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USE OF MULTI-NETWORK FIELDBUS FOR INTEGRATION OF LOW-LEVEL INTELLIGENT CONTROLLER WITHIN CONTROL ARCHITECTURE OF FAST PULSED SYSTEM AT CERN

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Abstract

Fieldbuses and Industrial Ethernet networks are extensively used for the control of fast-pulsed magnets at CERN. With the ongoing trend to develop increasingly more complex low-level intelligent controllers near to the actuators and sensors, the flexibility to integrate these within different control architectures grows in importance. In order to reduce development efforts and keep the fieldbus choice open, a multi-network fieldbus technology has been selected for the network-interfacing part of the controllers. Such an approach has been successfully implemented for several projects including the development of high voltage capacitor chargers/dischargers, the surveillance of floating solid-state switches and the monitoring of a power triggering system that, today, are interfaced either to Profibus-DP or Profinet networks. The integration of various fieldbus interfaces within the controller and the required embedded software/gateware to manage the network communication are presented. The gain in flexibility, modularity and openness obtained through this approach is also reviewed.

INTRODUCTION

In the late 1980s, the PLC-based automation systems became increasingly popular in the manufacturing industries aiming to improve their productivity. The need to reduce costs and downtime while ensuring a high level of flexibility has led to the search for innovative decentralized solutions. Some automation manufacturers decided to join their efforts on a fieldbus project to find out a homogeneous common solution. The Profibus standard was born. Today, the PI Organisation (Profibus and Profinet International) counts over 1400 member companies worldwide [1]. Subsequently, a protocol based on Ethernet, Profinet, was designed with a first version available from 2001 onward [2]. Meanwhile, the ongoing trend to develop increasingly more complex low-level intelligent controllers near to the actuators and sensors and the flexibility to integrate these within different control architectures has grown in importance. The integration of fieldbuses into the actuators and sensors themselves proves this, reducing development efforts, as well as cabling costs.

CONTEXT

The CERN Accelerator Beam Transfer group (TE-ABT) is responsible for beam injection, extraction and dump systems for the whole CERN accelerator complex. TE-ABT has based its slow-control architecture on fieldbuses during the last two decades using off-the-shelf PLC components from Siemens. As a choice of fieldbuses, TE-ABT has focused its developments on Profibus-DP and Profinet networks. However, other fieldbuses may be used in the future and a multi-network fieldbus technology is currently envisaged as the best solution. A few commercial companies offers such multi-network device modules to integrate within custom hardware: Hilscher, HMS Industrial Networks, Kunbus are examples. TE-ABT has decided to integrate Anybus products from HMS Industrial Networks in its hardware.

MOTIVATION

As a need to decrease costs in cabling and get rid of PLC-based deported I/O controls which are greedy in terms of space, complex and challenging to modify or add functionalities, TE-ABT has embedded Profibus-DP interface modules in its hardware. One major concern about using commercial off-the-shelve fieldbus modules is their lifetime. As an example, the old Power Trigger Controller card (described below) that has been developed fifteen years ago was integrating an earlier Profibus-DP module from HMS Industrial Networks. This module is now obsolete and it has been necessary to replace it by the CompactCom M40 module in the new version of the card. Thus, the old Profibus-DP modules will be thrown away because no compatible Profinet modules can be ordered in such quantities (only spares in low quantities can still be ordered).

The new modules offer more flexibility than HMS's previous version (no need to redesign the front panel and replacing the module is easier). However, their expected lifetime won't be more than twenty years. The same problem of obsolescence is found with FPGA devices or other sensible components anyway, forcing designers to redevelop a complete PCB.

As Profibus in existing TE-ABT slow control architectures is being replaced by Ethernet-based fieldbuses during the next few years, HMS CompactCom M40 have been selected to move from one to the other without having to redesign and re-validate the hardware. For new projects, only Ethernet-based fieldbuses are being used.

