INTEGRATED MOTOR AND CONTROL UNIT FOR INDUSTRIAL VARIABLE SPEED DRIVE SYSTEMS

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ABSTRACT

Variable speed drives serve an important function in several industrial applications. They match motor torque and speed to the load, saving energy when load requirements are reduced. The best way to decrease the speed of an induction motor is by feeding it from a variable frequency electronic power converter. In recent years a tendency of integrating the motor and its frequency converter into a single unit could be observed. The integration is done to reduce electromagnetic emissions, reduce installation and commissioning costs etc. A prototype of such a compact variable drive system will be presented in this paper.

1. INTRODUCTION

A drive system's energy efficiency can be improved by reducing energy losses throughout the whole system, or by improving the efficiency of the system's major components. The variable speed drives offer the largest single opportunity for increasing a drive system's energy efficiency. Therefore is currently great interest in adding variable speed capability to motorised appliances and products, which were operated at fixed speed in the past. The reasons include the increasing cost of energy as well as the extra value customers place on the variable speed feature.

Several industrial processes require variable speeds. Adjustable speeds can optimise a process to save energy and obtain utility company rebates, for example in many fan and pump applications, where the application requires speed trimming, respectively controlled starting and stopping. These operations require high precision speed or torque control [1].

Variable speed drives are also common in heating, ventilation and air conditioning applications. In these cases variable speed operation makes simple to slow down the fan when air demand is lower, in order to reduce electricity use in a facility. The output of such equipment can be varied by changing motor speed or by using dampers and reducing valves with constant speed motors. Dampers and reducing valves waste energy. Another typical application of variable speed drives is in pump control, where the variable speed control can help protect equipment during high or low volume operation. Such industrial applications are numerous and also include conveyor control, where variable speed operation makes simple to co-ordinate conveyor velocity with desired production rate.

In the past, varying the speed of an induction motor was achieved using techniques such as multiple winding motors, variable transformers, or triac drives. In general, none of these techniques is ideal for industrial applications and as a result, variable speed drives were used more in appliances.

The best way to reduce the speed of an induction motor is by feeding it from a variable frequency electronic power converter (inverter) that converts constant frequency a.c. power input into a variable frequency output. Thus the motor speed varies in proportion to the drive output frequency. In addition to providing speed control, the variable speed drive system provides soft starting, whereby a motor starts slowly and then speeds up. This reduces the mechanical stress on both the motor and equipment driven by the motor.

The simplest speed variation possibility is the employing the so-called V/F drive technique, which maintains the flux level in the induction motor constant by varying both the voltage and frequency of the applied voltages in proportion, allowing speed to be varied over a wide range [2].

Savings by using the variable speed drives are considerable. For example for fans and pumps the power consumed is proportional to the cube root of shaft speed. If the speed is reduced by 10%, the flow is also reduced by 10%, while power consumption is reduced by 27%. If speed is reduced by 20%, the power is reduced by 49%. Compared to throttling as a means of flow control, speed reduction provides dramatic energy savings.

2. COMPACT VARIABLE SPEED DRIVES

Until recently the electric motors and their control electronics were operated in separate locations, connected by often lengthy and costly wiring for power, control, and communication. Electronic controls generally reside in safer, cooler, and more centralised enclosures, while motors face more severe conditions of temperature, humidity, vibration, dust, washdown cleaning, and more, found in the industrial world [3].

In the last decade, however, the two technologies converged and time became right to unify the motors and their drive systems. The new compact drive system combines within a single unit an ac motor (in most of the cases an induction motor), an integrated frequency converter, and an EMC filter, which prevents harmonics from affecting the service life of the motor and drive.

These compact systems goes under a variety of names in the literature (smart motors, variable-speed motors, integral motors, integrated motors, integrated motor drives, etc.). Their market share is in expansion and also their power range. In present typical value of the maximum power of such a compact drive system is 7.5 kW [4].

The compact variable speed drives has several advantages over the drive units built up separately from individual items:

- lower installed system cost (wiring, installation, and panel space or special electrical control rooms savings)
- short motor leads eliminate standing wave dv/dt failures and reflected voltage spikes
- possibility of built-in prevention of voltage peaks at the motor terminals
- optimum motor-inverter match
- no design problems with motor-inverter rating, filters or power cable length
- guaranteed electromagnetic compatibility
- possibility of promoting decentralized control architectures, etc.

