitation is from the stator. The electromagnetic torque is developed due to the tendency of the rotor to take up a minimum reluctance position for the stator flux. This is the position when the high permeance rotor axis (d-axis) is aligned with the stator filed axis.

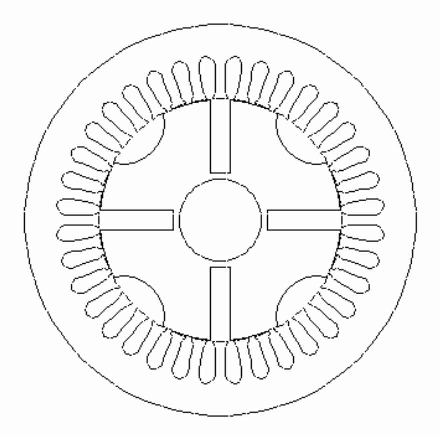


Fig. 1. The motor's structure

The reluctance synchronous machine used in the compact drive to be presented was specially designed for this purpose. Its basic structure is given in Fig. 1.

The starting point was a commercially available induction motor (3MA 100L type produced by S.C. IAME S.A. Sf. Gheorghe, Romania). Its main characteristics are included in Table I.

Item	Value
Rated power	2.2 kW (3 hp)
Rated speed	1420 r/min
Rated current	5.29 A at 400 V
Rated power factor (cosφ)	0.80
Efficiency	79 %

Table I. The main characteristics of the initial induction motor

The case and the stator remained unchanged. The rotor core was made of crude induction machine magnetic sheets and has a concentrated nonmagnetic material on the rotor d-axis and a semicircular slot with the minimum radius on the q-axis. There is a core bridge between the rotor segments of height b.

The simplified rotor structure of its elementary counterpart (of p=1) is given in Fig. 2. The rotor structure is consolidated with insulated bars placed in the semicircular holes and belted together with two special rings fixed on the shaft.

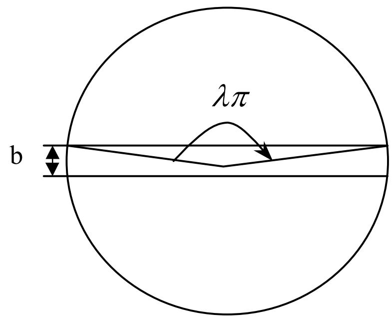


Fig. 2. The simplified rotor structure

The principal elements of the rotor geometry were optimised by numeric 2D magnetic field analysis performed using the MagNet package [7]. The best values found out were:

$$b = 5 \text{ mm}$$
$$\lambda = 0.9315 \tag{1}$$

The values of the magnetising inductances (M_d and M_q) and the saliency ratio $K=M_d/M_q$ were computed both analytically and via the 2D FEM analysis.

The two magnetising inductances were calculated using the following relations:

$$\begin{aligned} M_d &= k_d M \\ M_q &= k_q M \end{aligned} \tag{2}$$

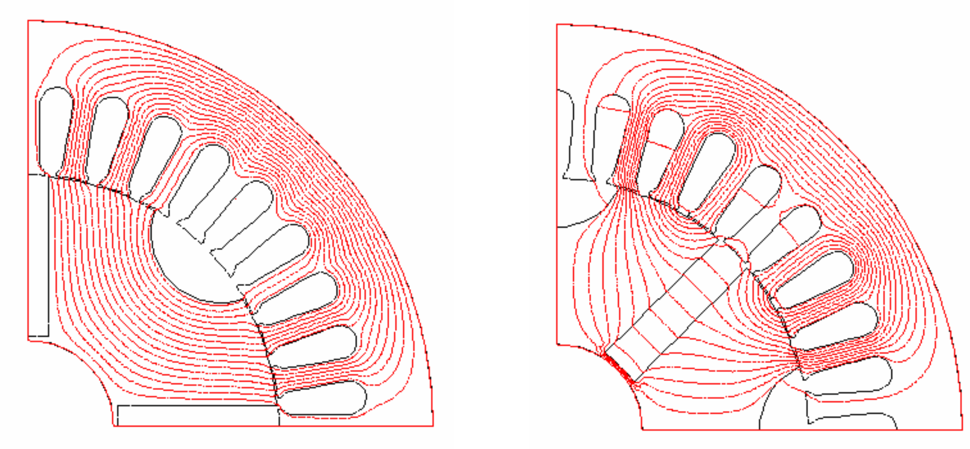
were the magnetising inductance's factors are (the signification of λ being given in Fig. 2):

