INTELLIGENT COMPACT DRIVE SYSTEM WITH A SYNCHRONOUS VARIABLE RELUCTANCE MOTOR

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Summary 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 variable reluctance motor will be presented in this paper.

1. INTRODUCTION

There are several ways to increase the efficiency of a drive system. One solution should be the use of variable speed motor drives (also called adjustable speed drives or adjustable frequency drives), which can save about half of the energy used by an electric motor when compared with electromechanical controls.

In such advanced drive systems the motor's torque and speed are matched 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 (having the power converter mounted on the motor) is expected to more than double over the next years [1].

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 cheaper production costs (no rotor cage), better controllability especially at low speed and because of its possibility to have a higher efficiency [2].

There were not found any reports on coupling synchronous variable reluctance motors with power converters into a single drive unit. Therefore a prototype of such an intelligent compact drive system should be of real interest for all the engineers working in this field.

2. THE MOTOR

The synchronous variable reluctance 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 field axis [3].

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

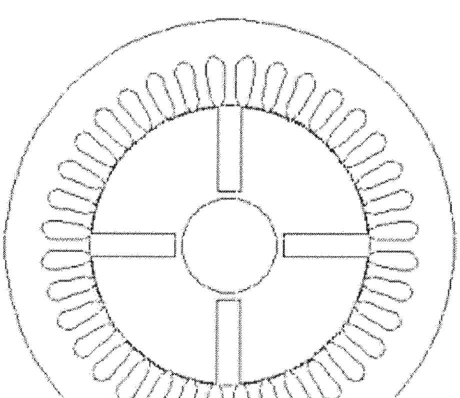


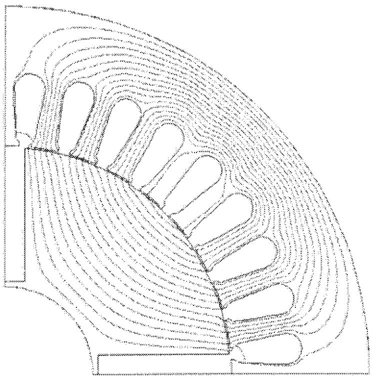
Fig. 1. The motor's structure.

The synchronous variable reluctance machine was constructed of a commercially available induction motor of 2.2 kW (3 hp) and 1420 r/min. Its case and its stator iron-core sheets remained unchanged.

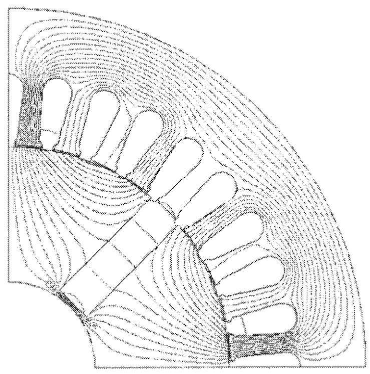
The rotor core was made of crude induction machine magnetic sheets and has a concentrated nonmagnetic material on the rotor d-axis. There are core bridges between the rotor segments.

The main elements of the rotor geometry were optimised by numeric 2D magnetic field analysis performed using the MagNet 6.10 package [4].

The flux plots and the air-gap flux density variation of the best variant of the designed synchronous variable reluctance motor on the d and q-axis obtained by the FEM analysis are given in Figs. 2a and 2b, respectively 3a and 3b.

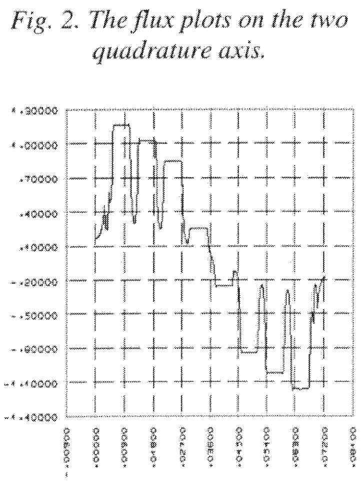


a) d-axis

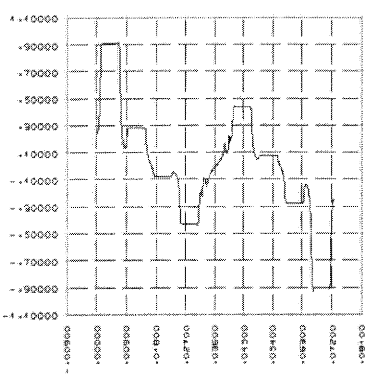


b) q-axis

Fig. 2. The flux plots on the two quadrature axis.



a) d-axis



b) q-axis

Fig. 3. The air-gap flux density variation on the two quadrature axis.