INTEGRATION EXAMPLES

Capacitor Charger/Discharger HV Power Supply

As a first example, a Profinet module has been integrated into in-house development of a capacitor charger/discharger high voltage power supply (CCD HVPS, see Fig. 2) for the renovation of the Proton Synchrotron Booster (PSB) injection transverse painting bumpers (KSW) [3, 4]. To power the four magnets of each of the four rings of the PSB

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KSW, 80 (16 × 120V + 64 × 1200V) of such high voltage power supplies are needed. The KSW control is based on PXI controllers with real-time software and FPGA logic.

To communicate with the power supplies, instead of adding complexity to the PXI controller or an additional set of deported I/O to generate analog references and readbacks, it was decided to integrate Profinet modules within the CCD HVPS and a Kunbus interface (see Fig. 1) in the PXI controller, allowing a significant cabling and infrastructure costs reduction.

Figure 1: PXI/Profinet interface module from Kunbus Industrial Communication.

Each Kunbus Profinet interface controls 18 independent power supplies via an Ethernet layer 2 switch. The integrated Profinet modules allow full control of the power supplies as HV ON/OFF, applying voltage and current references, voltage and current readback, enabling/disabling the feedback regulation, etc. Adding new functionalities or new data to the fieldbus is feasible without touching the hardware or the cabling.

The Profinet modules integrated in these power supplies are Anybus-IC modules from HMS. The modules are Profinet-based, but can easily, but only, be replaced by another Ethernet-based fieldbus (EtherNet/IP or DeviceNet), as the RJ45 connector is mounted on the PCB itself. In its simplest implementation, which is enough for this application data throughput, the Anybus-IC modules don't need an embedded processor to communicate with the host. A synchronous serial interface similar to the Motorola SPI is implemented in the controller FPGA for input and output registers (shift registers), as well as for status and addressing of the module. Thus, the FPGA is exclusively dedicated to the power supply regulation. However, this basic implementation of the Anybus-IC module doesn't offer full functionalities. Another asynchronous serial interface, which has been connected to the FPGA in case of future needs, can be used for configuration and data exchange. In this case, a soft microcontroller would be integrated in the FPGA for initialization and communication with the Anybus module. A supplementary RS-232 text-based monitoring interface may be used for debugging and is also connected to the FPGA.

Figure 2: CCD HVPS with integrated PROFINET interface.

GTO Stack Surveillance System

Another application where the same Profinet fieldbus modules have been integrated is a GTO Stack Surveillance system. This system measures, using floating and self-powered voltage-controlled oscillators (VCOs), the anode-cathode voltage of each Gate Turn-On (GTO) in a stacked solid-state based high voltage switch. All the VCOs are connected via optical fiber to FPGA-based receiver cards (GSSR card, see Fig. 3), connected to a slow control PLC via hard-wired interlock and warning signals for safety, and via a Profinet interface to get statuses of each receiver card and the frequency of each of the VCOs.

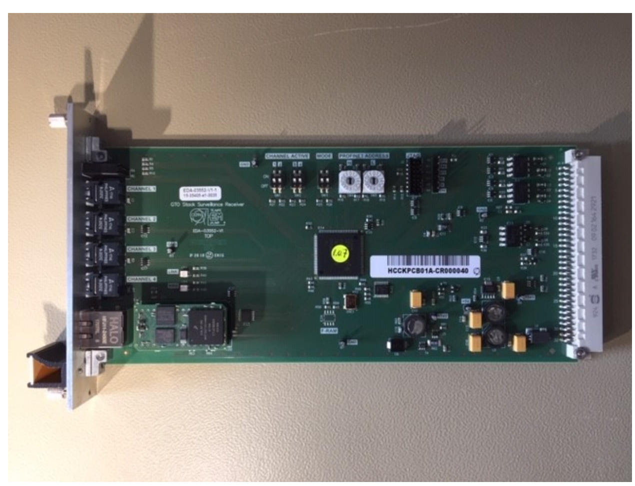

Figure 3: GTO Stack Surveillance Receiver card.

This system is based on the same Anybus-IC Profinet module as in the previously discussed project. A change

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to another Ethernet filedbus being very unlikely, the RJ45 connector has also been put directly on the PCB.

The GSSR cards can survey up to four stacked GTOs. For a higher number of stacked GTOs, these cards can be put in parallel for stacks up to any size.

