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A MODULAR OPTICAL FIRING INTERFACE FOR CERN'S GENERIC POWER CONVERTER CONTROL PLATFORM

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Abstract

The power converters group at CERN has developed a third generic converter controller (FGC3) and regulation platform (RegFGC3), capable of controlling any of CERN's power converters. This platform provides electrical connections to the low-level control elements of power converters, and in some cases a galvanic isolation is required between the converter controller output, and the power converter under control. To meet these requirements, a companion optical firing platform has been developed, which converts the electrical firing pulses from the RegFGC3 and FGC3 platforms into optical drive signals. This platform provides various protection mechanisms to verify the integrity of the firing information. For example, checking for illegal firing states, dead-time, and drive errors. In order to provide a more scalable and generic solution to cover various user requirements, this platform has been subsequently upgraded to a modular system. This paper describes the first version of the proposed solution, the Optical Firing Interface and then it focuses on its scalable and modular version, the Modular Optical Firing Interface. Basic principles, design and configurations in use are described.

INTRODUCTION

Nowadays, isolated gate drivers are widely used across many industries such as automotive, telecommunication and power distribution [1] [2]. Physical and electrical isolation is required for various reasons. Protection from high voltages surges and common voltages differences are classical examples of risks leading to isolation requirements. In industrial applications, control electronics usually stands at a significant lower voltage than the power electronics. Therefore, low-voltage electronics needs to be isolated from hazardous voltages in order to protect the equipment as well as the operating personnel. Noise rejection and EMI reduction are other classical isolation needs in noisy environments such as factories and power plants.

Isolation can be achieved mainly through three different means: inductive, capacitive and optical. At high voltages (>1200V) optical insulation offers several advantages when compared to inductive and capacitive such as very high EMI immunity and very good insulation can be achieved. Many commercial-of-the-shelf optically isolated gate drivers are available today in the market. In addition to gate driving, fibre optical transmission is also used to transfer faults and statuses from the power converter to the controller. Following this trend in the industry, some of the new power converter topologies being developed at CERN require optical isolation for monitoring and control. POPSB, the converter used to power the Proton Synchrotron Booster machine magnets, is one example of application requiring optical firing. Figure 1 shows the isolated IGBT driver currently used in the POPSB.

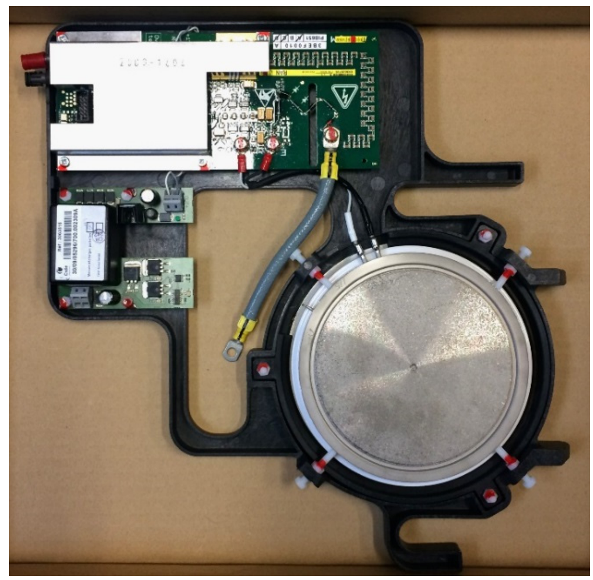

Figure 1 : View of an isolated IGBT module.

THE REGFGC3 OPTICAL FIRING INTERFACE

The RegFGC3 is the result of a joint development effort for a robust, reliable and generic cross-platform control system for power converter control at CERN [3]. Using a scalable and flexible approach, different boards have been designed to cover specific control functionalities such as analogue protection, regulation and signal acquisition. The interface with the high power switching components consists of a variable number of electrical signals (0-15Volts), while commands and statuses are exchanged using dry contacts and relays. The first RegFGC3 based converter requiring optical firing was the POPSB system [4]. This converter is based on a four quadrant “H-Bridge” topology consisting of three parallel legs sharing the current. Each leg consists of a stack of four IGBTs (Figure 2) for a total of 12 switching components. Every IGBT driver interface consists of a control signal (the firing pulse) and a status signal. The firing pulse is a simple ON/OFF signal issued by the control system firing board while the feedback signal is a flag released by the IGBT driver module to acknowledge the conduction. Different protection mechanisms are required to prevent the control system from sending illegal conduction states to the IGBTs.

