Supervision of the pulsed power supply of a fusion experiment

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Teaser: The new NI solution for the supervision of the fusion pulsed power supply is robust, as demonstrated by the faultless operation since 2015. It came to no false alarms and experimental interruptions due to signal distortions, which has considerably saved time and money.

NI Product(s) Used: cRIO (NI-9038, NI-9064, NI-9149), C-Module (NI-9205, NI-9425, NI-9242, Ni-9227, NI-9375, NI-9469), LabVIEW software and LabVIEW FPGA module.

Industry: fusion research

Challenge: The power supply of the fusion experiment ASDEX Upgrade in Garching based on three flywheel generators has expanded with additional equipment over the years. The reliability and accuracy of the old supervisory system could no more cope with the increased complexity.

Solution: A new distributed embedded system from NI was implemented. Measurement, digitalization and data processing is now done close to the signal source. The recorded signals are stored locally, making the whole system more stable and independent from the supply network performance.

Application

The energy for ASDEX Upgrade, Germany's largest experiment for nuclear fusion research of the Tokamak type, is provided by three separate networks based on flywheel generators. They can supply an electrical power up to 600 MW for a time period of about 10 seconds [1]. The permanent refinement and flexibility in approach, characteristic to a fundamental research project, lead to a continuously increasing hardware complexity, which also has to be supervised.