Power Trigger Controller

The newest modules from HMS, the CompactCom M40, have been integrated in a Power Trigger Controller (PTC, see Fig. 4) card for the post-mortem analysis of LHC's Beam Dumping System (LBDS) kicker generator signals. It analyses a variety of digital and analogue signals after each pulse to ensure the pulsed Power Trigger Modules have correctly functioned, and then communicates the results to the PLC-based slow-control. The CompactCom M40 has been chosen because of its extensive flexibility. These modules are fitted from the front panel of the cards via a CompactFlash type connector. However, it is not compatible with CompactFlash bus standard, as this module offers a wide variety of communication interfaces (parallel 8 or 16 bits, SPI, synchronous serial interface shift registers). The PTC is an FPGA-based card with an ARM Cortex-M3 softcore integrated to communicate with the Anybus module via a parallel 16 bits bus. The ARM softcore initializes the CompactCom M40 modules and sets some network-specific parameters, according to the module detected and initiates the data transactions.

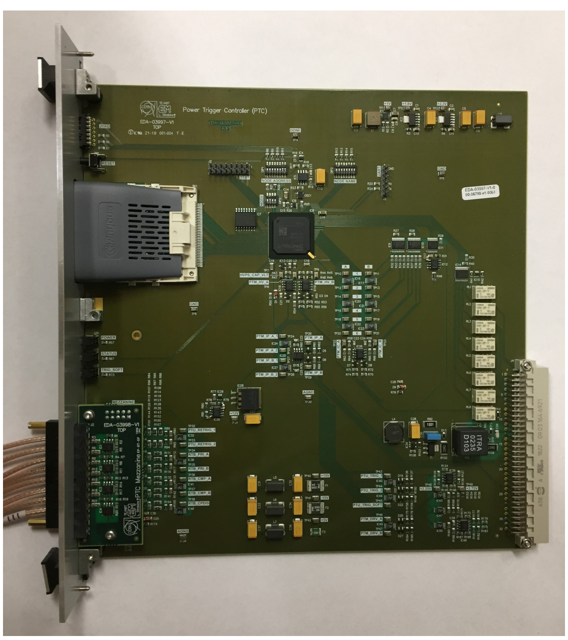

Figure 4: Power Trigger Controller card with CompactCom M40 module.

The PTC card is being renovated to add functionalities during CERN long shutdown in 2019-2020. The LBDS fieldbus network is currently based on Profibus-DP. In 2023, during the CERN third long shutdown, the LBDS slow control will move to Profinet. As to not invest time and money in redesigning the PTC card, only the CompactCom M40 modules will have to be replaced by Profinet ones. The advantage of the CompactCom modules is that the PTC cards won't need to be dismounted ; the modules can be replaced directly from the front panel.

CONCLUSION

The above example projects show that the use of fieldbus embedded hardware for the control of fast-pulsed magnets at CERN is increasing with the ongoing trend to develop more complex low-level intelligent controllers located closer to the actuators and sensors. CERN Accelerator Beam Transfer group will continue to integrate these modules in its control architectures in the future. The gain of flexibility integrating fieldbus embedded hardware within control architectures is extremely high, as well as the gain in the deployed infrastructure. In the past, TE-ABT was using dedicated PLC modules to communicate with low level actuators and sensors garnering a huge cost for producing interface crates in between the actuators/sensors and the slow control. Adding a feature or diagnostics was increasing the price even more.

In term of flexibility, modifying the fieldbus frame for adding or removing data is fairly easy to achieve. In terms of infrastructure, integrating Ethernet fieldbus modules saves space and a high cost of cabling using Ethernet layer 2 switches and standard connectors/cables. If the actuators or sensors are far away from the slow control system, adding one or more modules can easily be done. Moreover, the CompactCom M40 Profinet modules have an internal switch allowing to easily add modules on the bus.

One drawback of fieldbus-based system may be the poor bandwidth. However, for the applications described above, this is not a limitation. Moreover, Ethernet-based fieldbuses offer much larger bandwidth than Profibus.

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