$$\begin{aligned} k_d &= \lambda - \frac{\sin \lambda\pi}{\pi} \\ k_q &= \lambda + \frac{\sin \lambda\pi}{\pi} - \frac{4}{\pi}\sin^2\left(\lambda\frac{\pi}{2}\right)\frac{1}{\frac{0{,}35}{b}\sin\lambda\frac{\pi}{2} + \lambda\frac{\pi}{2}} \end{aligned} \tag{3}$$

The following results were obtained:

$$\begin{aligned} M_d &= 0.1817 \text{ H} \\ M_q &= 0.0481 \text{ H} \\ K &= \frac{M_d}{M_q} = 3.7748 \\ M_d - M_q &= 0.1336 \text{ H} \end{aligned} \tag{4}$$

The flux plots of the designed synchronous reluctance motor on the *d* and *q*-axis obtained by the 2D FEM analysis are given in Fig. 3 [7].



a) *d*-axis b) *q*-axis

Fig. 3. The flux plots of the designed motor on the two quadrature axis

As it can be seen the designed reluctance synchronous motor has high performance, but its segmental construction is more complicated that of the conventional machine, and it is less robust mainly because of the requirement for non-magnetic discs and bolts to secure a rotor core to the shaft. Therefore its manufacturing cost seems to be higher [8].

3. THE FREQUENCY CONVERTER

The other basic unit of the compact variable speed drive system is the frequency converter.

The converter was selected upon a profound analysis of all the products available on the market. The chosen converter was of SIMOVERT MASTERDRIVES – Motion Control type, Z=C43 model, made by SIEMENS (its Siemens code is 6SE7021-0E50-Z). Its outline is given in Fig. 4.

The basic parameters of the converter are the following:

- Input voltage: 380-500 V
- Input frequency: 47-63 Hz
- Maximum current: 10A
- The output voltage can be varied from 0 V to the input voltage
- The output frequency can be set in the domain of 0 ÷ 400 Hz
- Protection class: IP65

This converter is well suited to assure the necessary specific control strategy for the reluctance synchronous motor [9].

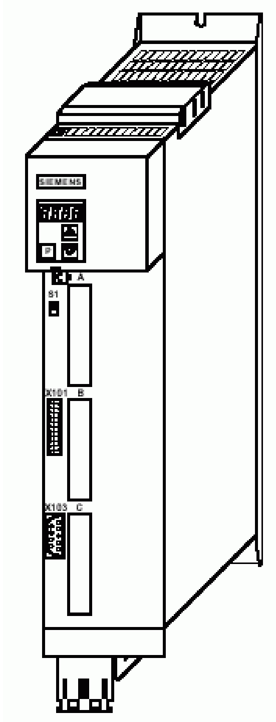


Fig. 4. The converter

4. THE PROTOTYPE OF THE COMPACT DRIVE SYSTEM

The reluctance synchronous motor and the selected frequency converter were mounted together to form a compact variable speed drive unit, shown in Fig. 5.