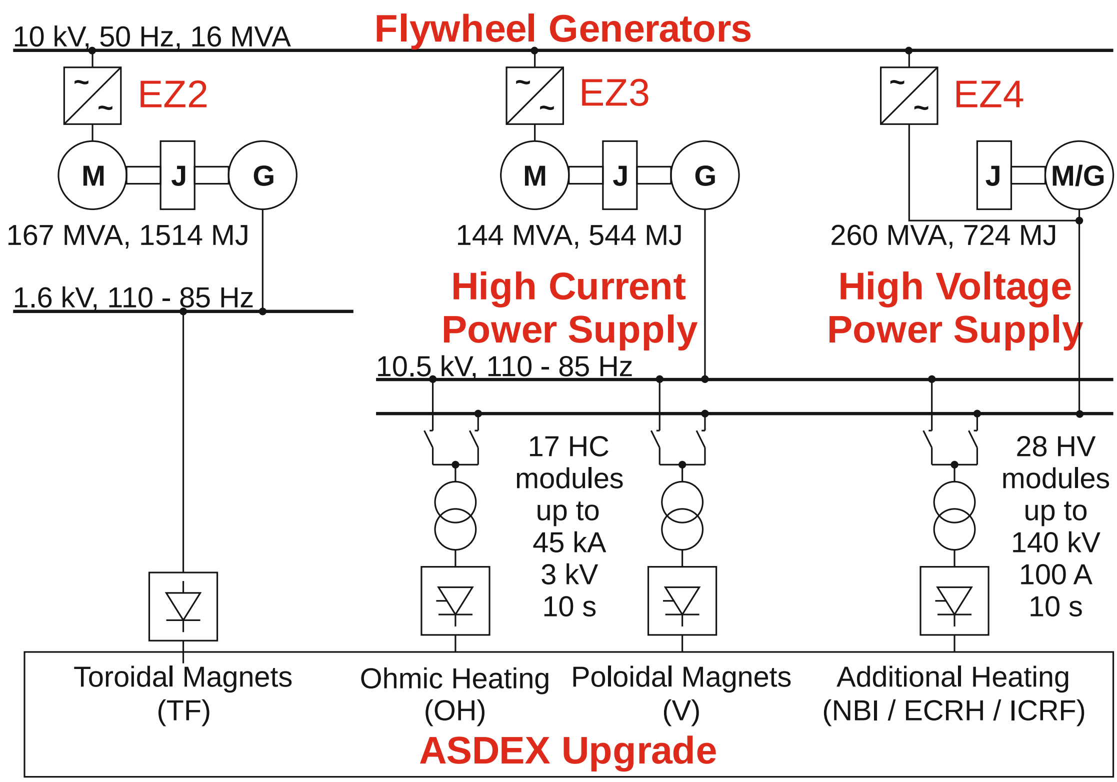

Fig.1: Fusion experiment power supply network

Old vs. new supervision and data acquisition

Different supervisory systems ensure a safe operation of the generators. To increase the reliability and accuracy, the old supervisory system, which was based on conventional hardware, has been replaced step by step by a new distributed embedded system from National Instruments (Fig.2). Measurement, digitalization and data processing is now done close to the signal source, increasing the measurement accuracy. The recorded signals are stored locally, making the whole system more stable and independent from the network performance. The data is also used for online monitoring by some cRIO and PXI systems which are linked via Ethernet.

