Development of Firmware for a Back-to-Back Motor Test Bench with CANopen Communication Protocol

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***Abstract*—This thesis focuses on the development of firmware for motor control using STM32CubeIDE, targeting the STM32F303RE microcontroller by STMicroelectronics. The firmware implements Field-Oriented Control (FOC) for a Surface Permanent Magnet (SPM) motor and establishes communication with a second inverter using the CANopen protocol. The first inverter, built around the STM32F303RE, controls the primary SPM motor and acts as the CANopen master. It communicates with a commercial inverter, the Micro Digital One by Microphase, which is configured as a CANopen slave. The two SPM motors are mechanically coupled in opposition and powered through a common DC link. In this back-to-back configuration, the primary motor (Machine Under Test) is controlled using custom firmware on the STM32F303RE, while the secondary motor (Driving Machine) is driven in speed mode by the Micro Digital One. The system demonstrates coordinated control of a dual-motor setup, leveraging both custom and commercial solutions within a shared DC power architecture and real-time communication over CANopen.**

I. Introduction

The objective of this thesis is to implement and manage real-time CANopen communication between two different converters: a develop testing converter based on the STM32F303RE microcontroller, which supplies and controls the Machine Under Test, and a commercial inverter, the Micro Digital One, which supplies the Driving Machine. The converters operate in a back-to-back configuration with a shared DC link and mechanically coupled motors, enabling bidirectional power flow and precise motor control coordination. The focus is on achieving robust communication and synchronized operation between the converters, leveraging the CANopen protocol and Field-Oriented Control.

II. Hardware components and assemby

The test bench is composed of the following parts:

- The STM32F303RE Nucleo-Board;
- The X-NUCLEO-IHM08M1 is a three-phase inverter expansion board developed for STM32 Nucleo platforms.
- The inverter by Microphase Micro digital One;
- The transceiver SN65HVD230 used for enabling CANopen network from STM32F303RE to Micro digital One;
- the motors in back-to-back configuration, the S160-1B303 and the S140-2B353;
- CAN analyser, used to minitor the CAnopen network messages;
- The Moxa adapter UPort 1130I (RS-422 to USB).

The STM32F303RE is a high-performance 32-bit microcontroller from STMicroelectronics, based on the ARM® Cortex®-M4 core with floating-point unit (FPU). Operating at a frequency of up to 72 MHz. The microcontroller offers a rich set of peripherals, including advanced timers, multiple ADCs , DACs, and communication interfaces. The Micro digital One is a very compact full digital regenerative servo drive for permanent Brushless and Brush DC servomotors. Can operate in torque, speed, and positioning control modes and supports fieldbus communication protocols such as CANopen. Before using the Micro Digital One, it is necessary to configure certain parameters based on the motor and the selected application. In this configuration, the STM32F303RE operates as the master node within the CANopen network. It initializes the network using the CANopenNode library and transmits the necessary configuration messages to the Micro Digital One controller. The Micro Digital One is considered correctly configured when it begins operating the S160-1B303 motor in speed control mode. Meanwhile, the S140-2B353 motor is controlled directly by the STM32F303RE using Field-Oriented Control (FOC).

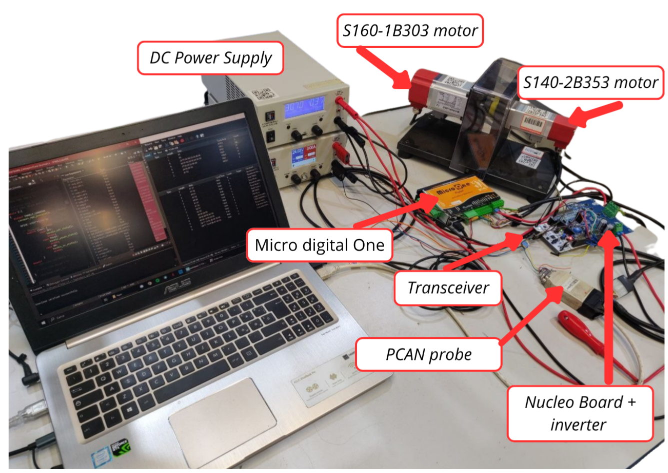

Fig. 1. Test bench overview

III. Firmware implementation

After the necessary initial configuration of the STM32F303RE using STM32CubeMX to enable the required peripherals, the setup of the Micro Digital One is partially performed using its dedicated software, Drive Watcher. This includes enabling CANopen communication and assigning a unique node ID to identify the Micro Digital One within the network.

Additional parameters must be configured on the Micro Digital One to enable proper speed control of the S160-1B303 motor. These settings are implemented in STM32CubeIDE for the STM32F303RE and transmitted to the Micro Digital One via CANopen using Service Data Objects (SDOs). In the CANopen network, in addition to the use of SDOs, one Transmit PDO (TPDO) and two Receive PDOs (RPDOs) are periodically transmitted for debugging purposes. The STM32F303RE is not only responsible for configuring the Micro Digital One and initializing the CANopen network, but also manages the Field-Oriented Control (FOC) of the S140-2B353 motor. The implemented FOC strategy applies a constant torque with a step variation, allowing the evaluation of two distinct operating points on the test bench.