Heating effects are the greatest enemy of these compact drive systems. Both the motor and frequency converter produce heat. As a result, thermal management of these integrated drive systems must be made with maximum attention. Optimised design of mechanical and structural components, heat sinks, cooling, and the layout of elements can contribute to the ideal solution.

As it was mentioned above, in the present the 7.5 kW output power represents a practical plateau above which heating effects build up significantly. Therefore very few commercially available products exists over this power limit. Drive units of larger power should require more complex designs and impact product costs.

The speed at which the motor runs affects thermal management. At significant speeds, the motor-shaft-driven fan provides substantial cooling, but becomes inadequate at low speeds. This usually means adding a separate constant-speed blower to the compact drive system [4].

Vibrations and electromagnetic interference (EMI) are some other environmental considerations for integrated motor-drives. The vibrations, shocks and electromagnetic emissions of the induction motor may affect the electronics.

Cost considerations for the compact drive systems aren' t simple either. Depending on size, a typical motor/drive package carries a premium on initial cost compared to an individual motor and drive. A rugged housing, thermal management, close-coupled wiring, and the special environmental design just mentioned all add to cost. Typical premiums today are in the 15÷20% range. But for a total installed system, cost of the integrated design seems to be lower [4].

3. THE PROTOTYPE OF A COMPACT VARIABLE SPEED DRIVE

The engineers of the Electrical Machines Department, Technical University of Cluj and FROSys Ltd. Cluj built up a prototype of a compact variable speed drive system with an induction motor.

As in the first stage the prototype was made especially for experimental purposes, the simplest technical solutions were adopted.

The starting point was a commercially available induction motor (of 3MA 100L type produced by S.C. I.A.M.E. 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 rpm
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

This motor was redesigned to meet the requirements of an inverter fed induction motor [5-6]. The voltage waveform produced by an inverter must be taken into account, because it differs from the relatively pure sinusoid provided by the a.c. line. At such a waveform the performance of the motor is different. The inherent voltage spikes may affect the motor's insulation. An other phenomenon to be considered is that load combination at variable speed differs from that at rated speed.

In the next step the original induction motor was modified at FROSys Ltd. Cluj upon its new design instructions.

The frequency converter most suited for this application was found the Siemens's MICROMASTER Integrated MI220/3 type (Siemens code 6SE9615-8DD10ZC87) [7]. This was fixed on the top of the motor.