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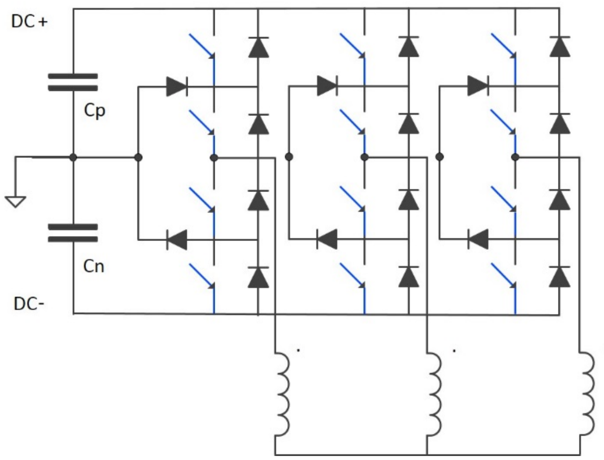

Figure 2 - View of the POPSB converter.

To meet these requirements ensuring flexibility a specific FPGA-based Optical Firing Interface (OFI) was designed. As shown in Figure 3**Error! Reference source not found.**, the OFI is installed between the RegFGC3 control system and the power converter. The electrical interface with the control system is made of two standard connectors (SKPULSE), each one consisting of six electrical firing pulses generated by the control firing board, three statuses and one command. The statutes are used by the OFI to notify the control system about the faulty conditions explained later in the paragraph. The command could be used as additional signal for crowbar activation. The optical interface with the power converter consists of 24 ST (bayonet type) optic connectors (12 transmitters and 12 receivers), a connection pair for possible crowbar activation and two additional optical connectors to allow the daisy chaining multiple OFIs in order to propagate a local fault.

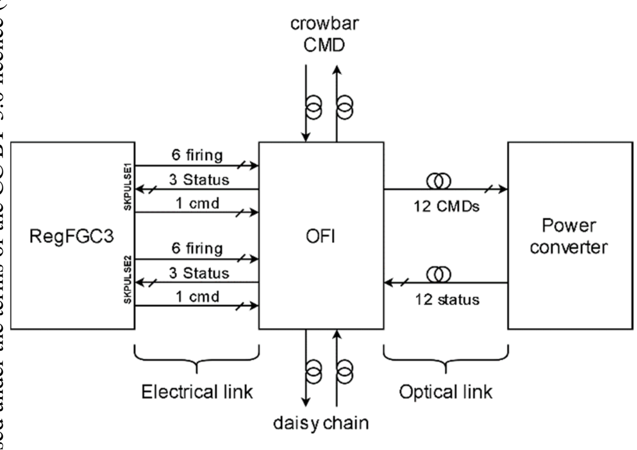

Figure 3 : System layout.

Figure 4 shows the simplified block diagram of the program. The OFI can work in two modes: complementary signal generation and normal mode. The mode can be selected using the "*Mode*" configuration parameter. In complementary signal generation mode, only 6 of the 12 firing pulses from the control system are used (upper or bottom leg IGBTs) and the OFI generates the six complementary signals with a settable dead time to prevent short circuits on the H-bridge. In normal signal generation mode, the 12 firing pulses from the control system are directly used to control the 12 IGBTs of the H-bridge.