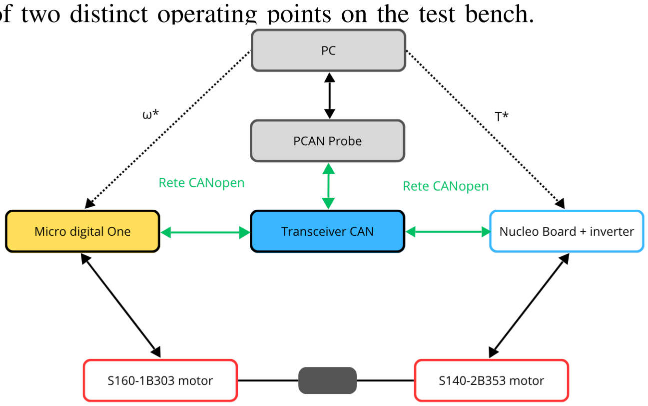

Fig. 2. Test bench schematic

IV. Experimental Results

The inverter maintains stable PWM modulation, ensuring consistent switching signals in steady-state conditions. The FOC controller effectively regulates motor currents, maintaining phase balance and minimizing current ripple. A relevant plot illustrates the shaft speed in response to the initial speed control and the subsequent application of FOC. Two distinct spikes appear in the same time window, corresponding to critical transitions in the control strategy. The **first spike** occurs when the control mode switches from speed-only to speed control combined with FOC. When a positive torque reference is applied, the spike corresponds to a rapid acceleration of the shaft. In contrast, with a negative torque reference, the spike is less severe due to a deceleration, which is partially mitigated by the Micro Digital One's speed control. The **second spike** represents the step change in the torque reference implemented in the firmware, designed to assess the test bench's dynamic response shortly after the control strategy transition. A positive step in torque results in a spike caused by shaft acceleration, while a negative step produces a negative spike due to deceleration. In the tests presented, both cases were evaluated: one with a positive step reference and one with a negative step reference.

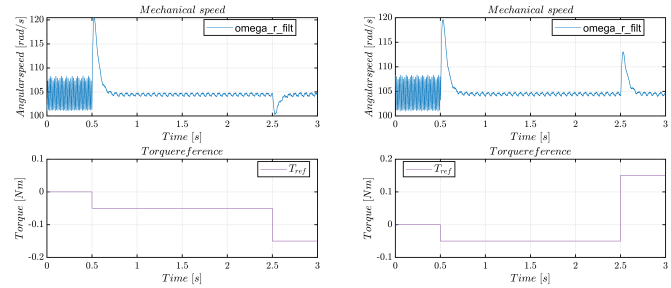

Fig. 3. Shaft speed with negative and positive torque reference

A critical test was carried out on the test bench to simulate one of the most dangerous fault conditions: the sudden loss of FOC, where the speed control is no longer able to maintain the reference speed, leading to a drop in shaft speed to zero. In such a scenario, the energy generated by the motor is no longer regulated or absorbed by active control and is instead fed back into the generator's DC bus. Since the generator cannot perform energy regeneration, its only response is to absorb the excess energy by increasing the DC bus voltage (V_{DC}). This can result in a dangerous overvoltage condition if the spike is significant. The test, conducted with the shaft speed approaching zero and without active FOC, showed only a minimal increase in V_{DC}. This indicates that the system demonstrates good resilience to this type of fault condition.

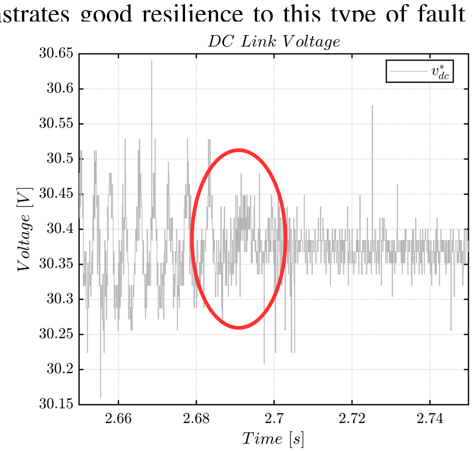

Fig. 4. VDC response to fault test

V. Conclusion

This thesis demonstrated the development of custom motor control firmware with integrated CANopen communication on an STM32F303RE microcontroller. The system successfully coordinated two SPM motors in a back-to-back setup, where the primary inverter (custom) controlled the Machine Under Test using FOC, and the secondary inverter (commercial) drove the Driving Machine in speed mode. The shared DC link and mechanical coupling enabled efficient energy exchange and realistic testing. The use of the open-source CANopenNode stack and built-in CAN peripheral proved to be an appropriate and cost-effective solution for real-time communication.