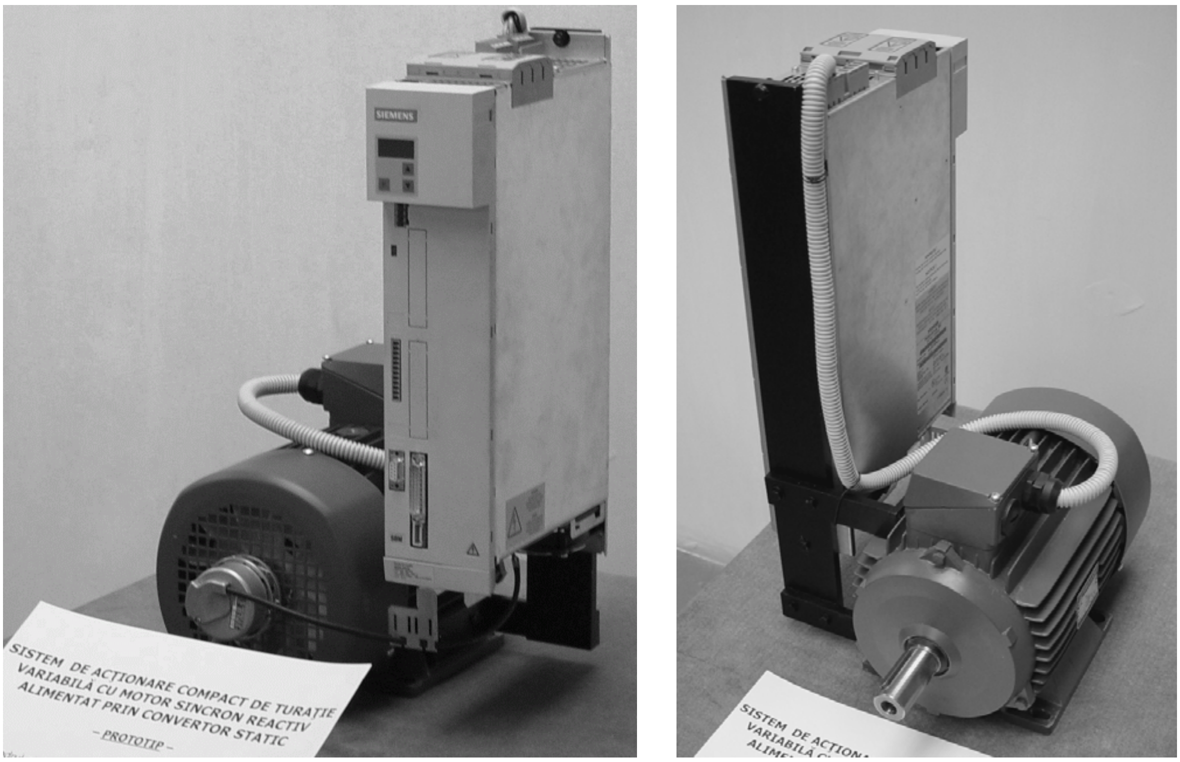
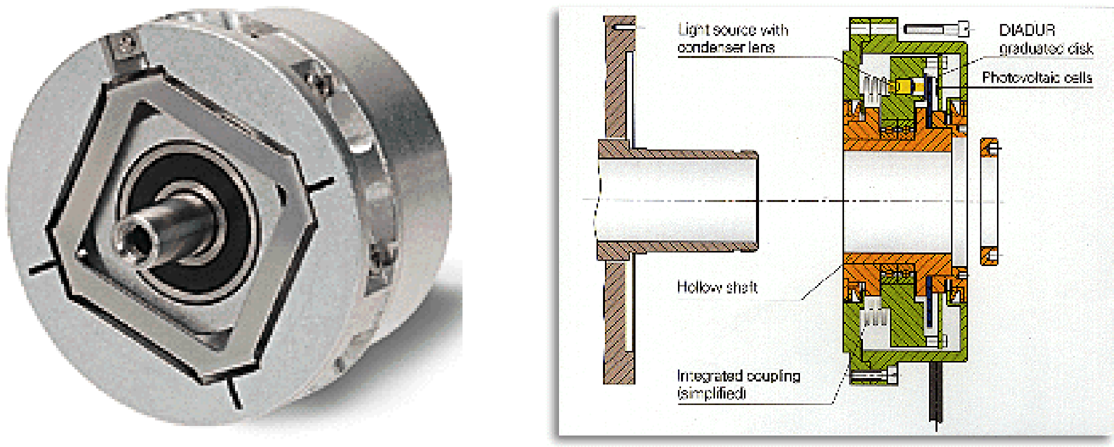


