Extension of the high current power supplies of ASDEX Upgrade The design of a new thyristor converter

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A number of 17 high current thyristor converters with an installed pulsed power of about 600 MVA feed the complex system of copper magnet coils, which induce the plasma current and provide positioning, shaping and ohmic heating of the plasma.

At the moment currents of up to ± 45 kA and voltage levels of up to ± 3 kV are possible for max. 10 seconds. But no currently available converter can reach all these parameters at the same time. To achieve this goal a new thyristor converter group, called "Group 7", to work in conjunction with the actual "Group 6", is planned.

This paper describes the design of the converter. Since the design of the power section will be in most parts a copy of the already existing converter "Group 6", the focus in this paper will be on the control system. A completely new design using a fully digital control system will be implemented. This paper also introduces the new FAST communication protocol and its aimed features and performance used for the control system.

Keywords: ASDEX Upgrade, thyristor converter, high current, phase-to-neutral voltage control, digital control system, FAST protocol

1. Introduction

The power supply of the coils of ASDEX Upgrade (AUG) consists of 17 high current converters [1]. Due to the successful program of AUG these converters come to their limits. At the same time the risk of failure increases because of ageing. At the moment all converters are in use and thus the area of operations is fixed. A failure of one converter can compromise the operation of AUG. Low power, high density discharges of AUG, which are used for studies of the core transport produced by turbulences and divertor detachment studies, are limited by the OH transformer flux. In order to increase the operational availability of AUG and to expand the possible operation scenarios a new thyristor converter group, called "Group 7", is planned [2].

2. (Re-) Design of the power stage

The design of the power section is in most parts a copy of the thyristor converter Group 6.

The converter consists of 2 identical units. Each unit contains 2 modules, resulting in a total of four identical modules [3]. The layout is given in Fig. 1.

The nominal pulsed rating is 4 x 22.5 kA @ 1.5 kV for 10 s, repeated every 5 min.

The converter has a very modular design and can be used in many different configurations (see Table 1). These different configurations can be realized by using the DC-switches, shown in Fig. 1.

To reach the full necessary power to supply the OH circuit of AUG (± 45 kA @ ± 3 kV) Group 7 has to be connected in series with the already existing converter Group 6. The units of the converters must be in anti-parallel-configuration and the modules in parallel-configuration (PX). For this series connection a DC-switch between the minus-pole of Group 6 and the plus-pole of Group 7 is necessary.

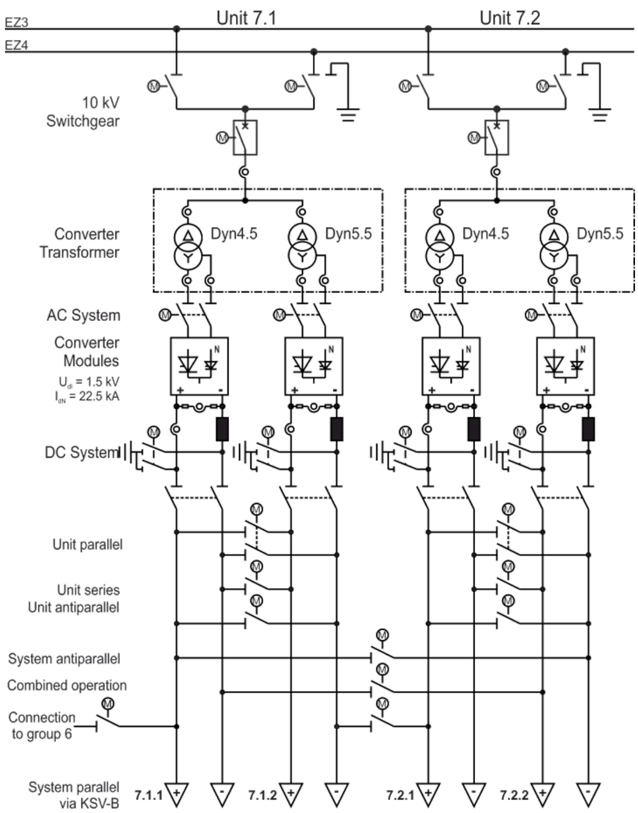

Fig. 1: Converter Layout

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Table 1: Converter configurations

