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BLDC MOTOR CONTROL DESIGN IN MATLAB/SIMULINK

Abstract: The article describes the simple way of BLDC motor control development in the Simulink environment. This way of development is also called *Model Based Design* approach, which is nowadays rapidly gaining popularity. MBD should be very effective method for development time reduction and finds usage especially during fast prototyping phase.
The simple BLDC motor controller has been created and presented in this paper. Because the Simulink itself cannot control any outside system or process itself, a real special software and hardware has to be connected to the personal computer. Described control algorithm has been developed for dSPACE environment with appropriate power and interface electronics. The sinusoidal control algorithms for low power sensor BLDC motor has been used.

1. Introduction

The Simulink environment, designed by The Mathworks, is complex engineering software suited for solving various kinds of technical problems. One of these problems from our point of view is the precise modeling of a BLDC motor control.

The partial task of our long-term interest in the Faculty of Mechanical engineering is to verify the usage of the Model Based Design approach for mechatronic applications. The MBD fundamentals will be better described in the following paragraph.

The presented article would like to inform readers about authors' MSc thesis, which has been done in the Department of Production Machines, Systems and Robotic, BUT.

2. Model Based Design fundamentals

2.1. MBD

The new development trends for control electronics has been used according to nowadays technical trends that lead to use the Model Based Design approach. MBD consists of several consequential steps, whose consecution is defined by the V-cycle. This new development method begins to leak not only to the scientific or research areas, but more often into the commercial production.

The new development life cycle enables verification, validation and testing during each phase of a development. Disclosure and correction of any mistake is already possible at the beginning, which is much cheaper and effective than whole device redesign during classical development procedures in the prototype phase. The other advantages, which MBD allows, are – development time and cost reduction, easier certification, faster and easier testing, help with accompanying documents, failures reduction.

The higher safety during testing is also quite important aspect. It is not necessary to work directly with a real system, which can be often dangerous. Firstly, the new code is tested on the HIL simulator and then, if no hazardous state occurs, could be applied in specific target system.

2.2. V-cycle diagram

The first step of the V-cycle, depicted in the ***Fig. 1***, is the device specification and requirements of each part. Development continues with the analysis of incoming parameters of future hardware and software. Mathematical description of the controlled system is also the integral part, conceptual design of the control algorithm either. The important part is also proper chose of the software environment for the whole Model Based Design procedures.

Complex software environment, which allows MBD methods, is i.e. MATLAB/Simulink. Simulink enables composition of the real system according to its mathematical and physical description. For created model of the system (i.e. model of motor) it is possible to design and realize any control algorithm and simulate it. Simulations make possible to designers the proper view of the dynamic and static points of a system. This phase is marked as Model-in-the-loop (MIL) in the V-cycle.

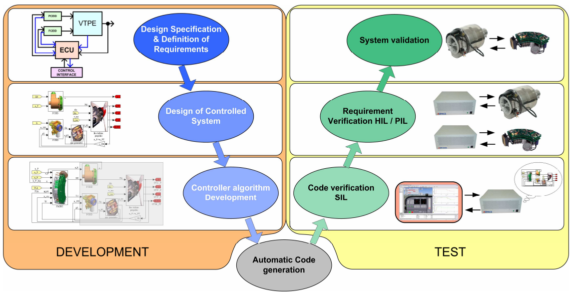

Fig. 1. Graphical diagram of the V-cycle

The next phase in the cycle is Software-in-the-loop (SIL). This part consists of automatic source code generation from the Simulink model. Real-Time-Workshop is used for this purpose, which is the integral part of the Simulink libraries. Testing of the automatically generated code is provided at the end of this phase. Results from the source code testing are compared with the model behave. If the results are equal with mathematical model, the next phase continues.

Hardware-in-the-loop is the next part of design. The main aim is again to prove the generated source code, but now at the real simulator. The code is uploaded to the appropriate HIL hardware simulator with various set of peripherals. The dSPACE system, which is compatible with MATLAB/Simulink, can be used.

The last step of the V cycle is the code generation and linking to the target platform (i.e. several embedded system). Real-Time-Workshop-Embedded-Coder is used for this step in the Simulink environment. This software package generates source code, which is optimized for the selected target platform (i.e. Freescale, Microchip microcontrollers).