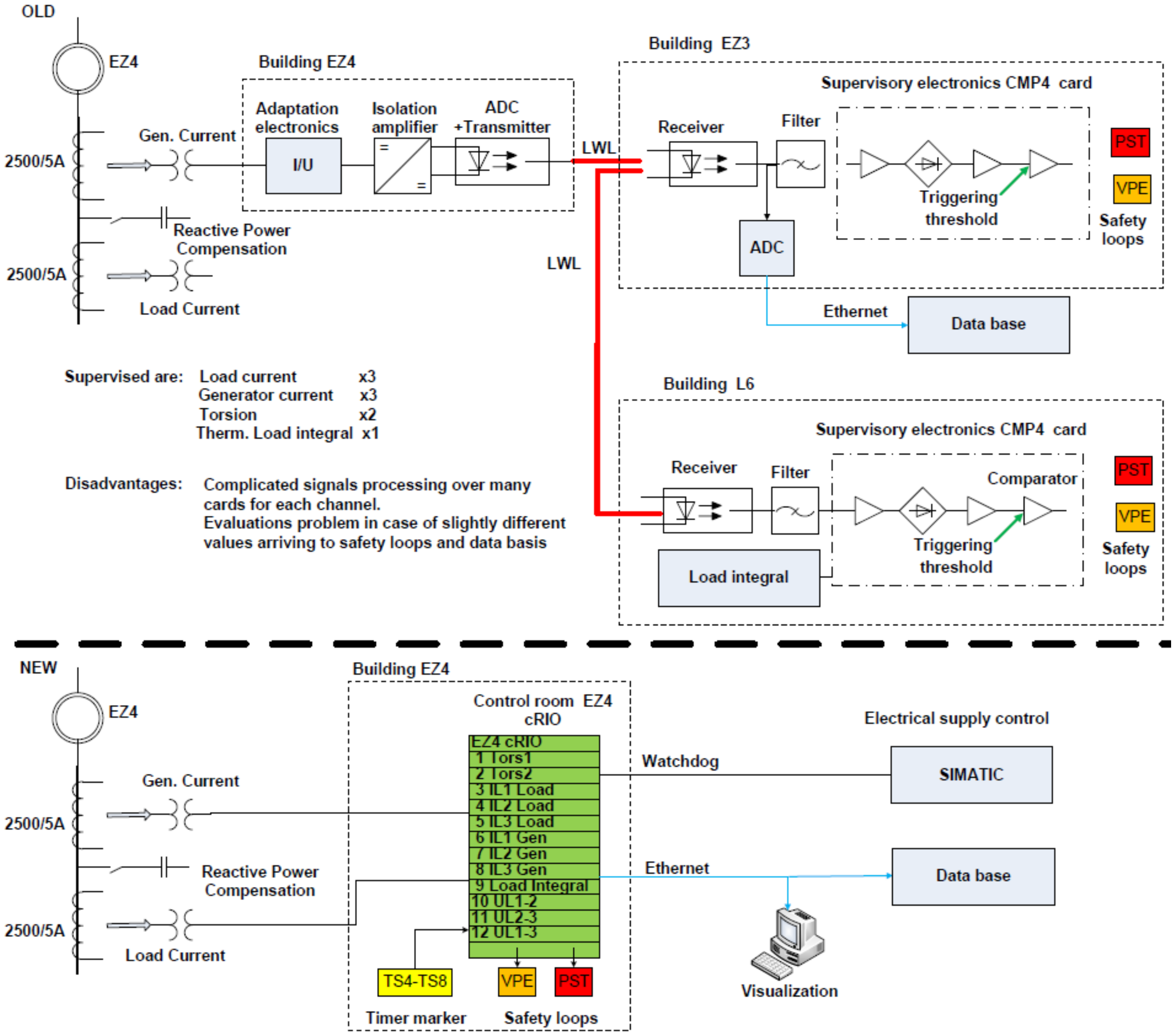

Fig.2: Old vs. new supervisory and data acquisition system

Distributed system architecture for supervision and data acquisition

The monitoring and data acquisition of the generators and of some installations of the power supply are based on distributed system architecture. [2] (Fig.3). All systems have the same sampling rate (10 kHz) and are controlled by an external trigger. The implemented NI-Hardware communicates internally over Network-Streams and with the external systems (e.g. SIMATIC) over OPC-Server and UDP Protocol. The measured data is saved locally on the own hard disk and simultaneously transmitted to a Windows-computer for real-time display. The file transfer for archiving is done by WebDAV-Protocol. A total of more than 350 channels are stored.

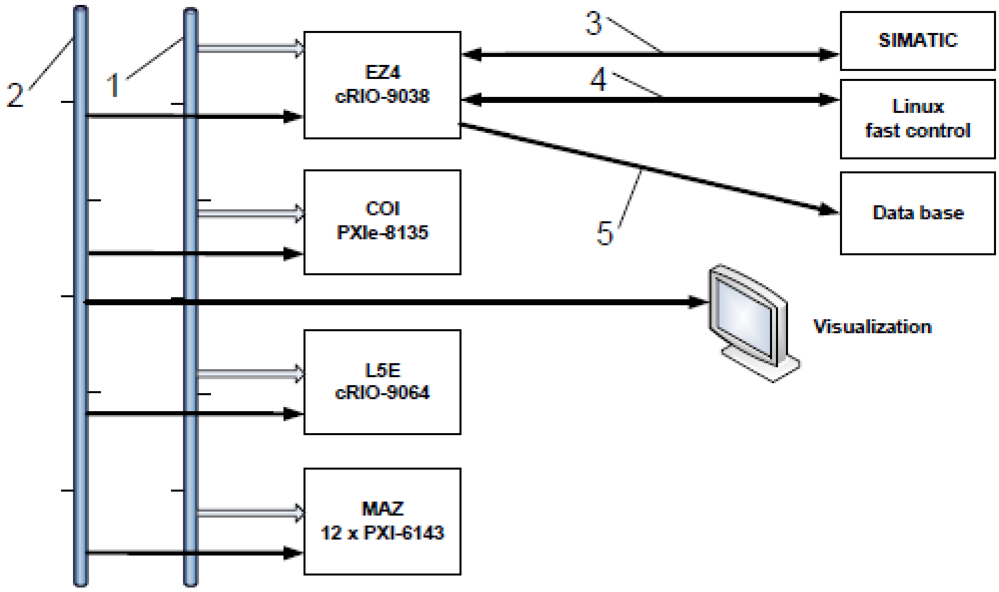

Fig. 3: Supervising hardware architecture. 1- Trigger signal, 2- Network connection between real-time computers and visualization, 3- Bidirectional connection to SIMATIC, 4 – Fiber optic cable for fast control, 5- Network connection to the data base

The real-time-computers have the following functions:

COI has a controller PXIe-8135 and three multifunction data acquisition cards PXI-6259. It serves to data acquisition for the COI converter for fast plasma control, which consists of two similar anti-parallel four-quadrant-converter, each one with a forced-commutation thyristor-based DC-switch. The installation is fed by 10,5 kV/85-110 Hz, with a pulsed power of 14MW and a nominal DC output current of 27 kA for each converter [3].

