Implementation of diagnostics functions in the IGBT drivers, part 2. – HW implementation

B. Klima, J. Knobloch, Z. Nouman, M. Pochyla

Abstract – **Diagnostics methods of power inverters are usually based on using measurements of feedback electric quantities. This paper proposes ways of direct diagnostics of power semiconductors parts in its drivers.**

In the first part of the article, there were proposed and described methods of direct power semiconductor's diagnostics for usage in voltage source inverters. Circuits for the diagnosis are assumed in power transistor driver. This paper will focus on hardware requirements, which flows from proposed solution, especially on microcontroller, control units and data collection form IGBT drivers. The description of hardware solutions for measurement of diagnostics quantities is introduced in the first part of the paper.

Index Terms— **Driver control; Drive controller; IGBT driver; Power transistor diagnosis**

I. INTRODUCTION

The electric drives diagnosis has increasing importance during past years. The reasons are increasing requirements on drives reliability and avoiding critical failures by planning of well-timed maintenance. The next requirement is determination of which part of the system draws to a failure or has failed and is necessary to repair or replace.

The electric drive is a system, which can be divided into several parts: driven mechanical system including bearing and gearboxes, electric motor, power inverter, which can be subdivided onto power semiconductor devices, transistor drivers, control circuits, sensors, communication interfaces and software. For each of mentioned parts there are developed diagnostics methods for failure detection or its prediction [2][3][4][5].

Authors gratefully acknowledge financial support from European Regional Development Fund under project No. CZ.1.05/2.1.00/01.0014.

The paper was published with support by the European social fund and the state budget of the Czech Republic in project CZ.1.07/2.3.00/09.0162 Knowledge and Skills in Mechatronics - Innovations Transfer to Practice and of the faculty project FEKT-S-11-14 Utilization of new technologies in the power electronics; of the project MSM 0021630516 Power sources, accumulation, and optimization of the energy utilization; and of the faculty project FEKT-S-10-17 Efficiency Mapping of the electrical AC Drives.

B. Klima is with Department of Power Electrical and Electronic Engineering, Brno university of technology, Technicka 10, 61600, Brno, Czech Republic (e-mail: klima@feec.vutbr.cz).

J. Knobloch is with Department of Power Electrical and Electronic Engineering, Brno university of technology, Technicka 10, 61600, Brno, Czech Republic (e-mail: xknobl00@stud.feec.vutbr.cz).

Z. Nouman is with Department of Power Electrical and Electronic Engineering, Brno university of technology, Technicka 10, 61600, Brno, Czech Republic (e-mail: xnouma00@stud.feec.vutbr.cz).

M. Pochyla is with Department of Power Electrical and Electronic Engineering, Brno university of technology, Technicka 10, 61600, Brno, Czech Republic (e-mail: xpochy00@stud.feec.vutbr.cz).

According to application field requirements (aerospace, railway traction, energetics and automotive applications) there are norms defined. According to the norms, systems are specified, developed and certified for whole life cycle. In many of these fields there are fault tolerant systems or backup systems required to assure high security integrity level (SIL) [1].

This paper focuses into the field of power inverter diagnosis. The implementation of diagnostics methods, advanced protection functions and methods of intelligent control is well known from literature and is used in industrial applications.

If we understand a power transistor driver as a key part, which directly touches the power transistor, it is clear, that only in this place it is possible to watch phenomena, taking place in power transistor. Monitoring and evaluating of these processes allows performing of very comfortable and circumspective control of the transistor and also allows monitoring of technical state of the transistor and course of downgrading its parameters, how has been written in the first part of the paper.

Standard drivers are built according to architecture in Fig. 1. It contains usually an output stage, secondary logic, protection circuits and secondary part of insulated power source on the secondary side (side of power transistor). On the primary side there are primary parts of power source and primary logic. The control PWM signal and power supply are transferred through the insulation barrier to the secondary side and transistor/driver error signal is transferred to the primary side.

Insulation barrier has to have high du/dt immunity, low parasitic capacity and static insulating capability according to the application field of the drive. These barriers are usually realized by using opto-couplers or signal transformers. In literature are mentioned other possibilities of insulation barrier realization, for example wireless control of IGBT drivers [9] etc. [6][7][10][11].