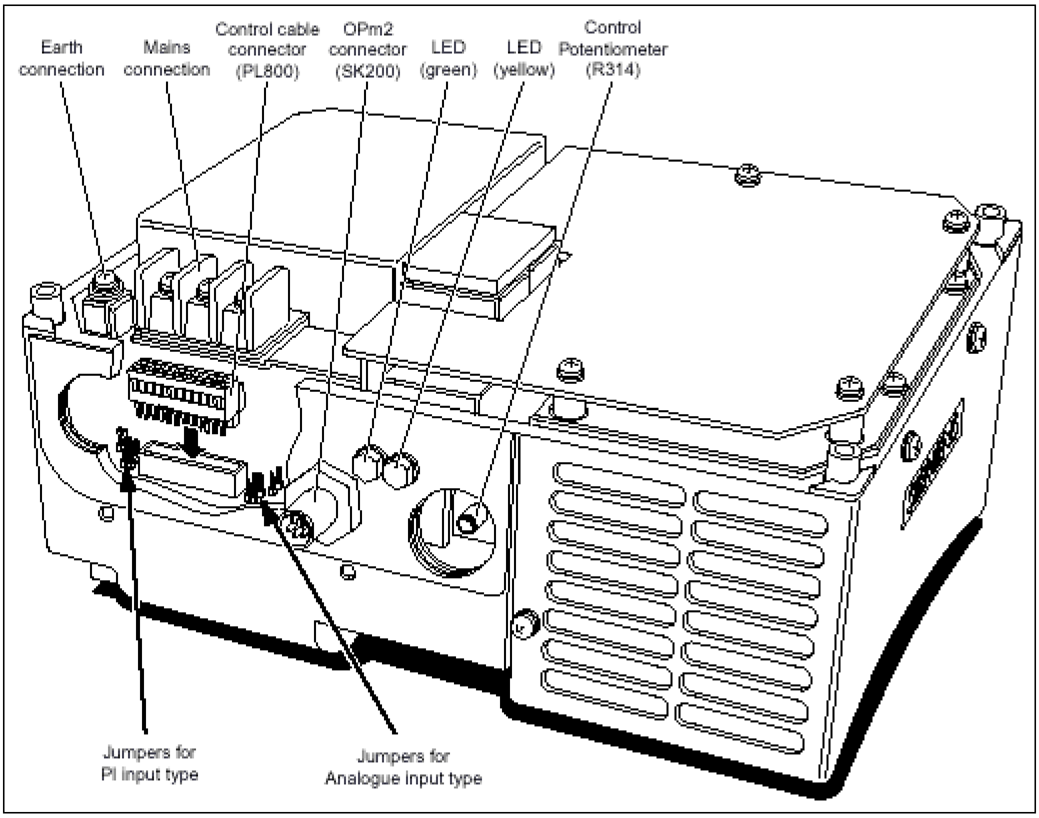


Fig. 1. The MICROMASTER Integrated inverter with its electrical connections

Very short internal connections were needed between the induction motor and its frequency converter.

Two views of the assembled compact variable speed drive system are shown in figure 2.

Fig. 2. The compact variable speed drive's prototype

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

- Manually from the built-in control potentiometer
- Manually from an external potentiometer disposed on a control panel
- Manually from an auxiliary Clear Text Display Module (of OPm2 type), figure 3.
- In automatic mode upon a user defined built in speed profile
- In automatic mode controlled from a higher level control unit via RS232 interface or PROFIBUS-DP serial bus [8]

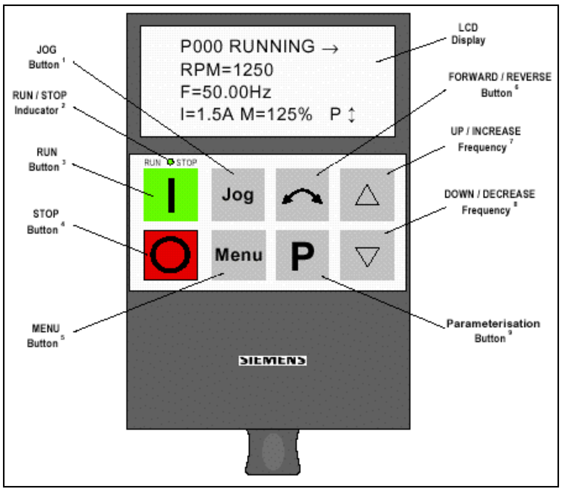
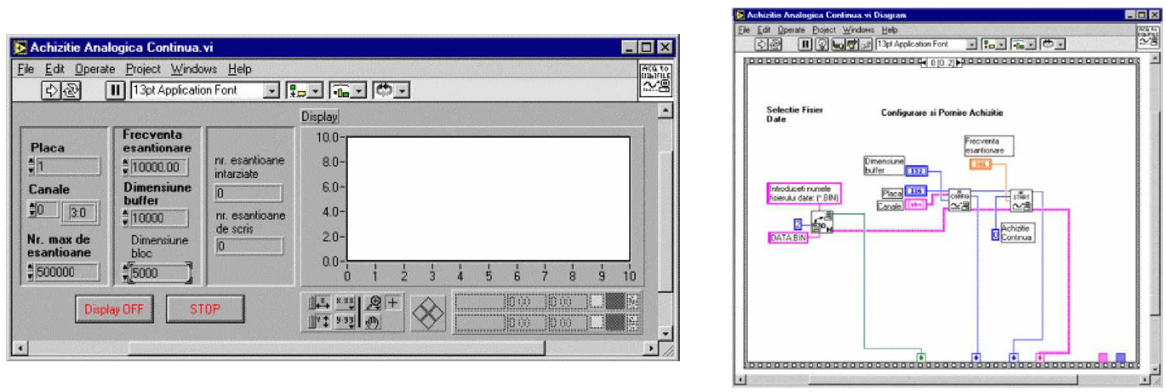


Fig. 3. The Clear Text Display Module

4. EXPERIMENTAL RESULTS

The built up prototype of the compact variable speed drive system with induction 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 d.c. 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.



a) Control panel b) Block diagram

Fig. 4. The components of the LabView program for data acquisition and storage

This is a powerful graphical programming development for data acquisition and control, data analysis, and data presentation [9].

