An Integrated Test System for AC Machine Drives Performance Analysis

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Keywords

Vector control, Test system, induction machine, DSP.

Abstract

This work presents an integrated Test System specially designed as a test bed for the experiments required to validate different types of new strategies and control schemes, based on vector control theories, parametric estimation, and neural networks applied to AC machine drives, and to analyze the effect of these control strategies over the mains quality. The equipment includes the power stage with the rectifier, the inverter, the respective filters and the drive circuits, the instrumentation stage and the signal processing and control stage. Due to its high versatility, this test bed can be used both in research laboratories and postgraduate courses.

Introduction

Due to its high dynamic performance, vector control theory has allowed for the use of AC machine drives in many applications previously reserved to DC machine drives. This theory has been intensively studied [1], and each proposal requires an initial work based on mathematical modeling and digital simulation to develop the required algorithms. But once new control strategies [2,3,4,7,8] or applications are proposed, many tests must be performed to validate them. The Test System must have high processing speed, precision, versatility, reliability and security.

The processing speed can be adjusted using different processors adequate for each application; very sophisticated algorithms will require powerful DSPs. The precision relays on the transducers quality and the analog to digital converters performance. Versatility is a very important characteristic for these test systems and depends on the design modularity and the software structure. The basic software must perform the basic tasks and each particular strategy ought to be concentrated in a dedicated microcontroller or DSP. Finally, reliability and security are very important items in any test system to guarantee people safety and equipment integrity.

The complete Test System power stage presented in this work includes two fully controlled power converters with their filters, one working as rectifier and the other as inverter. Both converters are similar and together allow system operation in four quadrants. The converters are implemented with full controlled bridges, each one with six IGBTs, and include a low power drive stage. Additionally, for simpler tests, a non-controlled rectifier with six power diodes is provided. The power stage is intended for driving electrical machines under 20 HP, with plate voltages under 480 V. The modulation frequency in under 20 kHz.

The measuring system includes voltage, current and speed transducers, and analog to digital converters. Hall effect sensors are used for the voltage and current transducers. Current sensors are connected to both converter outputs. Voltage sensors are connected to the primary and secondary transformer coils while the inverter output voltages are determined using one voltage sensor connected to the DC link plus the information about the IGBTs states. The angular speed is determined using a high-resolution optical encoder. Voltage and current data is digitized using a motion coprocessor board or a dedicated A/D board. Speed data is processed separately, counting the corresponding pulses. The encoder circuitry is connected directly to the DSP bus, controlled by interrupts.

All the information is monitored in a PC. The control algorithms are programmed in assembler and in C++ for the Analog Devices DSP ADSP-2106. Figure 1 presents the block diagram for the developed Test System.