Of course, standard drivers can include other advanced functions. One example is intelligent control of switching-on and switching-off process to minimize transistor's power losses [8].

II. PROPOSED DRIVER ARCHITECTURE

In comparison with standard architecture (fig. 1), an upgrade of driver architecture is necessary for purposes of proposed diagnostics in the driver.). The proposed driver assumes analogue measurements of various quantities on the secondary side, quantitative evaluation of measured data and storage of their long-time courses for monitoring particular

978-1-4244-9303-6/11/$26.00 ©2011 IEEE

power transistor or driver secondary circuits' parameters downgrading.

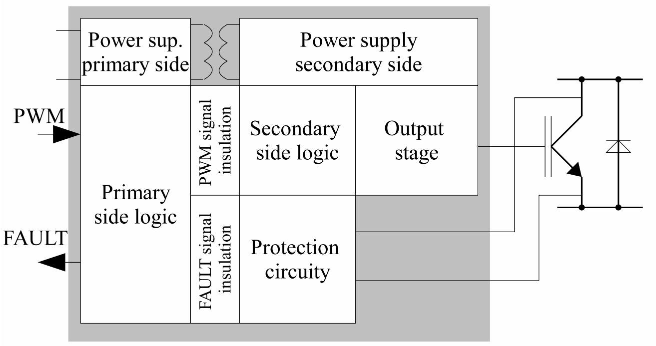

Fig. 1. Standard driver architecture

Possibility of parameters setting in the driver is also assumed. Threshold values of particular protection circuits and limiting values of long-time monitored quantities are mentioned as driver parameters.

Specific requirements for hardware upgrade results from previous. Upgrade of particular detection circuits for sensing of particular quantities is clear. Multichannel ADC converter is necessary for digital processing of the measured data. For these purposes it is also necessary to involve some programmable device (microcontroller or FPGA). RAM and FLASH memory is necessary for measured data storage. The next requirement is data transfer in both directions. Measured data transfer from driver side to inverter controller side and parameter writing in reverse direction is assumed. For these purpose it is necessary to upgrade inverter control

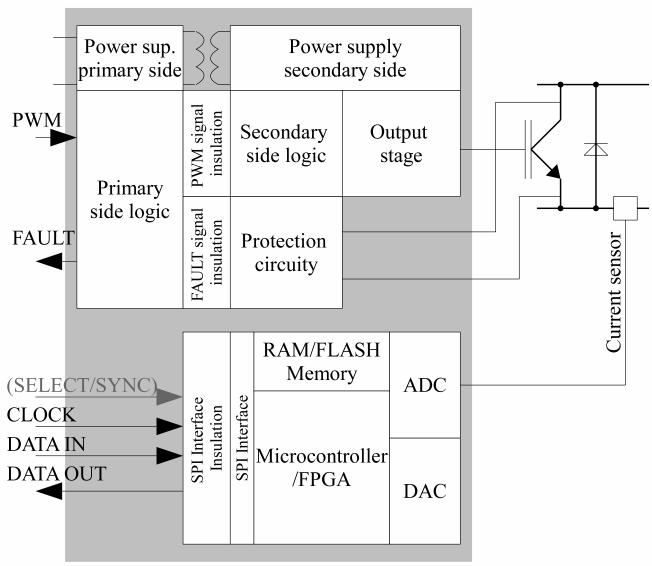

Fig. 2. Driver architecture with implemented diagnostics functions

interface with an insulated data interface (in both directions). In the first part of this work, there is described an option with inverter output current measurement , which can serve as redundant sensors for the primary current sensors failure detection or standard current feedback sensor can be replaced by current measuring in the drivers. Due this feature is necessary to perform periodic data transfer each modulation cycle of the inverter. The current measurement must be synchronized with PWM cycle in similar way as it is written in [13]. On the other hand, monitored quantities which aren't important for drive control and which serves for long-time monitoring of transistor and driver parameters can be transferred in longer intervals.

III. Driver Interface

The data transfer of PWM control signal and back transfer of error signal are assumed by using of separate insulated channels, as is shown in fig. 2. and 3. Separate error signal is not necessary, because error information is transferred also through the data interface. But in the case of requirement for switching-off some other transistors of inverter in the same moment, when an error in certain transistor occured, the separate error signal is necessary.