Here the front panel and the block diagram of that program is presented (figure 4), which realises the acquisition and the storage of the measured data.

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.

For the its more powerful data plotting capabilities the final processing of the measured data was made in MATLAB 6 environment [10].

Various tests were made with the compact variable speed drive system at different loads: starting, stopping, reversing, speed modification, etc. In all the cases the stator voltages and the currents of the drive system were acquired and stored.

The thermal checking of the drive system was also made in this stage of the experiments.

The lowest frequency at which the drive system could move was of 0.3 Hz. This means a speed of 7 rpm. In figure 5 the plots of the measured currents at this speed in steady-state regime are shown. The current waveforms at reversing the motor from +800 rpm to -800 rpm are given in figure 6.

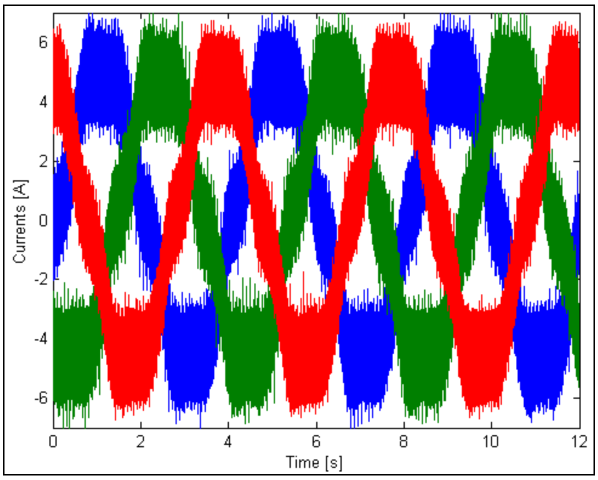


Fig. 5. Measured currents in steady-state regime at 0,3 Hz

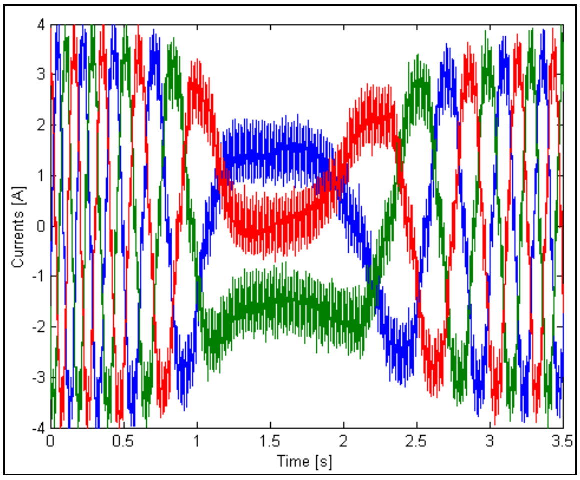


Fig. 6. Measured currents at reversing the motor

As it can be seen in figure 5 at low speeds the harmonic content of the current is quite high, but the fundamentals can be clearly distinguished. In figure 6 the decrease of the frequency of the currents can be clearly observed before the reversing and the frequency increase after it. When the reversing transient process is finished the motor will run in an other steady-state regime with the same speed before the reversing.

For the thermal checking of the motor a temperature probe was built in the motor on its stator windings. The probe was connected to the frequency converter at it TB1 input. This way the temperature inside the induction motor could be red directly from the converter's display.

The temperature values were taken from 5 to 5 minutes. The temperature curves of the motor were plotted for different loads and speeds.