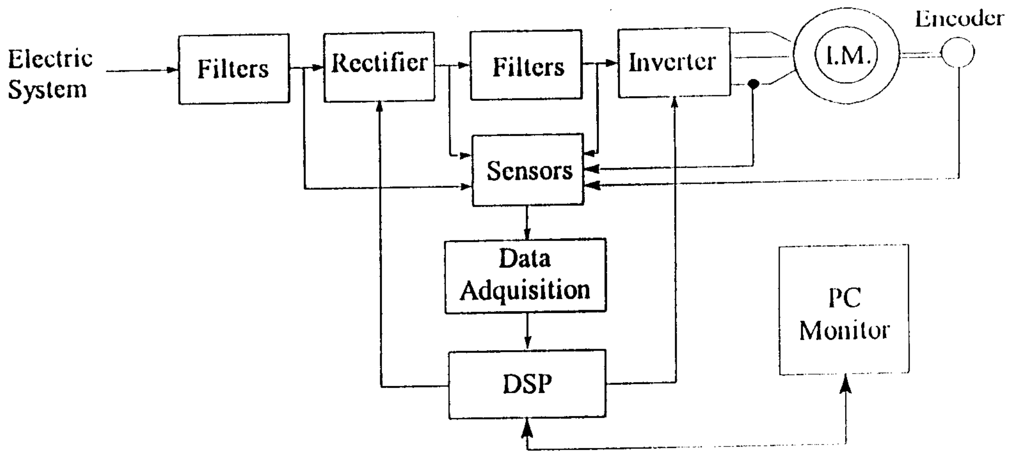

Fig. 1: Test System Block Diagram

Hardware Description

The power stage

This stage includes the rectifier and the inverter with their drive circuits and filters. Both converters are implemented with three dual IGBTs modules, type EUPEC FF50R12KF2, each one with and upper-lower device array and their corresponding antiparallel diode, rated at: V_{ce} = 1200V, i_c = 50A; t_{on}= 0.4 µs t_{off} = 0.2 µs and P = 400 W per IGBT. Figure 2 shows one of the three converter legs. Each converter has an H31 heat sink and it is air cooled with a small fan. The thermal impedance is lower than 0.07 °C/W.

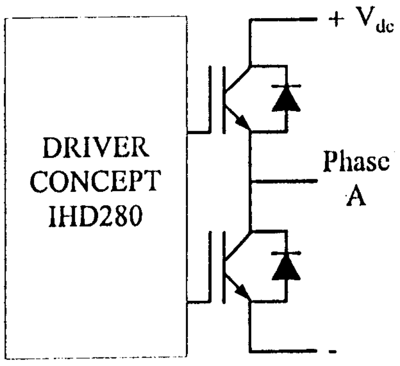

Fig. 2: Phase A driver detail

The inverter and rectifier circuit blocks can be interchanged. IGBT devices were selected because they fulfill the voltage, current and commutation speed requirements for the tests that will be performed and because they are the best option in order to reduce the driver circuits power requirements.

A vector-controlled rectifier, implemented with IGBTs, is used to maximize input power factor and minimize the harmonic pollution sent by the rectifier to the mains. This is one of the problems that are being studied carefully in order to improve service quality [7], [8]. In those experiments that do not require this kind of rectifier control techniques, a non-controlled rectifier can be used to provide the required DC voltage for the inverter operation.

In the first version no snubber circuits have been incorporated; previsions have been taken to include different classical and loss-less snubber circuits to test the system performance with each configuration.

The drive circuits for the inverter and the controlled rectifier have been implemented, each with three IHD280 integrate modules from CONCEPT [10]. Protection circuits between each driver module and the IGBTs gate terminals have been included. Each driver consumes less than 2 W; the input voltage is 15 V and can deliver 200 mA. The turn-on and turn-off delay times are under 60 ns. The drive circuits have been mounted very close to the power circuits (less than 10 cm) to minimize noise influence. A protection circuit is required to guarantee the driver circuit performance.

Two filters have been included in the Test System, one to reduce the current injection back to the mains and the other to keep the DC link total distortion factor below 5%. The first filter is tuned to the 30th harmonic and up. The low order harmonic can be minimized using the vector control technique to operate the rectifier. The second filter includes two Long Life 2200 μF, 450 V Electrolytic capacitors in parallel with a 1 μF, 450 V high-speed capacitor.

The instrumentation stage

Voltage and current measurements must be performed to obtain data for the vector control and parametric estimation techniques. On the other hand, speed measurement must be performed with the possible highest accuracy in order to validate the sensorless speed measurement techniques that are being studied [3]. All the required measurements are carried out in the instrumentation stage.

Voltage and current measurements

Instrumentation cards have been designed for measuring two voltages and three currents at the transformer primary and secondary terminals, three currents at the inverter output, and the DC link voltage and current. Voltage (LEM LV-25-P) and current (LEM LA-55-P/SPI) [11] Hall effect sensors have been used in these cards. Figure 3 shows the Hall effect transducer circuit.

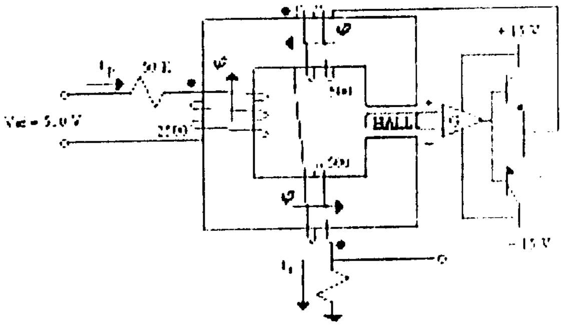

Fig. 3: Hall effect voltage transducer circuit.