L5E is a CompactRIO system with 2 modules for analogue measurements of the high current converters for supplying the magnet coils of the experiment with a pulsed power of 580 MVA and current up to 45 kA/10 s.

MAZ includes a PXI-Chassis with 12 PXI-6143 cards and serves for the simultaneous measurement of the magnetic probes over 96 channels. This chassis is connected over a MXI-cable with a LabVIEW-computer.

EZ4 consists of a CompactRIO Chassis with a cRIO-9038-controller (Fig.4). It captures and monitors the electrical parameters of the flywheel generator EZ4.

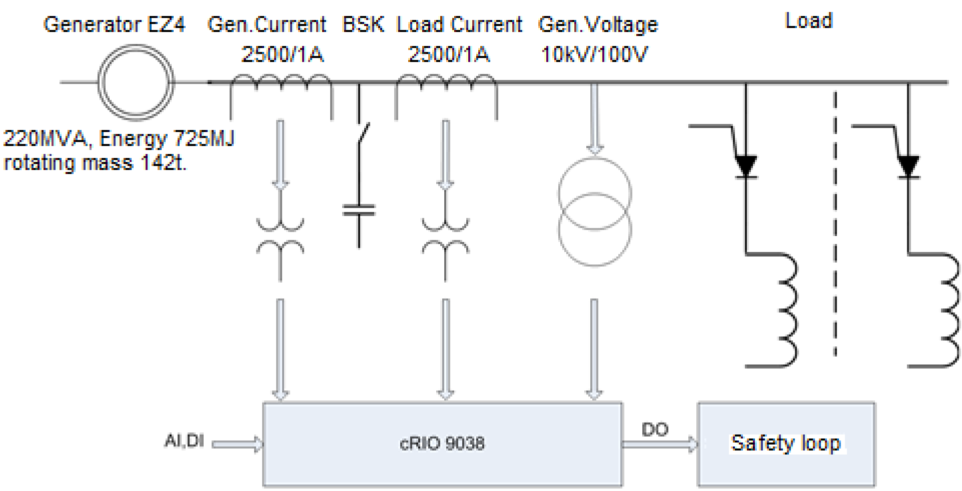

Fig. 4: Supervising system of generator EZ4 with input and output signals

Modules of the C-Series with Delta-Sigma-Analogue-Digital-Converter are used for the direct measurement of currents and voltages of the transducers (measuring transformers). The 4th order elliptical filter (Cauer) implemented in the FPGA has a very steep transition in the transfer function. For the filter design LabVIEW Digital Filter Design Toolkit was used. The obtained values are used for the calculation of important generator parameters: active and reactive power, thermal stress, stored mechanical energy and consumed electric power. The optimized calculation of these values in the FPGA is realized with LabVIEW FPGA IP-Builder. When stipulated limits are exceeded the system will, by the help of safety loops, trigger a premature pulse end respectively an immediate pulse stop of the experiment and will report the cause. A deterministic connection between cRIO and the Linux-computer for fast control of the plasma discharges (4 in Fig. 3) is realized by fiber optic cable. For this purpose the 4B/5B signal coding is implemented in the FPGA, transmitting data together with control symbols.

Synchronization

In difference to the event triggered data acquisition, the monitoring system runs continuously. In order to synchronize these two systems, a procedure as shown in (Fig. 5) is implemented.

