RAPID CONTROL PROTOTYPING FOR ELECTRIC DRIVES

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Abstract: This paper presents an approach to rapid prototyping of control algorithms for electric motors with dSpace real-time simulation platform. dSpace board DS1103 is connected to Freescale 3-Phase BLDC/PMSM Low-Voltage Motor Control Drive providing sufficient power output to the electric motor. Control action is performed by pulse width modulated (PWM) signals generated in dSpace board using Simulink Real-Time Interface (RTI) libraries provided by dSpace manufacturer. Motor outputs (speed, currents and voltages) are measured directly by dSpace with encoder interfaces and A/D converters.

Keywords: dSpace, Freescale, Rapid Control Prototyping, Electric Motor Control

1 INTRODUCTION

In recent years the economic aspects of electric drive manufacturing such as raw materials costs and availability are accelerating development of new types of electric motors. These new motors often provide cost effective solution for manufacturer but they usually require development or modification of current control algorithms. Real-time simulation platforms such as dSpace allow us to decrease time needed for development cycle to a minimum.
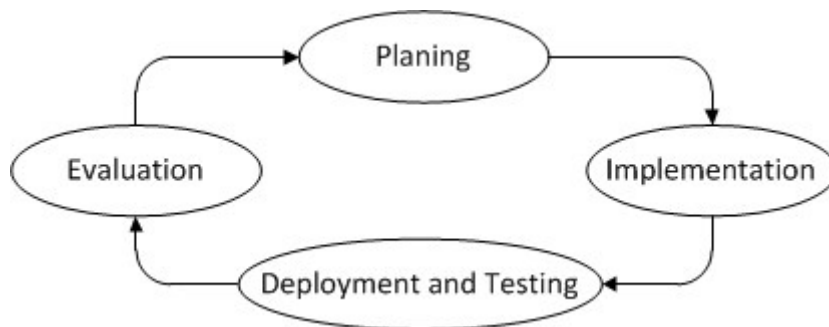

Figure 1: Development Cycle.

Implementation of a control loop is carried out in Simulink environment. An RTI library provides blocks that implement the I/O capabilities of dSpace system in Simulink model. Simulink model is compiled and downloaded to dSpace platform after which automated measurement and analysis can be started.

2 DSPACE SIMULATION HARDWARE

Real-time hardware DS1103 is based on PowerPC microprocessor supplemented by Texas Instruments TMS320F240 DSP processor. The TMS320F240 slave DSP is loaded with firmware that al-
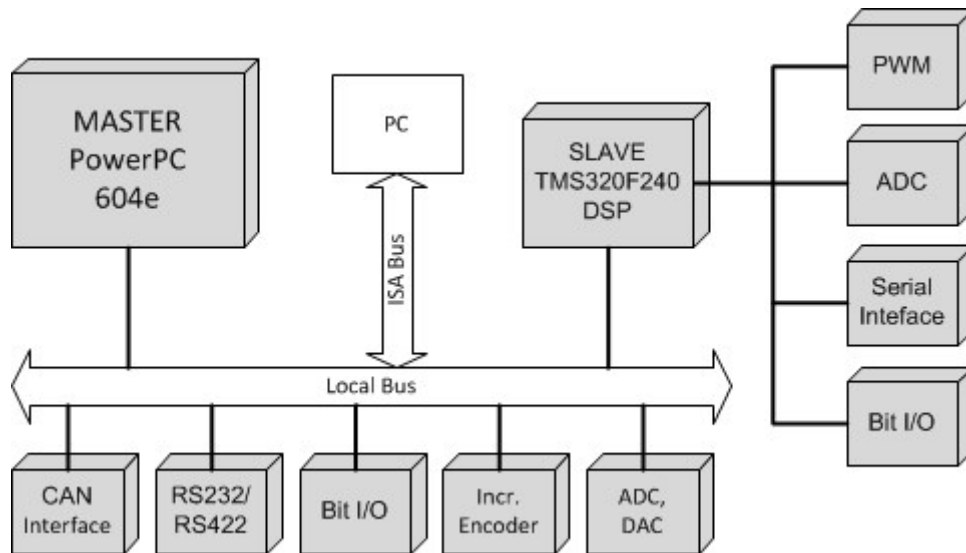
Figure 2: DSpace Board Architecture.

lows access to the different peripheral devices of the slave DSP. Also user specific DSP function, not covered by standard firmware, can be compiled and loaded to the DSP. Manufacturer's support for this processor is no longer available so it is not possible to find compiler for 64b operating system. Functions needed for motor control (SPI, PWM) are already pre-defined in slave DSP so there was no need to compile custom code.

Programs for master PowerPC can be compiled directly from the C-code using RTIlib containing the functions provided by the DS1003 Processor Board or using Simulink Real-Time Workshop. Besides the PWM module and SPI interface provided by slave processor the Encoder interface and A/D modules controlled by master PowerPC are used for closed loop motor control to measure the rotor speed and stator currents.