The resulting firing signals go through a safety chain consisting of multiple verification stages to ensure that no illegal conditions are sent to the switching components.. In the first stage, the *IGBT ON Time Check*, the length of the IGBT firing pulse is checked. If the minimum ON time is not respected, the corresponding pulse time is extended to match it and if this check fails multiple times within a defined time window a fault is asserted. In the second stage, the *Leg State Check*, the resulting firing signals from the first stage are checked to verify that no illegal state are sent to the legs (e.g. short circuit of a leg). If a forbidden state occur, the signal is blocked and a fault is asserted. The following block, *Soft stop*, is the last interface before the signals are sent to the drivers. Depending on the origin of the fault a soft stop sequence can be executed. The soft stop sequence will play an IGBT sequence to remove the energy from the power converter. The last check mechanism, *Driving Check*, ensures that the IGBT conduction happened as expected. For this, the block receives the IGBT status from the 12 receivers and if it does get the status within a fixed period of time a conduction fault is asserted.

The OFI implements a post mortem log consisting of a RAM memory used as a circular buffer. The firing signals are continuously saved in the RAM at a configurable period. When a fault occurs, the power converter starts the stop procedure and holds the logging data. The user can download the memory content through a USB port located on the front panel (see Figure 5). The LEDs on the front panel indicate which IGBT generated the fault.

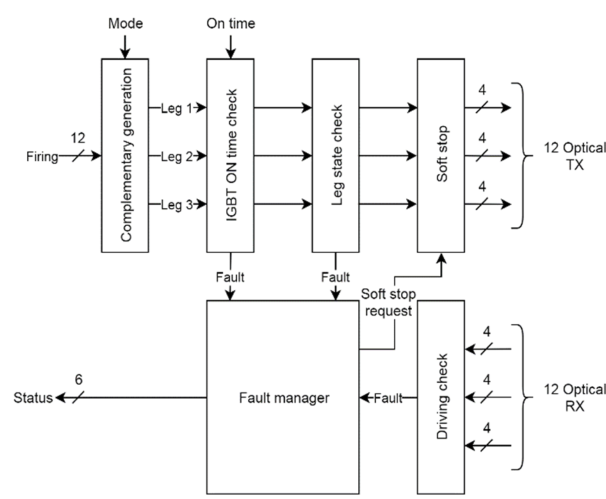

Figure 4 : OFI program diagram.

Figure 5 shows the mechanical view of the OFI consisting of a standard 3U crate. The optical connectors, USB debug interface and the status LEDs are located on the front panel while the connectors with the control system are on

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the rear panel. To give more flexibility, the optical receivers are mounted on two mezzanines that can be replaced in case a different optical connector standard is required.

Figure 5 : View of the OFI front panel.

THE MODULAR OPTICAL FIRING INTERFACE

Although the Optical Firing Interface has been successfully deployed in the target system, the introduction of new power converter topologies requiring optical isolation showed the interest of developing a more generic and scalable solution. The application requirements significantly differ not only by driving complexity but also by number of fibre links as well as fibre connector topologies. In order to cover all user-cases and to provide a modular and scalable solution, a new interface called Modular Optical Firing Interface (MOFI) was developed.

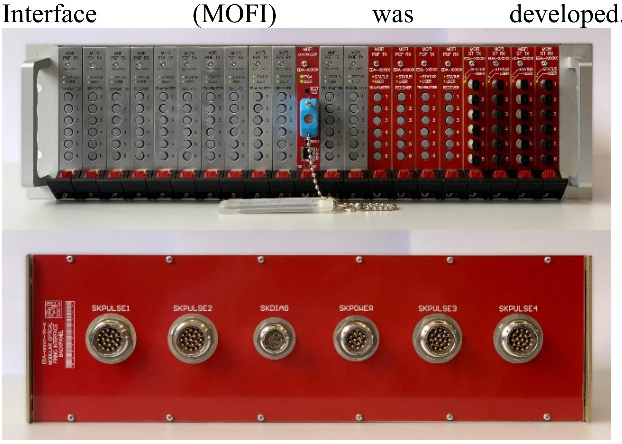

Figure 6 shows the proposed system consisting of a 3U, 19' electronic crate hosting a main controller board and a variable number of receiver and transmitter boards. A complete system can host up to 20 boards providing a maximum of 120 optical signals. Similarly to the OFI, the MOFI crate is connected to the RegFGC3 through four SKPULSE connectors located on the rear panel. Every connector provides six firing pulses, three statuses and one extra command signal. The SKDIAG connector is used to connect the MOFI to the control system diagnostic bus. The SKPOWER Burndy connector provides power to the MOFI crate.