Fig. 5. Two views of the compact drive system's prototype

To ensure the actual position signal necessary for the control system an incremental position transducer was coupled to the synchronous reluctance motor. This is of ERN 1387 type, made by dr. Johannes Heidenhain GmbH (Germany). Its picture, respectively its internal structure is given in Fig. 6.



a) the case b) the internal structure

Fig. 6. The incremental position transducer

Very short internal connections were needed between the reluctance synchronous motor and the frequency converter. This is very important for the electromagnetic compatibility of the entire compact variable speed drive system.

The converter was fixed on the synchronous reluctance motor using a special designed part given in Fig. 7.

Fig. 7. The assembly part

The speed of the above presented compact drive system can be modified in several ways:

- Manually from the built-in control potentiometer on the frequency converter
- Manually from an external potentiometer disposed on a control panel
- Manually from an OPS1 type auxiliary Clear Text Display Module (see Fig. 8)
- In automatic mode upon a user defined built in speed profile

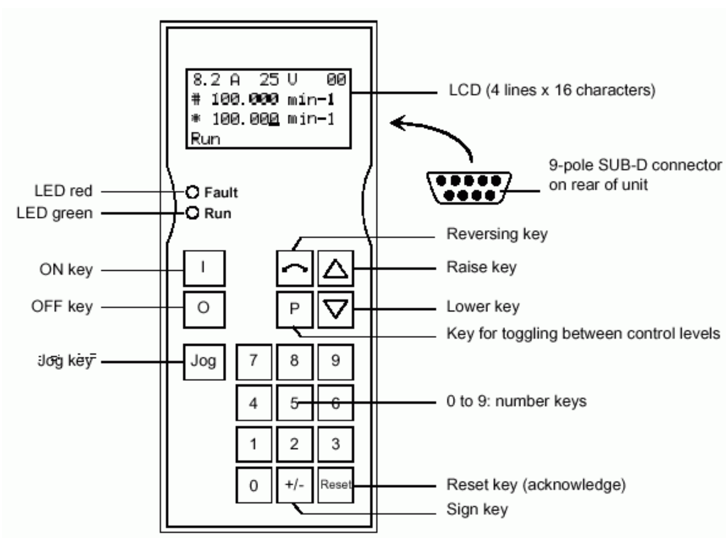


Fig. 8. OPS1 type display unit

- In automatic mode controlled from a higher level control unit via RS232 interface or PROFIBUS-DP serial bus

5. EXPERIMENTAL RESULTS

The built up prototype of the compact variable speed drive system with synchronous reluctance motor was tested on a high performance test bench. The mechanical part of the bench contains two mechanically coupled electric motors, a PC computer controlled rectifier (SIMOREG) fed dc motor for breaking and loading purposes and the motor to be tested. Sensors of LEM measure the voltages and currents and give signals to the data acquisition unit.

The measurement part of the bench consists of a usual Pentium processor based PC having a National Instruments AT-MIO-16XE-10 type acquisition board. This delivers high performance and reliable data acquisition capabilities, having 1.25 MS/s sampling rate, 16 single-ended analogue inputs. It features both analogue and digital triggering capability, as well as two 12-bit analogue outputs, two 24-bit, 20 MHz counter/timers and eight digital I/O lines. The electrical signals generated by the transducers are optimised for the input range of the DAQ board. The SCXI 1140 type signal conditioning accessory amplifies the low-level signals, and then isolates and filters them for more accurate measurements.

Several programs written in LabVIEW 6i co-ordinate all the data acquisition and the test measurement processes. This is a powerful graphical programming development for data acquisition and control, data analysis, and data presentation.