3. Simulink model

Firstly, the Simulink model, Fig. 2, of the sinusoidal control has to be designed. Two fundamental groups of blocks are used in this case. The first group of blocks consists of standard parts from Simulink libraries. The second one is blocks from the Real-Time-Interface (RTI) library, which are used for dSPACE system peripherals settings. Setting and common work with the RTI blocks is similar to the classical ones. All the blocks are connected to each other by standard links in Simulink.

The Simulink model is divided into the two main parts – *Measurement and Control PWM*. The schematic diagram is in the Fig. 2. The Digital I/O Setup block is used for setting the digital and analog input/output ports into dSPACE system. The BIT IN and BIT OUT blocks are for *Fault* detection and for *Reset* purpose of the power electronic. For setting the current and speed controller is the ON/OFF CONTROLER block used.

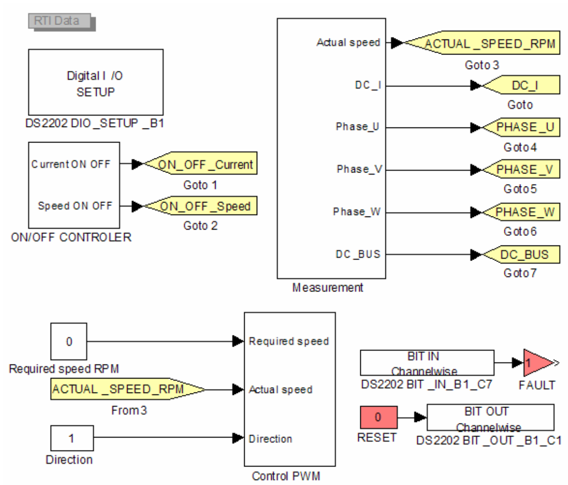

Fig. 2 Schematic diagram of the Simulink model

The measurement part, right side of the Fig. 2, is used for measurement of the all analog values from the power electronic and BLDC motor. It consists of the 5 analog inputs and actual rotational speed. The Frequency block is connected to a Hall sensor in the BLDC motor and senses the rectangular signal frequency. This value is then recalculated to revolutions per minute.

The Control PWM block, bottom side of the Fig. 2, consists of closed loop control, input and detection of a Hall sensor, commutation logic and PWM setting blocks of the dSPACE system. It is the essential part for whole model and is used for commutation and control. There is Switch of controller block, which can be used for fast switching of various control loops according to designer's requirements. Switching pin is ported out from the structure for easy control from the dSPACE environment.

Unfortunately, there is not enough space for detail description and schematic diagrams of each Simulink model blocks. The Fig. 2 depicts only the main parts from the top view of the model. The other important sub-blocks, inside

Control PWM block are – current and speed PID controller, Hall sensor measurement, BEMF voltage detection… The right controller setting is for smooth BLDC motor control necessary.

When the Simulink model works properly, the next step according to the V-cycle will be compilation and Hardware-In-the-Loop phase.

4. dSPACE system environment

The model, described above, is possible to compile by Real-Time-Workshop (RTW – part of the Simulink). Automatically generated code is prepared for linking to the dSPACE hardware. Linked code is then executed in a real-time. It is necessary to prepare graphical user interface (GUI) for controlling and watching the behavior of the model. There is the Control Desk environment for this purposes and it is a part of the dSPACE system. Control Desk software enables interactive control of all blocks used in the model. The GUI is designed and executed on the common personal computer (PC). Design of the motor control interface is in the Fig. 3.

