The Quench Detection System of W7-X

1. General

The superconducting magnet system of Wendelstein7-X (W7-X) consists of 50 non planar coils, 20 planar coils, 14 current leads and about 120 bus sections. All of these superconducting components must be supervised continuously through a very well useful and reliable Quench Detection System (QDS). The QDS of W7-X should be able, to supervise all the differential voltages of the super conductors in each component and to start a fast discharge of the magnet system in case of a quench. The quench signal voltages must safely detect voltages in the mV-Range in a couple of milliseconds. The quench detectors must always work efficiently in a very noisy environment with a high reliability.

The quench detection system should work total self-sustaining, must have a self diagnostic function and all quench detector parameters must be electronically adjustable and configurable. The system must record all the voltage measuring data in case of a quench and save for further analyses.

The Quench Detection System is separated in couple of subsystems at five locations, to coordinate the spatial distribution to the QD ports of the machine W7-X. Each subsystem generates two quench detection status signals and failure status signals, which coupled to two intelligent QD Interfaces, where the signals will be evaluated and processed, before the control of the main magnet power supply will initiate a fast or a slow discharge of the magnet system.

The development of the Quench Detection Units (QDU) has been performed in cooperation between the Max-Planck-Institut für Plasmaphysik Greifswald and the Karlsruhe Institut of Technology (KIT), Institut für Prozessdaten-Verarbeitung und Elektronik. The manufacturing of nearly 580 series QDU was done by the company PRETTL Elektronik Lübeck, die manufacturing of the series backplanes is right under way by the company Dresden Elektronik. The UPS based power supply for the subsystems have been developed by the IPP using the switch mode power supply units of the company PULS power and an own design of the magnetic shield housing.

2. Functional Parts of the Quench Detection System

The W7-X Quench Detection System consists of following function units:

- 10 QD subsystems
- 2 QD interfaces
- 1 QD host system

The QD host system consist of a rugged industrial PC with a 32“LCD monitor and a UPS supported DC power supply. The communication between the QD subsystems and the host is realized by fiber optic cables using special fiber optic electronic Ethernet switches in all subsystems. The link between the subsystems is using an open ring structure (Figure 1). The QD System can be added with some further QD subsystems. At the W7-X there will be nine subsystems active operating; one additional subsystem will be in active reserve.