Unit Configuration				
Single module (E1, E2)	6-pulse	2-quadrant	+ 22.5 kA	± 1.5 kV
Parallel (P)	12-pulse	2-quadrant	+ 45 kA	± 1.5 kV
Series (R)	12-pulse	2-quadrant	+ 22.5 kA	± 3.0 kV
Anti-Parallel (X)	6-pulse	4-quadrant	± 22.5 kA	± 1.5 kV
System Configuration				
Units parallel / system parallel (PP)	12-pulse	2-quadrant	+ 90.0 kA	± 1.5 kV
Units series / system parallel (RP)	12-pulse	2-quadrant	+ 45.0 kA	± 3.0 kV
Units parallel / system anti-parallel (PX)	12-pulse	4-quadrant	± 45.0 kA	± 1.5 kV
Units series / system anti-parallel (RX)	12-pulse	4-quadrant	± 22.5 kA	± 3.0 kV
Combined Configuration				
Units parallel / system anti-parallel / Groups 6 and 7 series (PXR)	12-pulse	4-quadrant	± 45.0 kA	± 3.0 kV

The new converter includes the so called “phase-to-neutral voltage control” with an arrangement of thyristors between the star-point of the transformer and the plus- and minus-poles of the DC-output. This allows a substantial reduction of the reactive power demand under partial-load operation. More details on the “phase-to-neutral voltage control” can also be found in [4]. Tests on Group 6 had shown, that a reactive power reduction of up to almost 40%, depending on the load current, is possible with this concept.

The design of the power part is described in detail in [3]. Since Group 6 is nearly 20 years old, the obsolescence of components is a major issue for the design of the power part of Group 7 and needs to be taken into account.

3. Control System

The control system of this converter is a completely new design. While Group 6 uses a mostly analog control system, Group 7 will get a fully digital control system, which will increase the reliability and simplify the design using more standard components.

The control system for one unit consists of two controllers, one for each module (Layout see Fig. 2). These controllers are placed in the LCCs (Local Control Cubicles). There could be up to 8 fiber optical links per controller to extension boards or other controllers. The extension boards have 8 analog and 16 digital inputs and could be extended by piggyback boards with analog or digital outputs and also with firing-pulse-amplifiers.