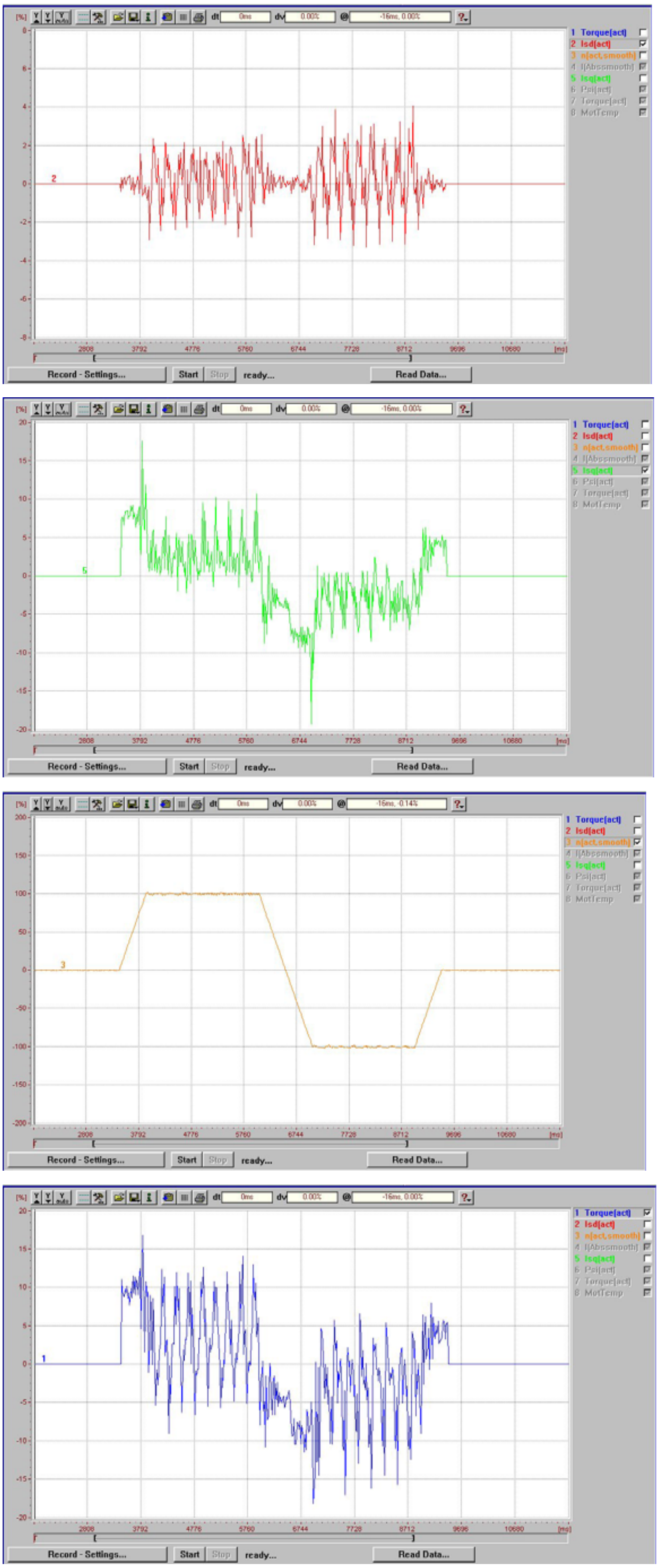
LabVIEW gives the flexibility of a powerful programming language without the associated difficulty and complexity because its graphical programming methodology is inherently intuitive to the users. The final processing of the measured data was made in MATLAB 6 [10].

Another easy way to visualise the variation of several characteristics of the drive system is by using SIMOVIS, a special program of SIEMENS, which interfaces to any drive system of the company using one of the drive's serial interfaces. It can be used to facilitate start-up, in setting and storing parameters, and as a diagnostic tool. With its graphic capabilities, oscilloscope functions can be displayed on a computer screen.