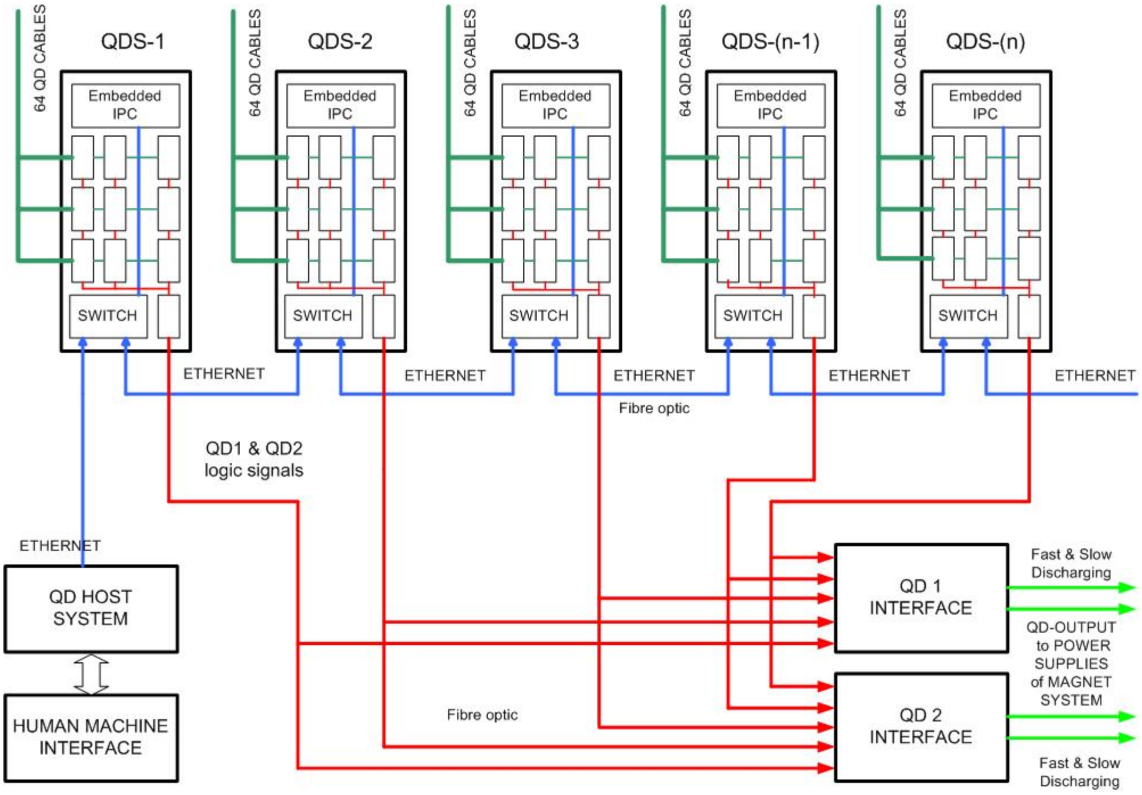

Figure 1: Quench Detection System of W7-X

3. Functional Parts of one QD Subsystem

One QD Subsystem consist of the following components

- 64 QD Units in 8 * 19“ Racks (Design KIT/IPP; Manufacturing PRETTL)
- 64 QD HV-Signal-cable (DRAKA type 3 x 0.6L/2.8 – 9kV)
- 64 QD HV-Signal-connector (LEMO type FCJ.4B.464.CLLY15)
- 1 Embedded Industrial PC with passive cooling (PLUG-IN type PICE 3110)
- 8 * 19“ Racks (3HU) with intelligent backplanes (Dresden Elektronik)
- 1 AC-DC UPS module 230V/50Hz // 24V DC (PULS POWER)
- 1 electronic-fiber-optic Ethernet switch (EKS Engel)
- 1 intelligent switching module (PHOENIX CONTACT)
- 4 electronic-fiber-optic converter (EKS Engel)
- EMC Filter Unit for 230V/50Hz main supply (EPCOS)
- Cooling Unit with Air-Water-Converter (SCHROFF)
- Electronic Cabinet IP67 LHX-3 (SCHROFF)

All Components are designed for the very high requirements of the design of the machine W7-X in accordance with the standards of EMC, environment temperature conditions, mechanical stress, and the DC magnet field conditions. The Quench Detection System will withstand all these requirements, because the quality characteristics were checked with a couple of standardized test procedures in certified laboratories.

Figure 2: Quench Detection Unit (QDU)

Each QDU is working self-sustaining, use a self test function, switchable cable break detection and consist of two parallel hardware detectors. They can work in parallel mode or in single detector mode with separated switch levels. The configuration of the QDU can be realized in a separate test unit or using the HMI software of the host system. There is also a data acquisition in parallel to the hardware detectors, which is digitizing the differential voltages of the super conducted components. The analog voltage values will be digitizing in a 12Bit data word, using a sample rate of 100kS/s and followed by a ring buffer memory. In case of a quench the ring memory will be stopped and a value sequence of about 10s can copy to the embedded PC in the QD-subsystem. The whole Quench Detector and the complete data acquisition and memory unit are operates totally electrically isolated with about 15kV isolation barrier. The Quench Detection Level can electronically switch in a range of -1,25V to +1,25V in 256 steps. The integration time constant of the internal filter can modify in a range of 0ms to 1s in 8 steps in 0-1-2-5 mode.

The symmetry adjustment of the QDU of the measuring circuit has been realized with electronically potentiometers, which can be controlled via the communication interface of the QDU using the software "QVision" in the host system. Due to the complete bipolar design of the whole measuring circuit it is possible to adjust an exact symmetry correction of the supervised part of super conducted coils. The parameter set-up dates of the detector will be saved in an onboard EPROM circuit and also in the embedded PC as initialization file.

The function principle of the Quench Detection at W7-X is shown in figure 3. The analog detector part and the digital voltage acquisition are operating in parallel. The analog detector is doubled to realize an inherent redundancy. Both detectors are operating in the single mode alternate, hence there operational ability will be checked while the inactive phase by a special internal circuit. Thus an internal failure function of one of the detectors will be detected very fast by the quench detector itself. Using the control interfaces the parameterization and the function supervision of the detector will be realized. In case of a quench the QD status signals QD1 and QD2 controls the fast discharge of the magnet system and the slow discharge at an uncritical failure function in relation to the safety modus; therefore see also chapter 4 QD Interfaces.