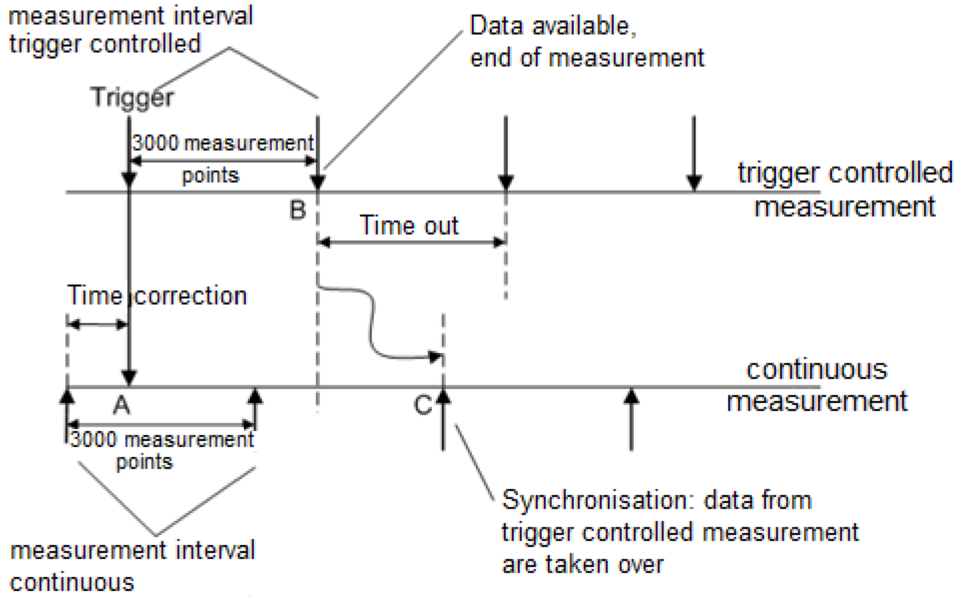

Fig.5: Synchronization of trigger based and continuous measurements

By the trigger-based measurement a predefined number of measurement points (e.g. 3000) will be read between A and B. By the continuous measurement the trigger appears within the measurement interval (Point A). The necessary 3000 measurement points, starting from the trigger (event), will be in this case accessible only at time point C. They will be taken from two consecutive intervals of the continuous measurement between points A and C and will be synchronized. Should no data be available after a Timeout, then the system continues to run without this data.

Visualization

The basis of visualization consists of the dynamic generation of Queues, which allows the operator to decide himself how many graphs are opened and how many curves should be displayed in each graph. The following tasks shall be solved:

- Simultaneous display of many signals, measured in various systems
- Simple subsequent evaluation
- Quick access of the saved data
- Comparison of signals from experiments at different times

- Display of the values after alarm release

The number of necessary visualization points is reduced dynamically by Max-Min-Decimation [4, 5]. The peak values are displayed on the graph despite the strongly reduced data. This algorithm increases the speed of visualization without loss of the peak values.

Benefits of the NI solution

The distributed system architecture as implemented by using the NI solution brings the following benefits:

- the measurement accuracy is increased
- the various systems are decoupled
- the safety of the supervised installations is improved
- the most important supervisory functions (measurement, filtering, computing and control) are shifted to the FPGA and thus a long term viability can be ensured
- the FPGA is programmed with NI software and no VHDL is necessary. The software can further be easily transferred to upcoming hardware without a great programming effort
- the continuously running as well as the sporadically triggered systems is synchronized with each other
- the Plugins ensure a permanent control of the implemented Hardware
- it is possible to expand the system, so that in the future also flywheel generator EZ3 will be retrofitted and connected
- real parallelity, more channels and functions, are achieved without a loss in speed
- the NI solution is robust, as demonstrated by the faultless operation since 2015. It came to no false alarms and experimental interruptions due to signal distortions, which has considerably saved time and money
- complex calculations (thermal load, reactive and active power in generator and load, etc.) can be performed in real time

The flexibility of the NI solution can accommodate unique applications such as our system. We could so solve the problems of a very complex and expensive system with a reasonable investment and time.

Acknowledgement This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. The views and options expressed herein do not necessarily reflect those of the European Commission.

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