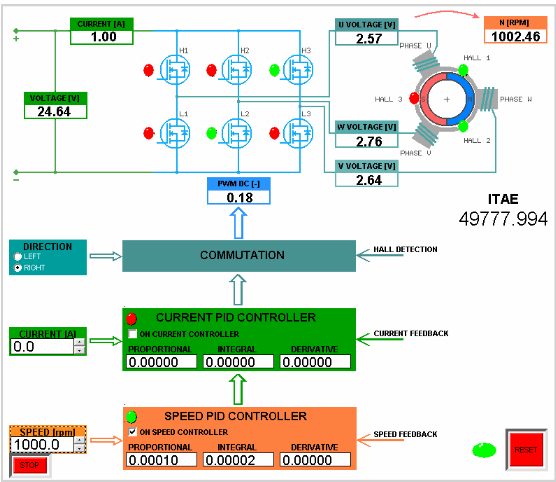

Fig. 3. GUI for motor control in Control Desk

The control interface was designed comfortable for users. The controllers (bottom side of the Fig. 3) are the most important part for reliable and smooth behavior of a motor and are made graphically. It is possible to switch the appropriate controller on/off by the common check button. There are several edit fields on all blocks for the parameters tuning.
The respond of the system is possible to watch promptly in the graph window on the left side. All collected courses it is possible to save and redraw in any software environment, such as Excel, MATLAB, MathCAD, etc. All electrical signals from the connected power electronic can be analyzed on-line (e.g. phase voltages, currents, state of all transistors, etc), because of real-time behave of the system.
The included graphs make possible promptly compare actual system respond or whether the actual speed is still in specified area.

5. Requirements for the HIL testing

In our testing example, controlled system is the BLDC motor produced by Anaheim Automation (BLY342S-24V-3000). The BLDC motor is connected to the power electronic, which is controlled by dSPACE system. Controlled algorithm from the Simulink environment is uploaded to this system and executed. There are several peripherals used in the dSPACE system, such as 5 analog inputs for voltage and current sensing from the motor windings, 5 digital inputs for Hall sensors and Fault state sensing, a digital output and 6 synchronous PWM channels. The connection diagram is in the Fig. 4.

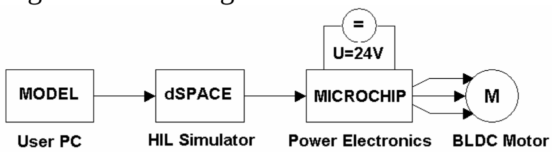

Fig. 4. Connection diagrame of the system

The Power Electronics consists of interface circuits and full 6 step inverter with appropriate protecting components. The interface board has several power supplies and circuits for optical interconnection of the logical signals from dSPACE and power drivers in the inverter.

The inverter is commercial evaluation kit by Microchip. It consists of power MOSFETs with appropriate integrated drivers. The maximal switching current reaches 30 Amps and the maximal DC bus voltage up to 50 Volts. The power electronic is also equipped by electrical brake, which is now not used. The electronic makes possible to measure any analog values from the electric drive and transforms ranges for dSPACE acquisition cards.

Because the dSPACE real-time systems is quite sensitive and expensive equipment, it is recommended by the producer to protect all digital and analog inputs and if it is possible make high-quality optical separation.

In the next paragraphs there is detail description of the power, interface electronics and briefly BLDC motor fundamentals.

6. BLDC motor fundamentals

Brushless Direct Current motors, depicted in the ***Fig. 5***, are one if the motor types rapidly gaining popularity. BLDCs were designed to replace the electro-mechanical commutator sub-system in a conventional Brushed DC motor due to several advantages that are:

- Higher reliability
- Lower maintenance, lower audible noise and EMI
- More power per unit volume due to more thermal efficiency
- Higher speed range, etc.

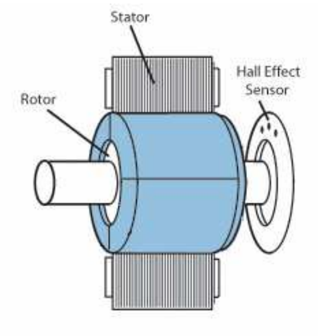

Fig. 5 BLDC motor architecture

In addition, the ration of torque delivered to the size of the motor is higher, making it useful in applications where space and weight are critical factors. To ensure the reliability of electric drives it is normally used sensor variation of the BLDC motor. From a modelling perspective it looks exactly like a DC motor, having a linear relationship between current and torque, voltage and rpm. The previous chapters deal with a BLDC motor with integrated Hall sensors.

7. Power electronic

The dSPACE system is not able to drive any DC brushless motor directly, but is able to deliver only logical control PWM signals on its outputs.

The power electronic, produced by Microchip, is the fundamental part of the whole chain. The power block determines basic motor parameters, such as maximal speed, current, voltage.

In our application the middle power electrical equipment is used. Any BLDC motor with up to 50 Volts and 30 Amps can be used. The power electronic is assembled by several fast protection circuits. Some over current protection is absolutely mandatory to protect the whole system and for comfortable controllers optimization.