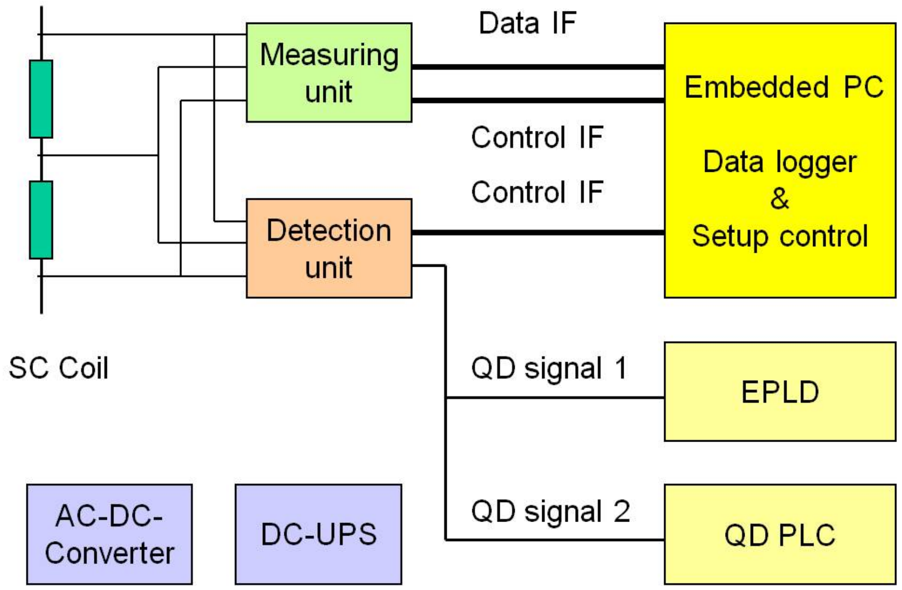

Figure 3: Principle of the Quench Detection at W7-X

4. Functional Parts of the QD Interfaces

Both QD Interfaces consist of the following components

- 4 CPLD - complex programmable logic device (Dresden Elektronik)
- 64 Channel Logic Switch Units (PHOENIX CONTACT)
- 32 Fiber optic-electronic converter to connect the fiber optic signals from the QD-subsystems (EKS Engel)
- AC-DC UPS Module to generate the internal UPS supported 24V DC operating voltage
- 2 electronic-fiber optic converter to link the control of the main magnet power supply with the QD interfaces

Important part of the QD interfaces is the so called “discharge logic“, which correlate the quench detection failure signals with the quench detection status signals in relation to the before set safety modus „Fundamental Safety” or „High Safety“. The correlation gives two several status output signals linked to the main magnet power supply, one is “fast discharge” and the other is “slow discharge”. The “discharge logic” was failsafe realized in Boole’s algebra using a complex programmable logic device (CPLD) with a special FPGA (field programmable gate array) circuit. The QD interfaces operate self-sustaining and the functionality is only like hardware logic, no software must be loaded before operate, no system crash is possible. The QD interfaces are using an UPS supported power supply to guarantee good signal isolation to the fed mains. Like the controls of the main magnet power supply the QD interfaces are doubled to have the same redundancy. The linking of systems, the QD interface and the magnet power supply control was realized by fiber-optic cables, to assure very high signal .isolation and a high immunity against electromagnetic fields between two systems. Figure 4 gives a view about the principle function of the “discharge logic” using a CPLD like in the QD system.