We can also discuss possibility of parallel operation of IGBT transistors in high current applications. In this case it is usually necessary to use another driver control signal which can perform soft switching-off all of these parallel transistors or all transistors in the inverter from the primary side. For this purpose there is required another individually insulated signal for control of each driver. This signal is not drawn in fig. 2. and 3.

Simultaneous data transfer from all power transistor drivers creates special requirements on inverter controller, especially on count of individual data channels. For each driver it is required one channel.

There are many types of serial communication interfaces, which can be used for purposes of both directional isolated data transfer with sufficient transfer speed. Due to requirements on data transfer synchronization with inverter control process, high communication speed, data transfer reliability and mainly for simplicity of implementation is designed system which uses synchronous peripheral interface (SPI) in present time with both directional transfer capability. At least three insulated signals are required. Serial clock (CLK), data going into the driver (DATAIN) and signal for data read from the driver (DATAOUT). Signal for definition of beginning and the end of data transfer (in figs. 2. and 3. called SELECT/SYNC) is not unavoidable for the data transfer in one master – one slave communication, but if this signal is used, the communication is more reliable and simple. It is also possible to use this signal for timing of variables sampling feedback in the driver, but it will be described in following text.

Insulation barrier is assumed by using of opto-couplers. The reason is simplicity. Physical realization of interface is not important for validating of presented ideas. However some other ways of driver control signals insulation are

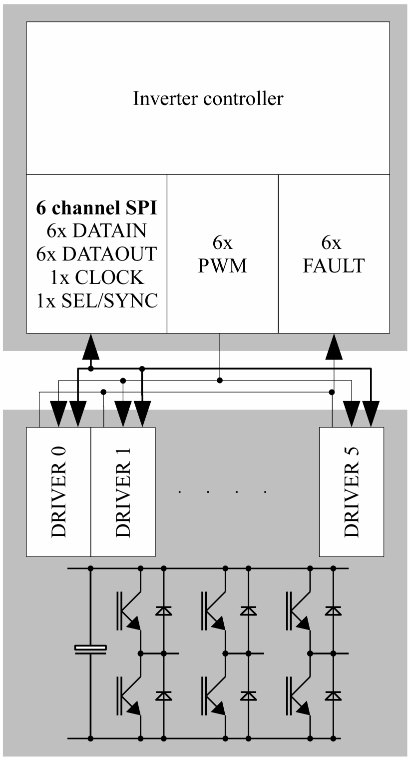

Fig. 3. Interface between inverter controller and IGBT drivers

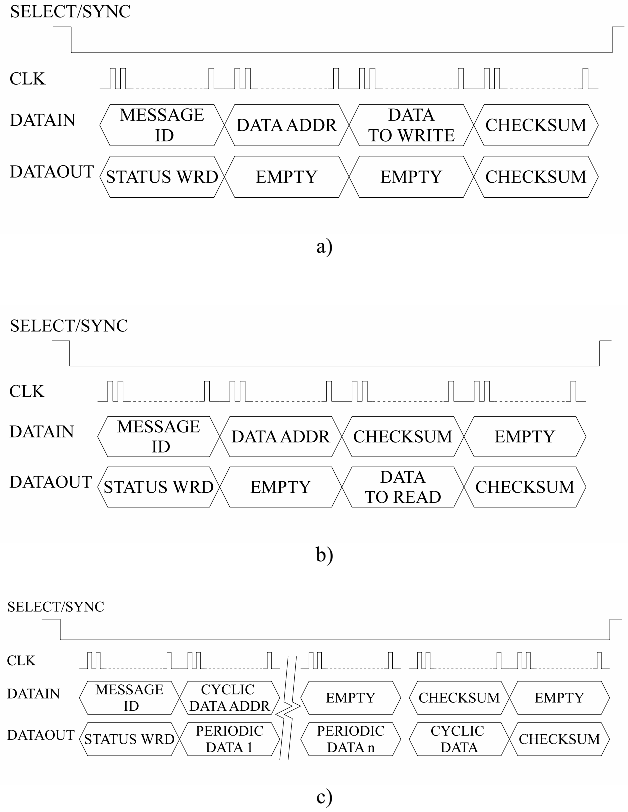

Fig. 4. Proposed SPI data transfer protocol: a) data frame for writing parameter into driver memory, b) data frame back reading of parameter or an individual variable, c) data frame for periodic data exchange between the driver and inverter controller

known. Ferromagnetic signal transformers or planar transformers without ferromagnetic material [10] are commonly used. There were mentioned methods of wireless driver control [9] or capacitive insulation of control signals [11].