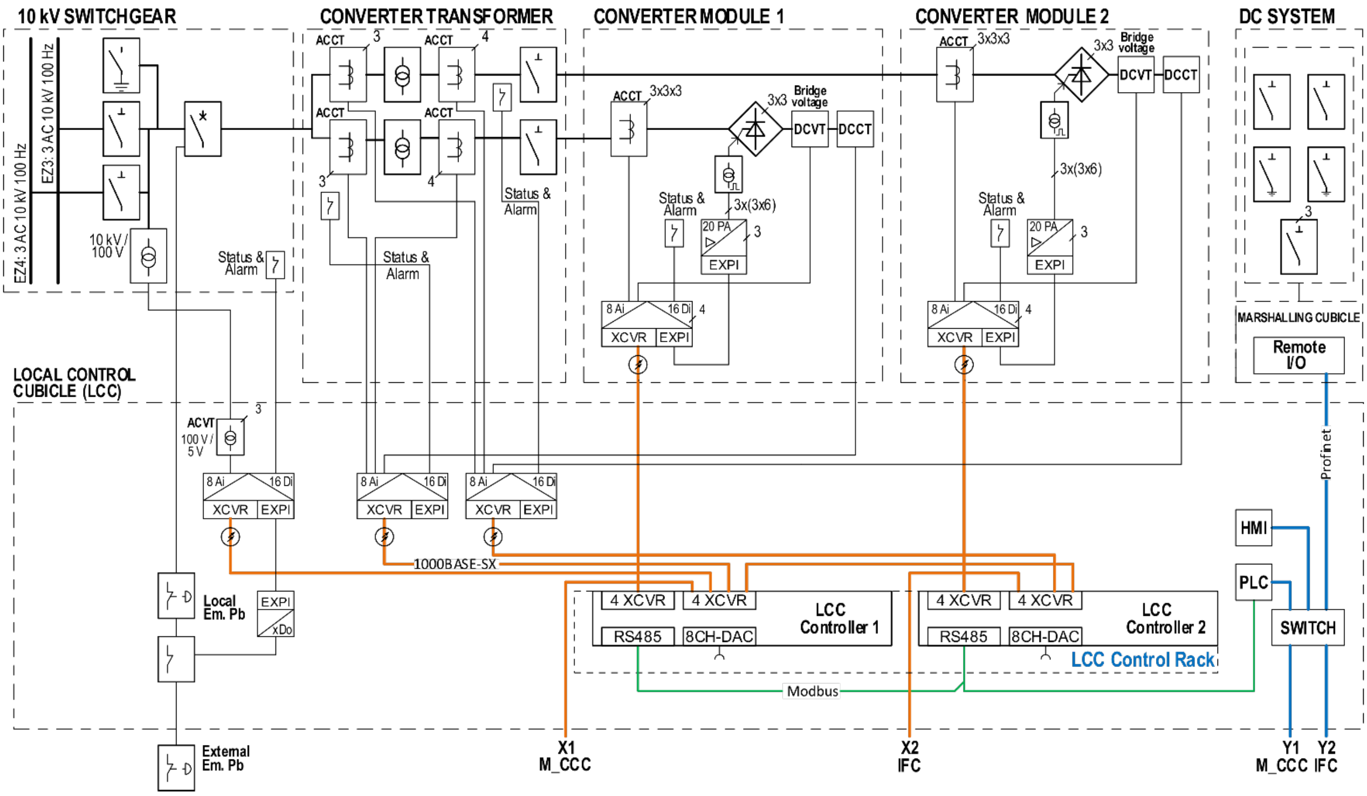

Fig. 2: Control system of one unit

The analog inputs are mainly used for acquisition of measuring signals, like current and voltage measurements. The digital inputs are used for status and alarm signals. The analog outputs are only used for providing measurements to external data acquisition systems. The digital outputs are especially used for safety signals. The main-controllers and also the extension boards are based on FPGAs.

The structure shown in Fig. 2 is the same for both units. There is also a primary control system, which is placed in the M_CCC (Master / Central Control Cubicle). This control system operates the converter in a system configuration, where both units have to work together (see system configurations in Table 1). The primary control system provides also the connection to Group 6 to operate both converters together (see combined configuration in Table 1). The interface to the AUG main control system for all configurations (unit, system and combined) is done by the IFC (Interface Cubicle).

The major challenges for this complex digital control system are to realize a data-connection with high enough throughput between all members of the control system and to strictly synchronize them.

The decentralized system reduces the amount of cabling and results in a more reliable and clearly structured system.

Using fiber-optical links brings some benefits such as avoidance of interference injection into the signal lines and also galvanic isolation, which is important for the power part.

The decentralized control system for Group 7 requires a fast synchronized timing for all data between the several components. This is necessary to ensure that the digital control system can operate safely and reliably to meet the requirements. For the processing of analog signals, dedicated ADC (analog-to-digital converter)-boards are used which are equipped with 14-bit ADCs and a fast throughput rate of 3 MSPS. All the signals are transferred to the main controllers via optical fiber connections (orange lines in Fig. 2). The fiber-optical connection is capable of high data rates. The data throughput of one fiber will be 1 Gbps.

The communication platform is based on Ethernet hardware to achieve high throughput. But only a high data rate is not sufficient. The thyristor pulse generation, control loops and other signal processing require real-time measurement data. The standard 1 Gbps Ethernet cannot provide the required real-time properties while maintaining high throughput. Ampulz designed for this purpose the FAST (Fast Ampulz Serial Transmission) protocol, which includes a custom link layer (OSI layer 2) on top of the IEEE802.3 Ethernet hardware layer, which is used for the first time in this converter. With Fast, point-to-point Ethernet links are established between boards. Routing of data, which is normally part of OSI layer 2, is done by the on-board FPGA of the controller. This allows Ampulz to reach up to 1 Gbps throughput while satisfying strict timing requirements between modules.