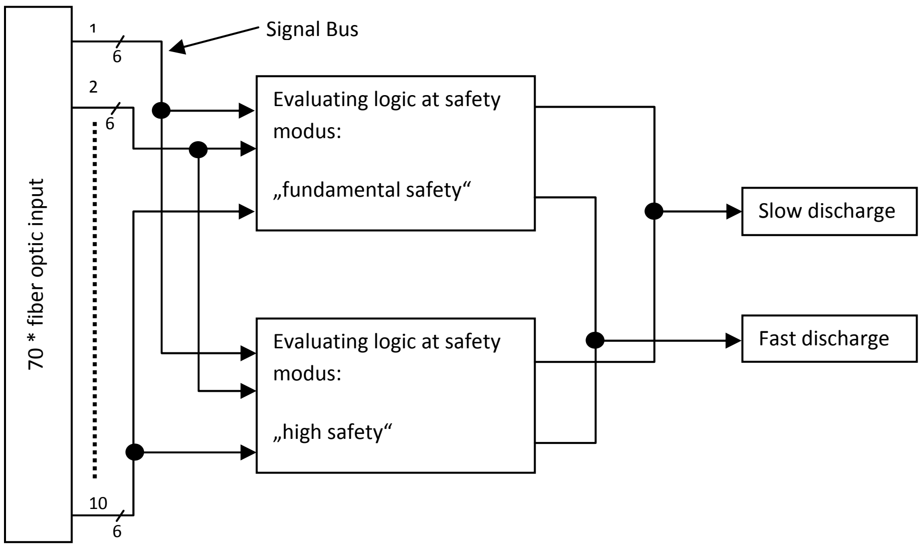

Figure 4: Principle of Discharge-Logic with a CPLD – complex programmable logic device

5. Operation and configuration of the QD System

The operation of the QD system use a human machine interface (HMI) demonstrated in figure 5. The special software for this application was developed at IPP named QControl. The configuration will be done with special software named QVision, developed at KIT/IPE. QControl manage the complete interactive communication between the QD subsystems and the QD interfaces using the QD host system. The usage of software QVision in the host system allows the simple configuration of all QD units. The standard operation of the QD system is to supervise all the super conducting components using the supervision mode “Kontrollbetrieb”; it means the continuous full automatic check of all the Quench voltages permanently.

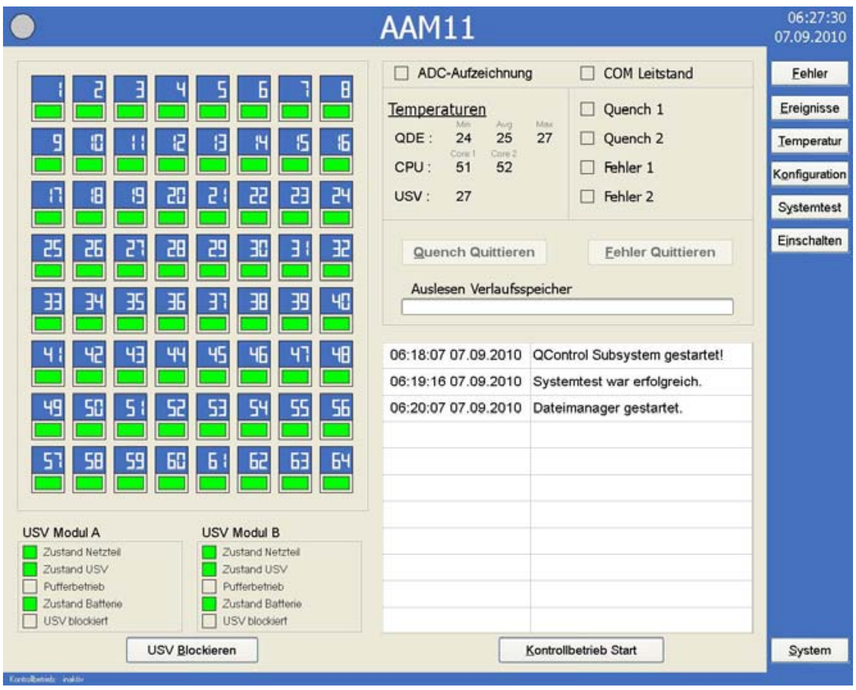

Figure 5: Human Machine Interface (HMI) of the QD subsystem

6. Integration in the Protection System of the Magnet Power Supply

The QD system generates all supervising signals of the super conducting components, which are necessary for the safe operating of the W7-X magnet system, i.e. Quench status signals and internal failure signals with redundancy and internal evaluation of the failure status. The QD system operates self-sustaining; all signal interfaces are using a fiber optic link. The QD interfaces evaluate the failure status in the QD system and generate two signal commands for fast discharge or for slow discharge in relation to the safety level. Due to the intelligent failure status evaluating the mechanical stress in the machine is lower, because only real quenches and critical failures generate the fast discharge. Figure 6 demonstrates the integration of the QD system in the main magnet power supply.