The two magnetising inductances were computed analytically [5]:

$$M_d = 0.1817\,\text{H}, \quad M_q = 0.0481\,\text{H}. \tag{1}$$

The obtained saliency ratio is quite good for such a simple structure [6]:

$$K = \frac{M_d}{M_q} = 3.7748 \tag{2}$$

and so is the difference between inductance's values on the two axis:

$$M_d - M_q = 0.1336\,\text{H}. \tag{3}$$

A photograph taken of the manufactured rotor is given in Fig. 4.

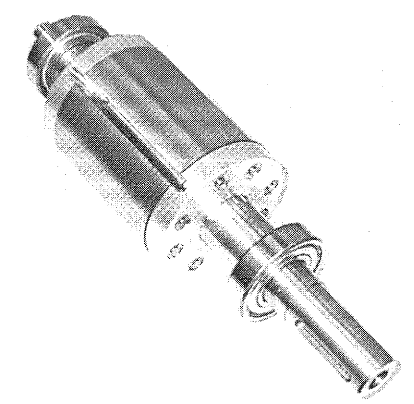


Fig. 4. The rotor of the motor.

As it can be seen the designed synchronous variable reluctance motor has quite good performances. Its segmental construction is more complicated than that of the conventional machine mainly because of the requirement for non-magnetic discs and bolts to secure a rotor core to the shaft.

3. THE FREQUENCY CONVERTER

The frequency converter is the other basic unit of the intelligent compact drive system in discussion. The frequency converter was selected from the products available on the market.

Since on the market there is no specialised power electronic converter to supply a synchronous variable reluctance motor a general-purpose converter was chosen: the SIMOVERT MASTERDRIVES – Motion Control type, Z–C43 model, made by SIEMENS [7].

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 synchronous variable reluctance motor [8].

4. THE PROTOTYPE

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

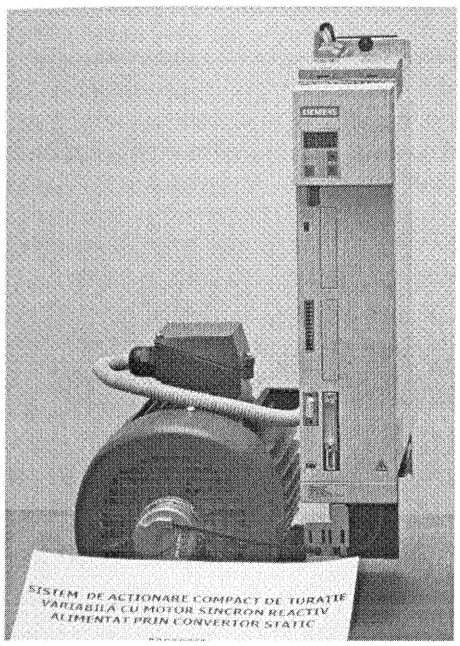


Fig. 5. The prototype of the intelligent compact drive system.

To ensure the actual position signal necessary for the control system an incremental position transducer was coupled to the synchronous variable reluctance motor. This is of ERN 1387 type, made by dr. Johannes Heidenhain GmbH (Germany).

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

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, from an external potentiometer disposed on a control panel or from an OPS1 type auxiliary Clear Text Display Module,
- In automatic mode upon a user defined built in speed profile or 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 variable reluctance motor was tested on a high performance test bench. The test bench consists of two mechanically coupled electric motors, a computer controlled dc motor for breaking and loading purposes and the motor to be tested. Voltage and current sensors 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.

Several LabVIEW 6i programs (virtual instruments) co-ordinates all the data acquisition and the testing processes. These virtual instruments feature great flexibility, leaving instrument definition in the hands of the user, who can easily combine a number of general-purpose hardware instruments with the processing capabilities of a computer.

The virtual instrument built up for the acquisition of the line currents and the feeding voltages of the motor is given in Fig. 6.