The voltage sensors can work up to 500 V_{rms} at 8 kHz, with a ±0.05% precision, and a delay time less than 3 µs. The current sensors can measure up to 50 A_{rms} at 150 kHz. These sensors isolate the measurement circuit from the power circuit and adjust the signals to the A/D conversion levels.

Data acquisition system

All analog to digital conversions can be performed in two different ways: Through a data acquisition board (PC-30F/S) with 16 12-bit channels, sampling at 330 kHz or using the motion coprocessor A/D conversion facility.

The data acquisition board also has three 8-bits bi-directional digital channels. This card can be programmed using high level languages (C++, Visual Basic, etc). It is possible to set each input gain independently. Acquisition is performed using DMA interrupts. Input signals can have up to ±10 V peak. In the Test System, programming was implemented in Borland C++ V 4.5. All the inputs are sampled every 100 µs.

The motion coprocessor ADMC201 [9] supports acquisition of 2, 3, or 4 channels. Converted channel results are stored in registers and the data can be read in any order. The sampling and conversion time for two channels is 8 µs, three channels is 11.2 µs, and four channels is 14.4 µs (using a 12.5 MHz system clock). A four channel sample and hold amplifier allows three-phase motor currents to be sampled simultaneously, reducing errors from phase coherency. Sample and hold acquisition time is 1.6 µs and conversion time per channel is 3.2 µs (using a 12.5 MHz system clock). The ADMC201 integrates a four channel simultaneous sampling analog-to-digital converter, four channel analog multiplexer, analog reference, vector transformation, six digital inputs/outputs, and three-phase PWM timers into a 68-pin.

Figure 4 and 5 show the acquired current and voltage waveforms respectively using the ADMC201 motion coprocessor.

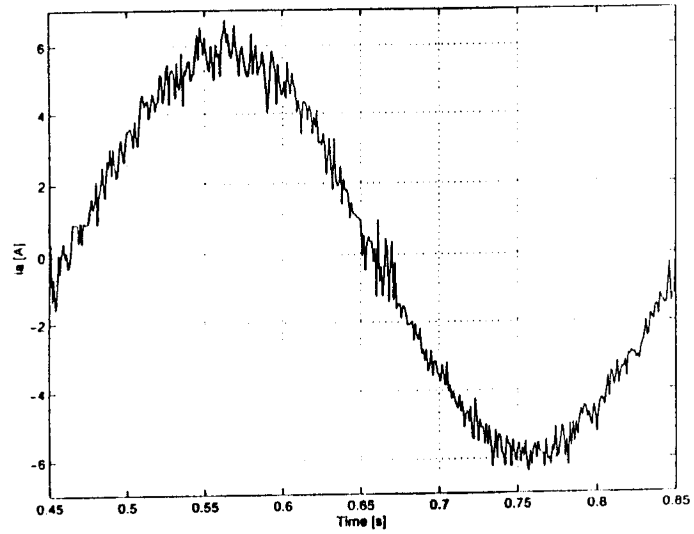

Fig. 4: Acquired Current Waveform

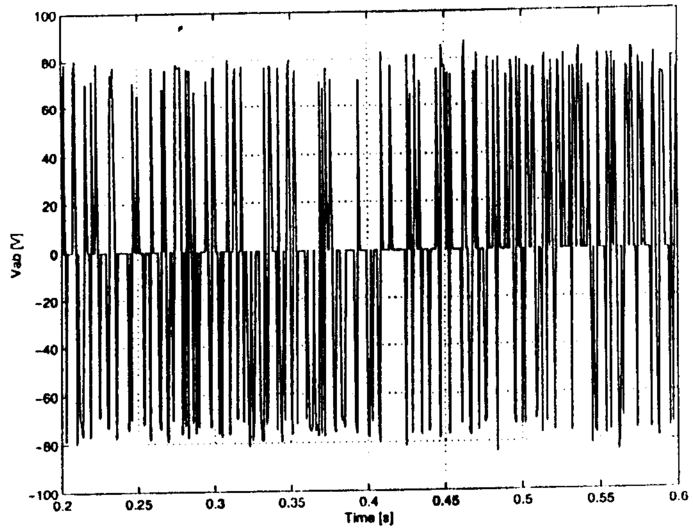

Fig. 5: Acquired Voltage Waveform

Speed measurement

It is achieved measuring the speed with an incremental optical encoder with 1000 pulses per cycle. This encoder is mechanically coupled to the machine axis. The pulse train produced in the encoder output is processed by a dedicated conversion circuit, that includes a frequency divider (LM74193), a Programmable Logic Device (PLD model LATTICE1016), a Gate Array Logic (GAL 22V10) and a 16 MHz clock. This circuit introduces the speed information directly in the PC bus. Fig. 6 presents the encoder and the dedicated conversion circuit board. This speed measurement can also be performed using the DSP board with the motion coprocessor.