2.1 MOTOR CONTROL DRIVE

Power output of dSpace platforms D/A converters is not sufficient for powering any larger types of electric drives. For this purpose DSpace PWM outputs are connected to 3-Phase BLDC/PMSM Low-Voltage Motor Control Drive. Driver board is capable of providing up to 24V and 5A power output from 3-phase bridge to the motor. Gate driving for the bridge is supplied by Freescale MC33927. This driver has built-in overcurrent, undervoltage and other safety functions. Gate driver is configurable thru commands send over Serial Peripheral Interface (SPI). The board enables the sensing of a variety of feedback signals suitable for different motor control techniques, such as all three phase currents, DC bus current, DC bus voltage and BEMF voltages.

Registers of MC33927 are configured after dSpace power-up. SPI communication is implemented in initialization section of Simulink model. Initialization is written in C language (slave SPI communication is not included in Simulink RTI library). First command sent after SPI initialization is deadtime calibration command. Deadtime prevents the turn-on of both transistors in the same phase until the deadtime has expired. Calibration pulse on SPI's /CS line with precise length has to follow this command. Required length of the pulse can be achieved by sending NULL command with precise speed of communication. This command will drop the /CS line to logic 0 in order to start the communication. For example SPI speed of 468750 Baud will provide approximately 24us wide pulse for 1.5us deadtime (see MC33927 datasheet for details). Successful deadtime command calibration
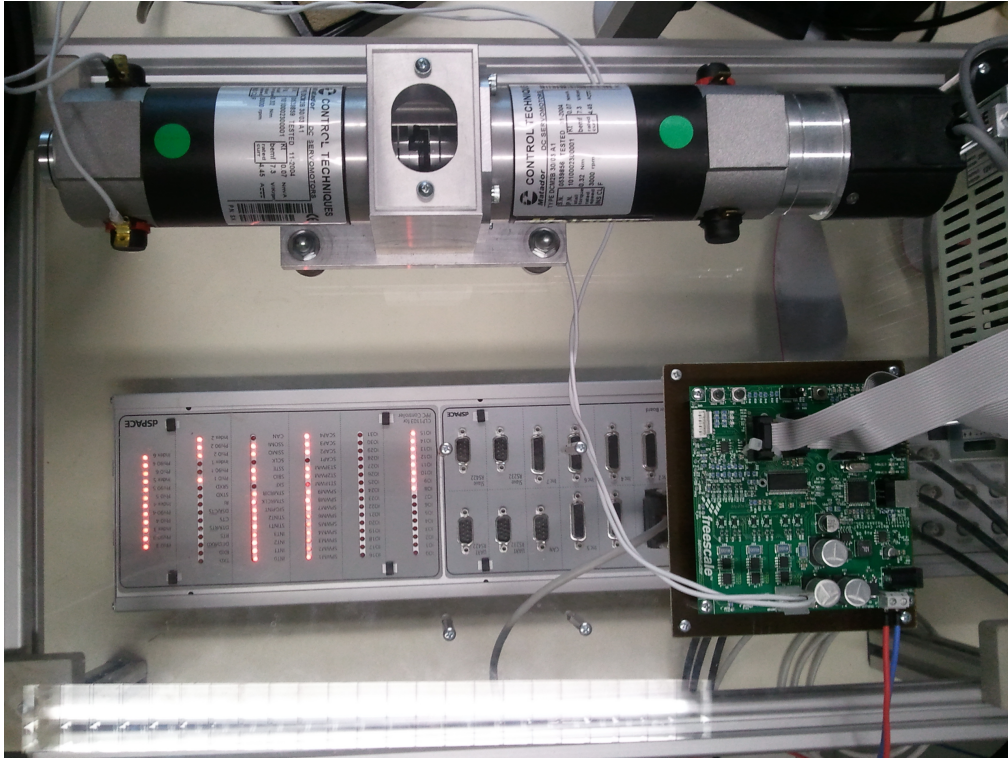
Figure 3: dSPACE I/O board with Freescale motor control drive and DC motor[3]

can be verified by reading status registers in the driver by SPI command. In order to fully enable outputs of the driver EN (enable) signals has to be set to logic 1.

3 CLOSED LOOP CONTROL IMPLEMENTATION

This section is an example of a closed-loop brush DC motor control with dSpace connected to Freescale drive board. Rotor speed and stator currents represent measured (controlled) variables and control action is applied by pulse width modulated voltage on stator winding.

3.1 ROTOR SPEED AND STATOR CURRENT SENSING

dSpace encoder interface is used to measure the rotor speed by a 1024bit rotary encoder. Simulink implementation of the encoder interface is composed of two blocks. First block serves as global encoder setup (dSpace has total of 7 encoder inputs) where the encoder type can be specified for each channel as single-ended or differential. Second block provides access to the position and delta position (speed) of the 7 encoder interface channels. Rotor speed acquired from the interface can be then then scaled to rotations per minute (RPM).