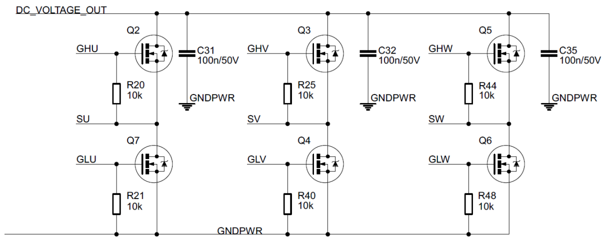

Fig. 6. Power electronic diagram

There is the basic inside structure of the power electronic in the Fig. 6. It consists of 6 power MOSFETs that are sequentially switched according to the requested speed and torque.

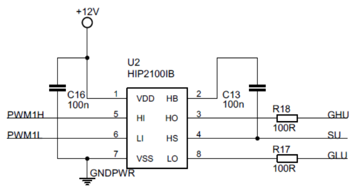

Fig. 7. The power MOSFET driver

The Fig. 7 depicts a power MOSFET driver which is necessary for very fast turning on/off one pair of MOSFETs. It must deliver the current up to 1.5 Amps to the appropriate transistor’s gate.

Because there is not enough space for detail description of the other parts of the power electronic, only the main parts have been briefly described. The last paragraph describes the interface board which is necessary for dSPACE system protection.

8. Interface between power electronic and dSPACE

The last described part of the HIL system is the interface board, which is in the Fig. 8 depicted. This part consists of three connectors that are used for Hall sensors from BLDC, dSPACE system and Power electronic.

The main purpose of the board is the optical isolation and protection of the dSPACE system, which could be damaged by the over voltage or over current fault. The electrostatic protection of the dSPACE inputs is also important.

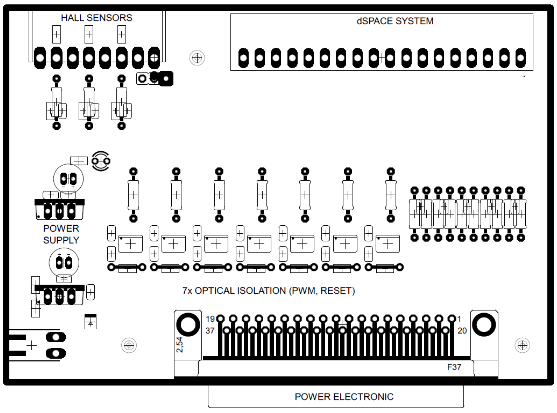

Fig. 8. Interface board for optical isolation

The main connector on the board (dSPACE connector) consists of 6 PWM logical outputs for Power electronic, 3 logical signals from Hall sensors and the RESET signal for the Power electronic.

Because the dSPACE system cannot drive directly the power electronic inputs, the optical isolation are also used for this purpose.

9. Conclusion

The project involves the development of control algorithms and electronics to improve performance and reliability of the BLDC motor in actuating devices for safety critical applications.

Because of this high demand, simulation and modeling tool are widely used to accelerate the development of control algorithms. The simulation results are tested on real hardware in the dSPACE environment. This type of development is called Model Based Design and is the integral part of every development department.

The main advantage of this modeling is its complexity, integrity and possibility to use is in any higher system without need to understand the principle of the BLDC motor in deep details. From the highest point of view, whole motor controller model is only the other Simulink component, which can be used in any complex systems.

Literature

[1] Hubik V., Sveda M., Singule V.: *On the development of BLDC motor control run-up algorithms for aerospace application*. In Conference Proceedings. Poznan: 2008, p. 1643-1647. ISBN 978-1-4244-1742-1.

[2] Hubik V., Sveda M., Singule V.: *Mathematical model of a sensorless BLDC motor for aerospace actuators.* In Modelling and Simulation MS 2008. Quebec City, Quebec, Canada: 2008, p. 165-169. ISBN: 978-0-88986-741-3.

[3] MATLAB SW producer: http://www.mathworks.com [cit. 2010-02-20]

[4] Sveda M., Oplustil V.: *Experience with integration and certification of COTS based embedded system into advanced avionic system*. In Symposium of Industrial Embedded Systems Proceedings. Lisbon, Portugal. ISBN 1-4244-0840-7.

[5] RTCA/DO-178B: Software Consideration in Airborne Systems and Equipment Certification. RTCA, Inc.: USA, 1992.

[6] RTCA/DO-254: Design Assurance Guidance for Airborne Electronic Hardware. FAA Advisory Circulars, AC No.: 20-152, June 30, 2005.

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Reviewer

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