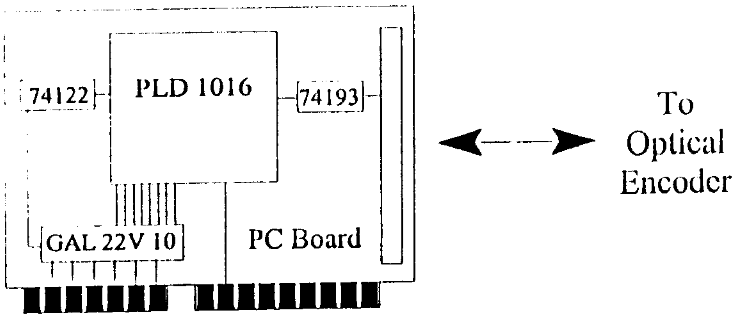

Fig 6: Encoder and the dedicated conversion circuit board.

The signal processing and control stage

All signal processing and control strategies are performed in the ADSP 21061 EZ-KIT Lite. A PC using the RS-232 Serial Port monitors this DSP. The trigger signals for the IGBT drive circuits are sent via copper wire with the appropriate shell to avoid EMI interference.

Prototype assembly

Figure 7 shows a frontal view of the designed Test System. This equipment has been developed in the Energy Conversion Laboratory in Simón Bolivar University.

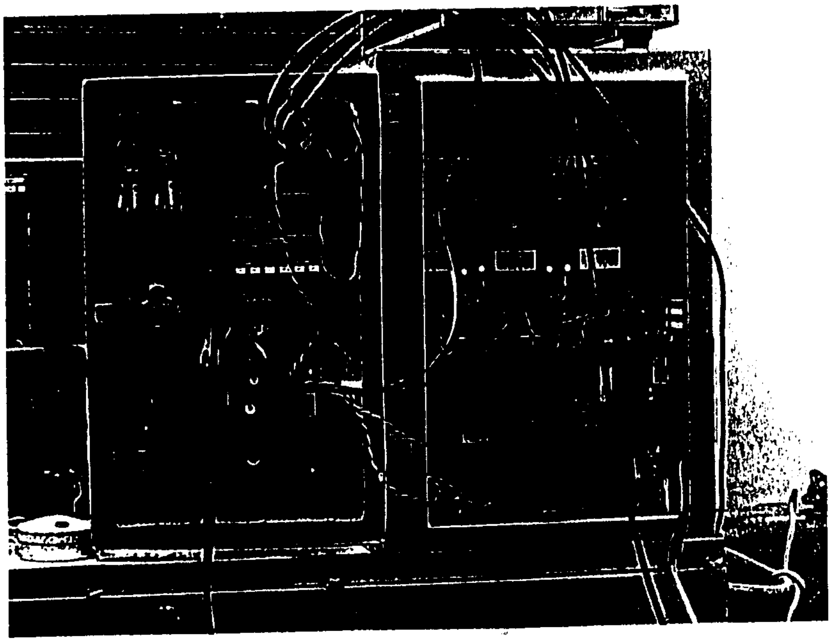

Fig. 7: Frontal view of the designed Test System

Software description

All the programs for data processing and control strategies have been written using the C++ compiler for the ADSP 2106x, employing a modular structure. As an example, Fig 8 shows the program modules and their interconnections to perform vector control [4]. In this figure, the MAIN module initializes all the program parameters, while the CLOCK module handles the Clock interrupt, and enables the communication between the motion coprocessor and the DSP. The EULER module performs the calculations for the non-measured variables (for example, inverter voltages, magnetization current, spatial vectors, etc.) using the numerical Euler integration method. This module can be replaced with others based on Neural Networks control, DTC or PWM strategies [5], [6]. The CONTROL module calculates the required current and torque values in order to keep the desired operation point. The INVERTER module determines the firing sequences for all the IGBTs. Additionally, the SIN/COS module calculates the sine and cosine values for the angles between 0 and 2π with three decimals precision, and the GLOBAL module contains the variable definitions required for all the modules.