In figures 7 and 8 the temperature curves obtained for 50%, respectively 100% of the rated load are given. These curves were plotted for three feeding frequencies: 6 Hz, 25 Hz and 50 Hz. For comparison purposes in both figures the temperature curve for no-load condition is also plotted.

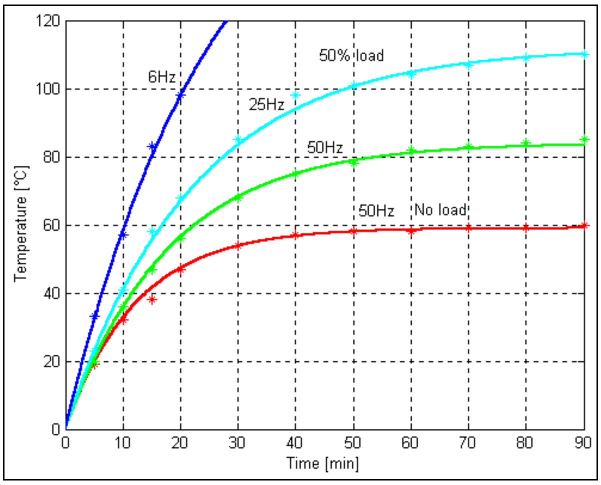


Fig. 7. Temperature curves for 50% load

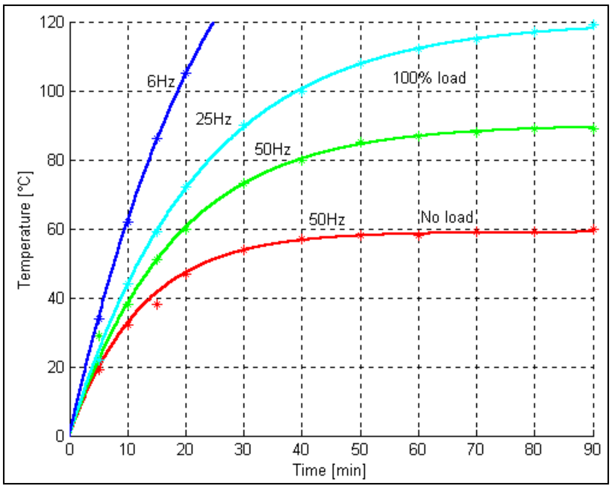


Fig. 8. Temperature curves for 100% load

As it can be seen from all the presented results the compact variable speed drive system designed and built up fulfils all the general requirements. It works well as well as at low speeds as at its rated speed. The temperature rise in the motor is higher then that admitted only at very low speeds.

In order not to exceed the temperature limits of the motor the loadabilty curve of the integrated drive system shown in figure 9 was established.

Upon this the maximum load at any speed can be determined easily by the users. The rated load can be applied in the wide frequency range of 25÷50 Hz. At the low 5 Hz only 20% of the rated load can be applied to the motor.

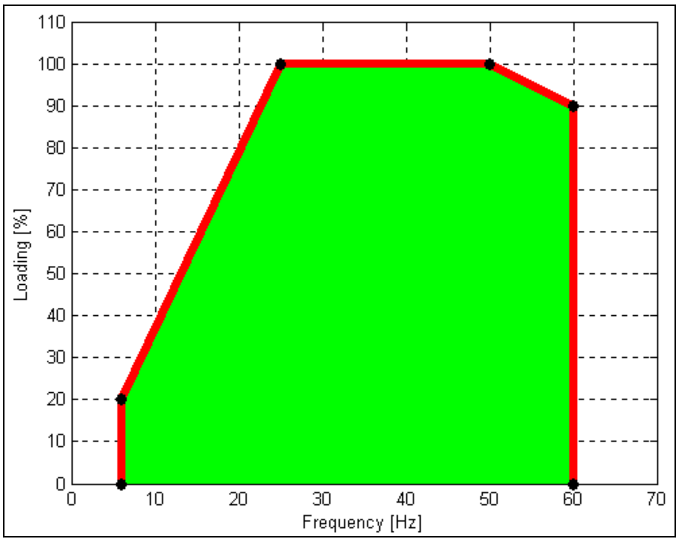


Fig. 9. The loadability curve of the drive system

5. ACKNOWLEDGEMENT

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