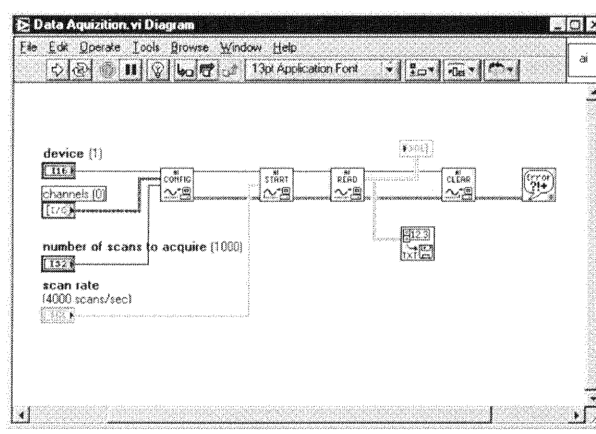


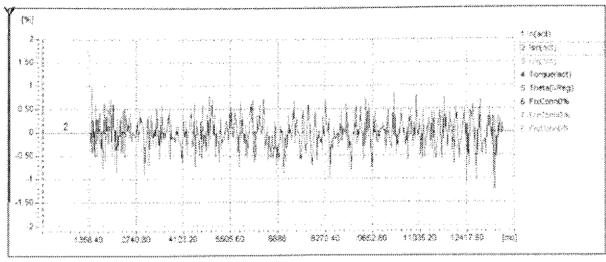
Fig. 6. Virtual instrument for data acquisition.

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 converter'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.

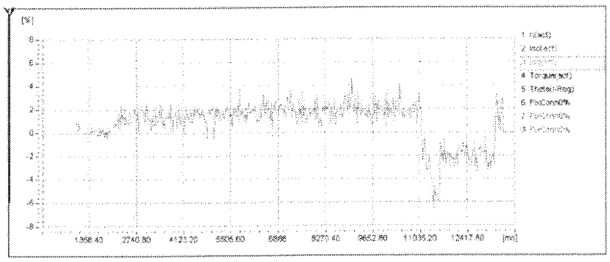
Various tests were performed on the intelligent compact variable speed drive system at different drive tasks and loads: starting, stopping, reversing, speed modification, etc. The thermal checking of the drive system was also made [9].

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 using a trapezoidal form imposed speed profile. It is reversed to the base speed, and stopped using a similar trapezoidal imposed speed profile.

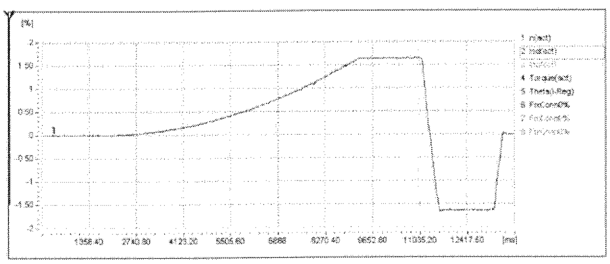
The main waveforms captured using the SIMOVIS program are given in Fig. 7.



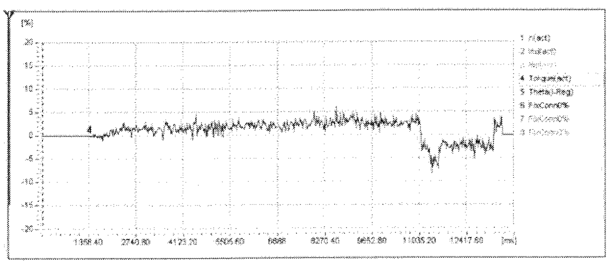
a) d-axis current (i_{sd})



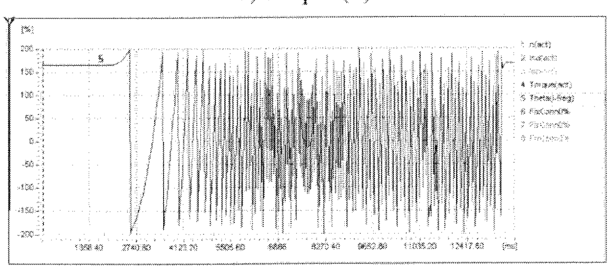
b) q-axis current (i_{sq})



c) speed (n)



d) torque (T)



e) internal angle (θ)

Fig. 7. Measured waveforms during starting, reversing and stopping the motor.

6. CONCLUSIONS

Besides the usual advantages of any compact drive system as optimum motor-inverter match, lower installation costs, full electromagnetic compatibility and local or decentralised control the above presented drive system benefits of a low cost motor which has very good control at low speed.

As it can be seen from the presented test results the intelligent compact drive system designed and built up using a synchronous variable reluctance machine has a very good controllability even, as it was already stated, the electronic converter is of general use one and has no specific control implemented.

It can be used in numerous industrial applications were the change of speed upon the load's requirements is needed.

Further improvements, mostly based on a more performant motor and an adequate electronic converter should be expected and this compact drive system may come as an important competitor on the market of the existing, induction machine based, systems.

Acknowledgement

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

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