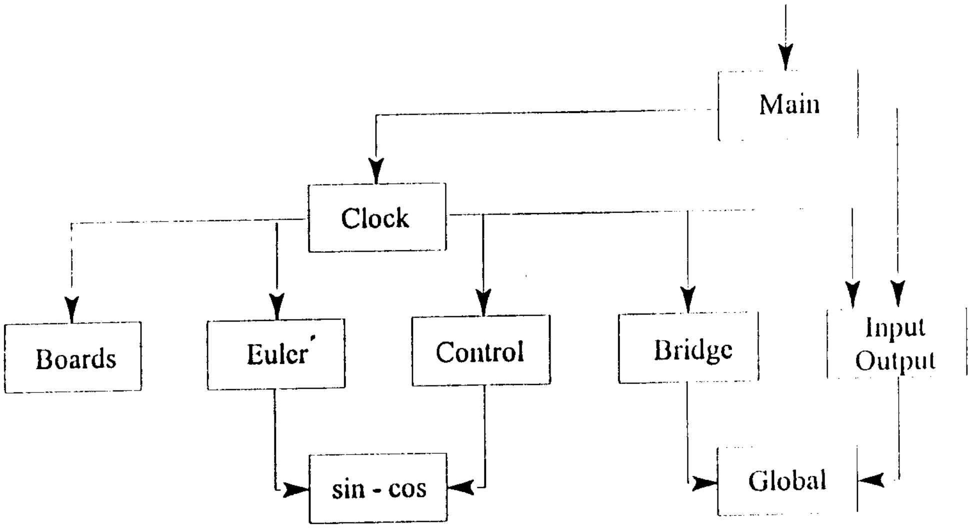

Fig. 8: Program structure

Results

The system developed can perform vector control over the AC machine applying different control strategies. It has been used to analyze spatial vector and DTC control performance, real time parametric estimation and sensorless speed measurement techniques. The equipment is also able to control the harmonic injection in the mains using the programmed strategy. As an example, Figure 9 shows the stator currents in alpha-beta coordinates, stator flux and rotor speed in an induction machine start up using field oriented control during the first stage and Direct Torque Control (DTC) during the normal operation.

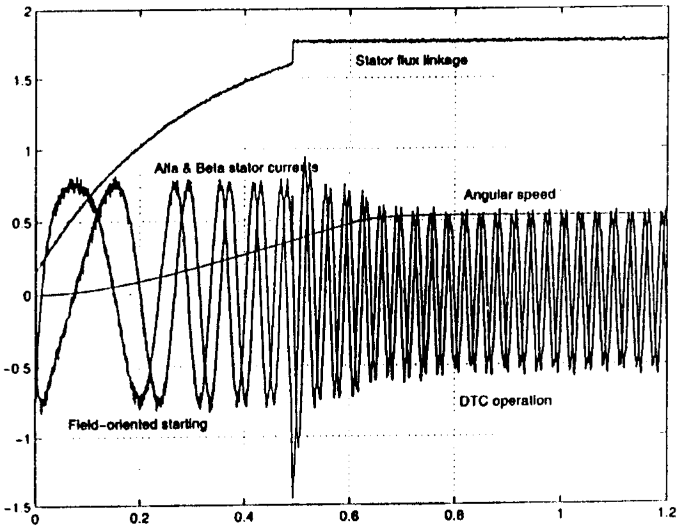

Fig. 9: Induction machine starts up using field-oriented control during the first stage and DTC during the normal operation

Conclusions

The Test System developed is able to perform many different control strategies including spatial vector control, neural network control, DTC control, PWM modulation, delta-modulation, mains harmonic reduction, on line parametric estimation, and sensorless speed measurement. Changing the control strategy in the Test System just implies writing a new modular C++ subroutine for the DSP; usually no major changes in the hardware layout will be necessary. The versatility, reliability and precision of the Test System make a very convenient resource for researchers and post-graduate students.

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