Various tests were made with the compact variable speed drive system at different loads: starting, stopping, reversing, speed modification, etc. The thermal checking of the drive system was also made.

The lowest frequency at which the drive system could move was of 0.1 Hz (at no-load). Of course due to its internal static friction the motor can't be started at this low speed, but if it is already running its speed can be reduced to this value. The maximum obtainable speed of the compact drive system is 2000 r/min (66 Hz).

From the great number of experiments done here only the results of a single set of measurements will be presented: the main waveforms at a typical movement cycle of the compact drive system. During this cycle the motor is started up to +1500 r/min using a trapezoidal form imposed speed profile, it is reversed to -1500 r/min, and stopped again using the same trapezoidal imposed speed profile. The waveforms (the current on the two orthogonal axes, the torque and the speed) captured using the SIMOVIS program are given in Fig. 9.



a) *d*-axis current

b) *q*-axis current

c) speed

d) torque

Fig. 9. Measured waveforms during a complete movement cycle of the motor

The heating of the power converter is no critical because it is not mounted directly on the motor, a serious heat source. Anyway the thermal checking of the compact drive system showed that neither in the motor, nor in the power converter the admitted temperature values were exceeded.

6. CONCLUSIONS

As any compact drive system this unit also have several advantages over the systems built up of standalone units: lower installation cost (wiring, installation, and panel space or special electrical control rooms savings), optimum motor-inverter match, no design problems with motor-inverter rating, filters or power cable length, guaranteed electromagnetic compatibility, possibility of promoting decentralised control architectures, etc.

As it could be seen from all the obtained results the compact variable speed drive system designed and built up fulfils all the general requirements for a modern variable drive system. It can be used in numerous industrial applications were the change of speed upon the load's requirements is needed.

7. ACKNOWLEDGEMENT

This research was made possible by funding of the Romanian National Ministry of Education, the Managerial Agency for Scientific Research, Innovation and Technological Transfer (AMCSIT-POLITEHNICA), grant no. 1104/2001.

8. REFERENCES

[1] Bartos, F.J., "Energy-efficient motors may now get respect," *Control Engineering online extra*, http://www.controleng.com/archives/2001/ctl0501.01/010502xtra.htm.

[2] Andreas, J.C., *Energy-efficient electric motors. Selection and application*, New York: Marcel Dekker, 1992.

[3] Bartos, F.J., "Efficient motors can ease energy crunch," *Control Engineering*, pp. 63-70, May 2001.

[4] Bartos, F.J., "Integrated Motor-Drives Seek Wider Market, User Acceptance," *Control Engineering*, pp. 19-23, December 2000.

[5] *Integrated motor market set for substantial growth*, Market report, IMS Research (http://www.imsresearch.com), 2003.

[6] Haataja, J., Pyrhönen, J., Niemelä, M. and Neuvonen, M, "Measurement of synchronous reluctance and induction motors in variable speed drives utilising IEEE 112 B test method," *Conference Record of the International Conference on Electrical Machines ICEM '2002*, Brugge (Belgium), on CD-ROM: 160.pdf, 2002.

[7] Viorel, I.A, Husain, I., Chişu, Ioana, Hedeşiu, H.C., Madescu, G. and Szabó, L., "Reluctance Synchronous Machine with a Particular Cageless Segmental Rotor," *Conference Record of the International Conference on Electrical Machines ICEM '2002*, Brugge (Belgium), on CD-ROM: 592.pdf, 2002.

[8] Jovanovic, M.G., *Sensorless Control of Synchronous Reluctance Machines*, Ph.D. dissertation, Department of ECE, University of Newcastle, Australia, 1997.

[9] *SIMOVERT MASTERDRIVES – Motion Control*, Reference Manual, SIEMENS, 1999.

[10] Szabó, L., *Medii de programare uzuale în ingineria electrică – MATLAB*, Cluj-Napoca: Editura MEDIAMIRA, 2003. ISBN: 973-9357-23-7.