Stator currents are more difficult to acquire. Freescale drive board is equipped with 4 sampling resistors. One is for bus current and one for each phase of the bridge. Because these resistors sample the current in the lower phase legs, they do not directly measure the phase current. However, given phase voltages for all three phases, phase current can be constructed mathematically from the lower phase leg values. Phase currents from sampling resistors are amplified and scaled so that +/-4A corresponds to +/-1.65V on current sensing output with 1.65V bias. Currents are present at the phase legs only when the lower transistors are open hence measurement has to be precisely timed to be aligned in the center of PWM pulse.

Precise current measurement is achieved with DSpace interrupt controller. Simulink block Master

Sync IO Setup can be used to select input signals and triggering source from many of the board's I/O units. It can be also specified whether the synchronization occurs on falling or raising edge of the triggering signal. Triggered measurement itself has to be placed in Simulink triggered subsystem. Slave DSP PWM interrupt is selected as triggering source for the subsystem. It is recommended to use Task Transition block whenever the transition from triggered subsystem to the rest of the Simulink model with different sampling interval occurs.

3.2 PWM GENERATION

dSpace slave DSP is capable of generating several types of PWM output signals (4 individual channels, 3 phase PWM, space vector PWM...) each connected to different connector pin. Only 3 phase PWM can be used as triggering source. Unfortunately the 3 phase PWM Simulink block has no deadtime settings so the deadtime has to be added in the Freescale control drive board (calibration over the SPI line is described above). One of many safety features of Freescale motor control drive board is inverted logic level for the high side transistor minimizing the probability of high side and low side transistor activation during power up or failure. Since the deadtime is not generated in dSpace one signal for high side or low side can be used to control driver for both sides of the bridge in each phase.

3.3 CLOSED LOOP SIMULATION

Since the stator currents are measurable it is possible to use cascade control structure to control both the rotor speed and stator current. Stator position of DC motor was fixed in order to identify time constant of the current loop. Identified plant is the first order transfer function so the step response can be measured to easily identify this unknown parameter.

The time constant was identified as $T = 0.0025s$. PI controller was used to achieve desired current. Time constants and gain of the controller were selected by frequency open loop shaping so that 0dB is crossed with -20dB/dek declanation at the highest frequency as possible. PI controller for outter speed loop was designed accordingly. Implementation of both controllers is done in Simulink environment using some of the build in functions for controller design (SISOTOOL).
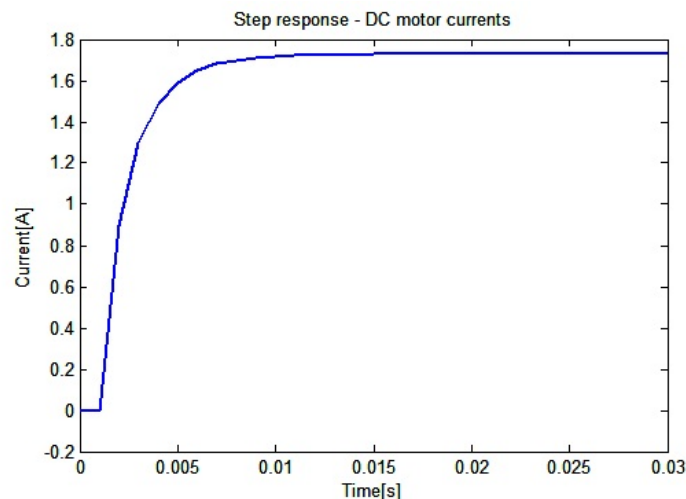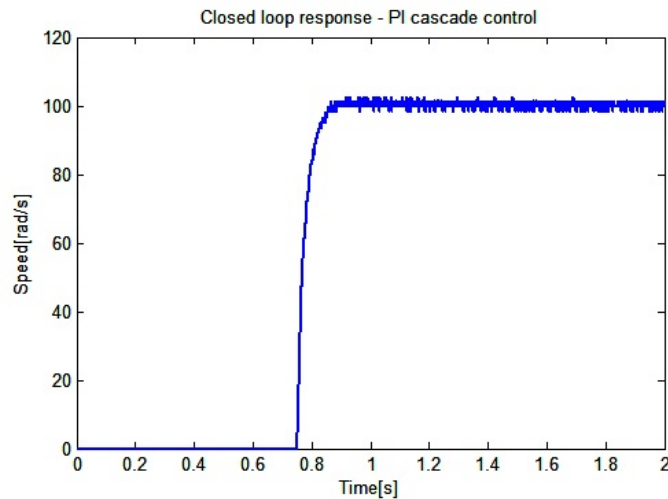

Figure 4: DC Motor current step response

Figure 5: Closed loop speed response

4 CONCLUSION

This article presented flexible dSpace development system extended by Freescale low-voltage drive for rapid development of motor control algorithms. dSpace platform provided all I/O connections needed for control of most types of electric drives. Freescale board served as a final power stage that was able to provide 4A of stator current into the motor after the deadtime calibration was done over the SPI line. Motor speed and stator currents were measured directly by dSpace through integrated interfaces. Simulation of newly developed algorithms is substantially easier since the whole closed loop can be developed in Simulink, measured and tested in dSpace control desk studio provided by dSpace Company. Simple example of DC motor control was presented at the end of article as demonstration of overall dSpace functionality.

ACKNOWLEDGEMENT

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