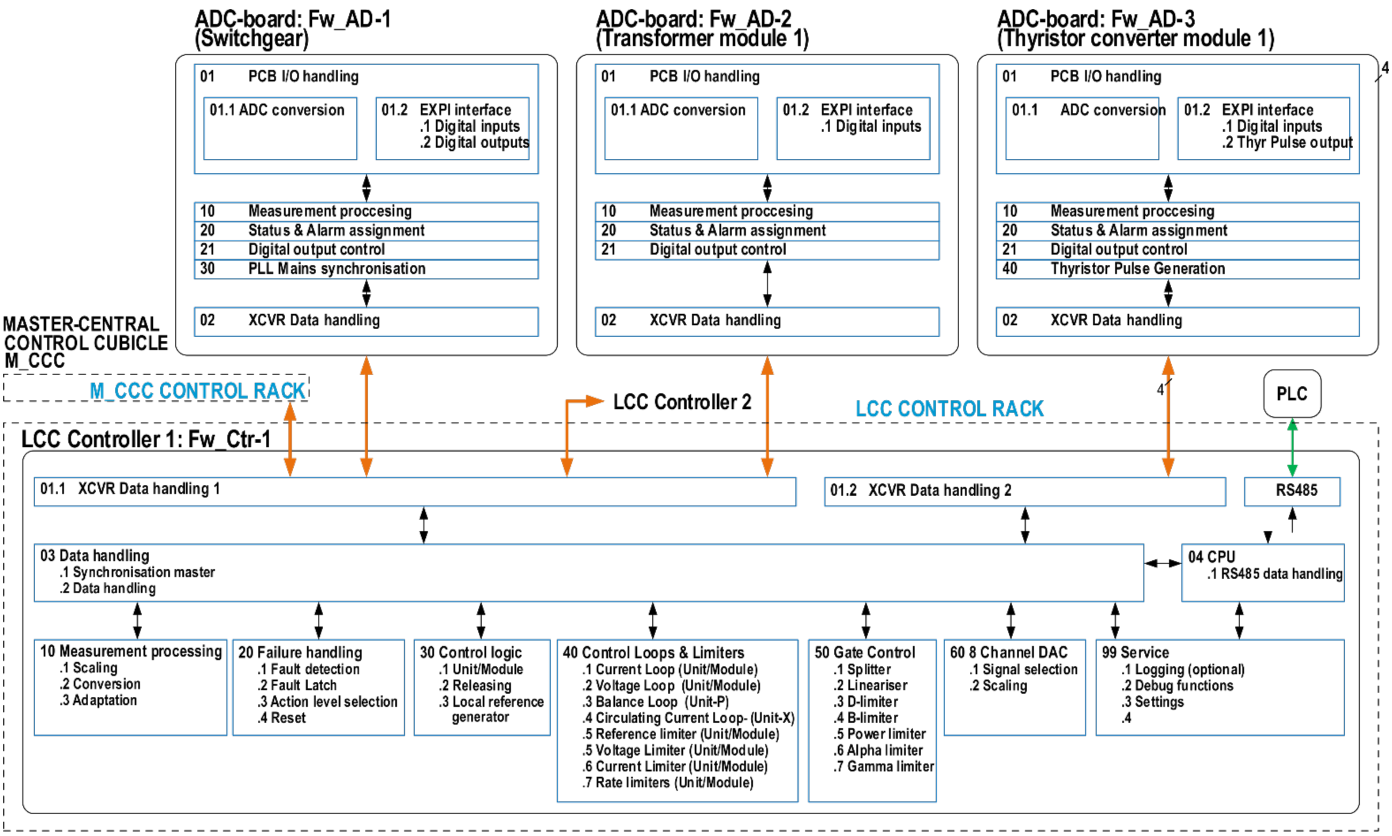

Fig. 3: Program structure for one converter module

By using the hardware platform of Ethernet obsolescence problems are greatly reduced. Ethernet is a widely used platform and therefore a wide variety of components is available. One of the main components is the SFP (small form-factor pluggable) module (Fig. 4). In the SFP casing, a module can be inserted with a glass fiber connection or a standard copper connection. For the Group 7 converter system, the glass fiber connection option is selected.

Fig. 4: SFP module

Using the FAST protocol, synchronization is achieved between all boards. The time synchronization leads to many advantages. One of them is better fault analysis. When an error occurs on one of the boards, a time stamp can be created for every signal in the system. The time stamp gives the possibility to create a sequence of events when multiple errors occur shortly after each other.

The programmable FPGA-based controllers make it much easier to implement changes in the control structure. For a better readability of the code and for an easier revision handling a modular program structure is used, as shown in Fig. 3. Already in the planning phase of the converter the program structure was divided into meaningful subroutines, like measurement processing, failure handling, control loops and gate control. This makes it also easier to test the routines and the subroutines can be split on several controllers.

Some hardware-related tasks, like in- and output-control, synchronization and thyristor pulse generation can be implemented directly on the extension boards.

While fast control issues like the control loops and the firing pulse generation are processed on a FPGA, less time-critical tasks, like operation of the disconnectors, will be done on a PLC (programmable logic controller).

The system can be operated via HMIs (human machine interfaces) with touch panels. These HMIs are connected to the PLCs. The data exchange with the FPGA-based controllers will be done via Modbus.

To integrate this digital control system, the interface to the AUG control system will be transformed from an analog plug with 40 digital and analog signals, to a mostly digital interface via Ethernet. This is a big step, because the complete interface to AUG is at the moment realized by analog plugs. The new digital bus connection should significantly reduce the effort to integrate new systems into the AUG control system.

4. Outlook & Conclusions

At the present time point the (Re-) Design of the converter Group 7 is almost completed and the production of first components has started.

Until April 2019 all components should be on site and the installation will start.

After the successful commissioning, operation is scheduled for 2020 on ASDEX Upgrade.

Beside the construction of the new converter, also some other works were performed to implement the converter in our supply network of the experiment. The 10kV-switchgear was extended, new thyristor crowbars were built and the cabling to the crossbar distributor was done.

The FAST protocol, which is introduced in this paper, shall become the new standard-protocol for converters and other applications from Ampulz.

Acknowledgments

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