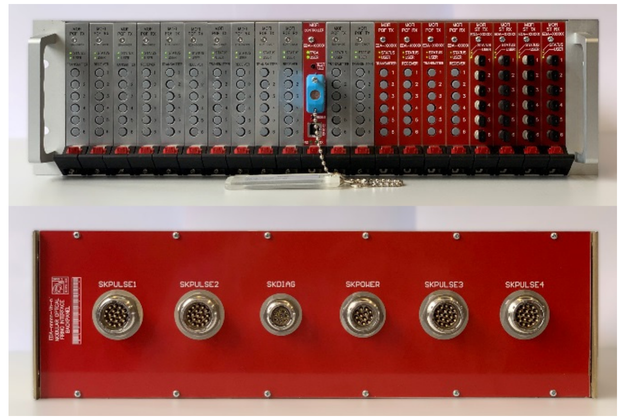

Figure 6 : Front and rear view of MOFI crate.

MOFI Controller

The MOFI controller is the main component of the system acting as the interface between the control system and the optical cards. Before being processed by the logic, the firing pulses from the control system are first scaled to adapt them to the FPGA voltage levels. The resulting optical signals are sent to the cards through six independent backplane lines. The MOFI controller communicates with all the optical cards through four I2C buss which allows the detection of the type of cards installed. By reading all the I2C slaves, the MOFI controller knows the position and the type of the cards installed in the crate. The front panel has two RGB LEDs, one gives the status of the FPGA (programming, boot, running and fault) and the second one is controlled by the user application. The front panel has a dongle port which is used to select the user application that will be executed. A reset switch is used to resets the FPGA and all the optical cards. An USB port on the front panel provides debug information.

As shown in Figure 7, the MOFI program is divided in two parts. A generic program, common to any application, makes the interface between the user application and the hardware. It synchronises all the external signals, selects the user application based on the front panel dongle and reads the TX and RX cards. The user application program is specific for each application and describes the behaviour of the corresponding application.

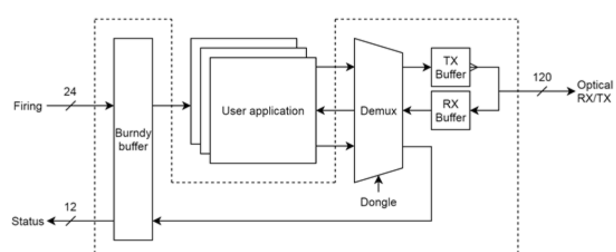

Figure 7 - MOFI Program diagram.

At start up the MOFI enters a starting sequence reading the dongle plugged on the front panel to find which user application will be executed. Then the MOFI controller

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communicates with all the optical cards to detect the composition of the crate and compares it with the composition expected by the user application. If they match, it starts executing the user application. While the MOFI controller is executing the user application, the MOFI controller keeps scanning all the optical cards as well as the dongle to detect if the configuration has changed.

Optical Boards

The optical boards make the interface between the electrical and the optical domains. Each card has six optical transceivers and they are grouped in two types: Receivers (RX) and Transmitters (TX). For each given type, two different optical transceivers are provided, ST (bayonet type) and POF (Plastic Optical Fiber). The optical cards have two RGB LEDs on the front panel. The STATUS led indicates if the correct card is plugged in the slot. The USER led is used by the running user application. An I2C slave chip allows to read the type, slot number and give control of the 2 LEDs.

CONCLUSIONS

One of the missions of the CERN Electrical Power Converter group is the standardization of the control equipment across the different converter families and accelerator facilities. This results in decreased maintenance effort and increased machine availability. Following the same approach, a generic modular firing interface has been developed to cover the isolation requirements of new converter topologies.

ACKNOWLEDGMENTS

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