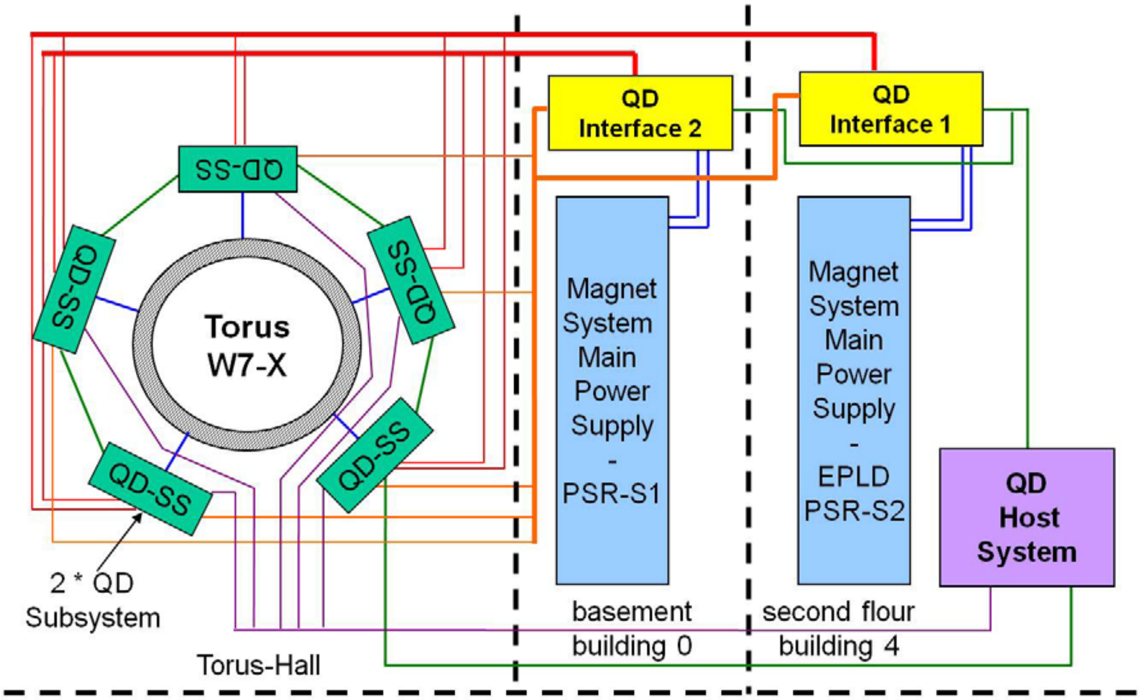

Figure 6: Integration of the QD System in the Control of Main Magnet Power Supply at W7-X

7. Status and Forecast

The development of the QD units has been finished end of 2007. The manufacturing of the series QD units at company PRETTL was finished in spring 2010. The first series QD subsystem and the first QD interface have been successful assembled in 2010. This QD subsystem was checked successful concerning EMC at company CEcert Wismar and DC magnet field at own IPP test rig. All the series QDU have been complete testing at the manufacturer PRETTL before delivering.

The other eight subsystems for W7-X and the second QD-Interface will be ready assembled up to end of 2010. The QD host system will be lumped together with well known rugged and very high reliable industrial components also up to end of 2010.

In 2011 after the completion of the special software for the operation, supervision and configuration will take a half year continuous system test, make sure that at the start of operation of W7-X machine no early failures will be in the QD system, which limits the operation durability.

Figure 7: Front view of QD Subsystem

8. Summary

The QD system of W7-X will supervise the operation status of all super conducting coils, all bus elements and all current leads to secure a safe operation of the magnet field at the machine. The system runs self-sustaining, it have an inherent redundancy and a complete self diagnosis in each QD units and in the QD interfaces, which are used for the intelligent link from the QD subsystems to the control of the main magnet power supply. The configuration of the whole QD system and all QD units will be performed by usage of ambitious software QVision at the human machine interface. In regular operating mode - the supervision of all super conducting components - the software QControl will be controlling the communication links between QD host system and QD subsystems and manage the correct display of important status information at the host system. The QD system will be complete assembled up to mid of 2011 followed by a six month continuous system test in a separate test plant under a special test procedure. The integration of the QD system in the W7-X system will be performed in 2012 and 2013.