The reason for using SPI and its signal here called SELECT/SYNC is mentioned synchronization feedback quantities in relation to modulation cycle period, especially for inverter output currents measured in the driver. Falling edge of SELCT/SYNC signal can be used as a command for sampling of relevant AD converter channel. Inverter controller can use one common signal for simultaneous sampling of all output currents of the inverter, or six of these signals can be used for sampling data in each driver in individual time.

IV. DATA EXCHANGE SPI PROTOCOL

For data exchange between inverter controller and drivers simple communication protocol for SPI is defined. As was said, there are following services required in the data transfer: driver parameters settings and periodic data reading from the driver at each modulation period. Readed data can be divided in two groups: feedback data used for control process (PERIODIC DATA) and data used for long time power transistor and driver secondary side monitoring. These data are called CYCLIC DATA, because they are mixed into periodic data frame. Each periodic message contains one issue of cyclic data addressed by inverter controller. At least two message types are necessary.

The first one is constant writing in to driver FLASH memory. The data frame is shown in fig. 4a. The message, which is sent into the driver, contains data field MESSAGE_ID = WRITE_CONSTANT. The following data field DATA ADDRESS contains address (negotiated index) of written data. The third field contains value of written parameter. Checksum is unavoidable. Driver status (STATUS WORD) is sent back in each type of message. Status word contains status flags of individual protection circuits and limit values overpassing.

The second message type is data exchange – MESSAGE_ID = DATA_EXCHANGE, see fig. 4c.

For periodic data exchange in each modulation period there are fields in outgoing data (PERIODIC_DATA1 to PERIODIC_DATAn) reserved. Only the inverter output current is assumed as periodic data. It means, that the data packet length is only four words including checksum. Incoming data contains address (index) of desired cyclic data, which value is sent back in outgoing data in next word. In this data frame there is the incoming checksum in penult data field. Therefore when incoming checksum is invalid, it is possible to make invalid also outgoing checksum in the last data field of outgoing data frame. Due to this feature the validity result of complete data transfer in inverter controller is immediately known.

For written data validation it is important to have possibility of backward data reading. For this purpose the next message type – parameter/variable reading (MESSAGE_ID = READ_DATA) fig 4b has been designed.

The desired SPI clock frequency for our purposes should be 8 MHz, assuming data transfer (data packet) length 10us, data field length 16 bit. Inverter switching frequency then can be up to 5 kHz.

V. Conclusion

The paper proposes a new architecture of an IGBT driver, which implements diagnostic methods of the power IGBT and also of the secondary circuits of the driver. Described methods uses quantitative evaluation of the measured diagnosis quantities for long-period watching of transistors downgrading parameters during its operation. Data from drivers are transferred into the inverter controller. These data serves for inverter critical failure prediction and for maintenance planning.

For these purposes a modified architecture of the IGBT driver and inverter controller enhanced by a diagnostics circuits at the secondary side of the driver and data interface between the driver and the inverter controller has been defined. The specific requirements need to develop special hardware for the driver and also for inverter controller.

In the present time the hardware for validation of presented ideas is prepared. The driver logic, its other circuits and inverter controller should be implemented in developed boards based on FPGA.

The aim of these papers is a presentation of ideas for direct IGBT diagnostics in the driver, with possibility of quantitative diagnosis for avoiding of critical drive failure and maintenance planning.

References

[1] IEC 61508. Functional safety of electrical/electronic/programmable electronic safety-related systems. 2002.

[2] Casadei, D.; Filippetti, F.; Rossi, C.; Stefani, A.; , "Closed loop bandwidth impact on doubly fed induction machine asymmetries detection based on rotor voltage signature analysis," Universities Power Engineering Conference, 2008. UPEC 2008. 43rd International , vol., no., pp.1-5, 1-4 Sept. 2008

[3] Cruz, S.M.A.; Stefani, A.; Filippetti, F.; Cardoso, A.J.M.; , "A New Model-Based Technique for the Diagnosis of Rotor Faults in RFOC Induction Motor Drives," Industrial Electronics, IEEE Transactions on , vol.55, no.12, pp.4218-4228, Dec. 2008

[4] Ondel, O.; Blanco, E.; Clerc, G.; , "Beyond the diagnosis: the forecast of state system Application in an induction machine," Diagnostics for Electric Machines, Power Electronics and Drives, 2007. SDEMPED 2007. IEEE International Symposium on , vol., no., pp.491-496, 6-8 Sept. 2007

[5] Onel, I.Y.; Benbouzid, M.E.H.; , "Induction Motors Bearing Failures Detection and Diagnosis: Park and Concordia Transform Approaches Comparative Study," Electric Machines & Drives Conference, 2007. IEMDC '07. IEEE International , vol.2, no., pp.1073-1078, 3-5 May 2007

[6] Herzer, R.; Pawel, S.; Lehmann, J.; , "IGBT driver chipset for high power applications," *Power Semiconductor Devices and ICs, 2002. Proceedings of the 14th International Symposium on* , vol., no., pp. 161- 164, 2002

[7] Dulau, L.; Pontarollo, S.; Boimond, A.; Garnier, J.-F.; Giraudo, N.; Terrasse, O.; , "A new gate driver integrated circuit for IGBT devices with advanced protections," *Power Electronics, IEEE Transactions on* , vol.21, no.1, pp. 38- 44, Jan. 2006

[8] Hemmer, R.; , "Intelligent IGBT drivers with exceptional driving and protection features," *Power Electronics and Applications, 2009. EPE '09. 13th European Conference on* , vol., no., pp.1-4, 8-10 Sept. 2009

[9] Batard, C.; Andrieux, G.; Ginot, N.; Mannah, M.A.; , "Wireless Transmission of IGBT Driver Control," *Applied Power Electronics Conference and Exposition, 2009. APEC 2009. Twenty-Fourth Annual IEEE* , vol., no., pp.1257-1262, 15-19 Feb. 2009

[10] Schmitt, G.; Kusserow, W.; Kennel, R.; , "Power supply for a IGBT-driver with high insulation voltage based on a printed planar transformers," *Power Electronics and Motion Control Conference, 2008. EPE-PEMC 2008. 13th* , vol., no., pp.1239-1242, 1-3 Sept. 2008

[11] Zeltner, Stefan; , "Insulating IGBT driver with PCB integrated capacitive coupling elements," *Integrated Power Electronics Systems (CIPS), 2010 6th International Conference on* , vol., no., pp.1-6, 16-18 March 2010

[12] Klima, B.; Knobloch, J.; Pochyla, M.; , "Intelligent IGBT driver concept for three-phase electric drive diagnostics," Design and Diagnostics of Electronic Circuits and Systems (DDECS), 2010 IEEE 13th International Symposium on , vol., no., pp.217-220, 14-16 April 2010. ISBN 978-1-4244-6612-2

Web pages:

[13] Freescale Inc. [online]. 2011 [cit. 2011-03-19]. Synchronizing the On-Chip Analog-to-Digital Converter on 56F80x Devices". Available from WWW: <http://cache.freescale.com/files/product/doc/AN1933.pdf?fsrch=1&sr=1>.

Biographies

Bohumil Klima was born in Velke Mezirici in Czech Republic, in year 1972. He graduated from Brno University of Technology in year 1996. Ph.D. degree he obtained in year 2002.
His special field of interest is mechatronic systems, AC drives digital control, independent traction in automotive field and electric drives diagnosis

Jan Knobloch was born in Brno in the Czech Republic in 1985. In 2009 Obtained the Master Degree programme at Brno University of Technology. At present time he is Ph.D. student at the same university. His field is electrical drives diagnostics.

Ziad Nouman was born in Siria inyear 1979. He graduated in Siria 2006. At present time he is Ph.D. student on Brno University of Technology. His field of interest is industrial automation and FPGA aplications.

Martin Pochyla was born in Martin in the Slovakia in 1985. In 2009 Obtained the Master Degree programme at Brno University of Technology. At present time he is Ph.D. student at the same university. His field is electric drive identification.