DCS Satellite: Enhanced Plant System Integration on ASDEX Upgrade

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Abstract

For present and future fusion experiments, a higher level of integration for plant systems into the discharge control system (DCS) is becoming increasingly important. The integration is required to enable more sophisticated control schemes where a comprehensive plasma system state is needed. This is especially the case for large fusion devices such as ITER. On ASDEX Upgrade the integration of diagnostics, actuators and evaluation codes is done in a unified concept, the DCS satellite. Here the DCS framework and signal exchange is adopted on e.g. diagnostic nodes, where specialized DCS application processes (AP) interact with the sensor hardware, import it into the DCS system and let other APs process the data. This concept allows automated configuration and identification of the current plant system setup prior to the discharge execution. A comprehensive plasma state is generated during a pulse by the DCS framework which enables information exchange between the different DCS systems.

So far this concept has successfully been demonstrated for National Instruments NI-RIO based FPGA diagnostics, video real time diagnostics (VRT) using CameraLink cameras, diagnostics using IPPs in-house standard SIO2 as well as diagnostic codes such as the equilibrium reconstruction code JANET++.

1. Introduction

The integration of plant systems and the discharge control system (DCS) will become more important for ASDEX Upgrade and future fusion experiments. Whereas nowadays experiments can mostly operate with a separation of diagnostics and control, a higher level of integration of different systems is necessary in the future. In ASDEX Upgrade, comprehensive information about the plasma system state is desired for sophisticated control, which will be an even higher demand for the operation of e.g. ITER. Complex control scenarios such as NTM control [1, 2, 3], current profile control for advanced tokamak scenarios [4, 5] or disruption avoidance [6, 7] require the coordinated interplay of various diagnostics, actuators and decision logic. ASDEX Upgrade is extending the integration of diagnostics, actuators and evaluation codes in a unified concept, the DCS satellite. Within the DCS satellite, the means to share information between different systems is provided in a unified way by the DCS framework [8, 9, 10]. This allows automated configuration and identification of the current plant system setup prior to the discharge execution. Systems can request information about the next discharge, change their setup accordingly and publish their settings to other systems. One example for this could be the electron cyclotron emission (ECE) diagnostics, which has to change its setup depending on the toroidal magnetic field of the discharge and make this information available for e.g. NTM mode localization [11]. During a pulse the availability of information provided by this framework enables the generation of a comprehensive plasma state which can then be used for control.

The DCS framework and the satellites are developed in C++ using Linux with real time kernel as an operating system. The real time part of the central DCS uses RedHawk as real time operating system, for the non real time services CentOS is used. The DCS satellites use CentOS with a real time kernel. On ASDEX Upgrade DCS is operated on off the shelf x86-64 hardware with multi socket mainboards to allow the separation between operating system (OS) and DCS processes. This allows the best compromise between ease of use and flexibility in the choice for the diagnostic setup.

The DCS satellite concept benefits from the ability of the DCS framework to incorporate different data types and rates, which is important since DCS satellites may deliver their data with different rates. DCS abstracts the communication between different members within the control system [12, 10]. So far the supported methods contain UDP and multicast Ethernet, shared memory and VMIC as well as Dolphin [13] reflective memory. The selection of the communication methods is transparent to the user and done via configuration in the DCS. At ASDEX Upgrade the real time communications between the services and systems is either done using shared memory, if they are instantiated on the same computer, or UDP Ethernet.

In the following the DCS satellite concept is introduced. Furthermore examples are given for which this concept has been successfully demonstrated. The new ASDEX Upgrade magnetics using National Instruments NI-RIO based FPGAs is described in section 2.2. The video real time diagnostics [14] (VRT) using CameraLink cameras are discussed in section 2.3. Furthermore diagnostics using IPPs in-house standard SIO2 [15] as well as diagnostic codes such as the equilibrium reconstruction code JANET++ [16] were implemented as DCS satellites but are not discussed in this paper. The interplay between DCS satellites with the central DCS are discussed in section 3. A conclusion about the concept is given in section 4.

2. DCS Satellite

The DCS satellite concept is intended to introduce an abstraction layer between control system and the various systems (diagnostics, actuators, evaluation codes, etc) required for operation. Owing to this abstraction, each DCS satellite is handled in similar manner by the central DCS. This simplifies development and maintenance.

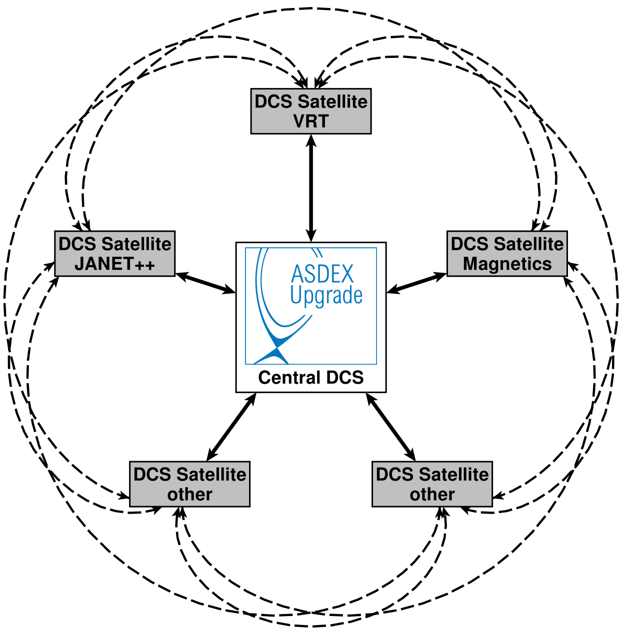

Figure 1: Illustration of DCS satellites communication with central DCS. The real time data and configuration communication is shown as bold arrows, the real time data only communication is shown as dashed arrow. Offline data storage is handled by the data management system at ASDEX Upgrade [17] and is not illustrated in this figure.

The communication paths of DCS satellites and central DCS are illustrated in figure 1. Exchange of configuration and real time data is indicated by a bold arrow, exchange of real time data only is indicated by dashed arrows.

2.1. Signals and Configuration

Prior to a discharge, the DCS satellite receives the configuration by the central DCS. During operation, the DCS satellite exchanges real time data with the control system and possibly other satellites. Each satellite can consume and/or produce data during operation, while the data handling is provided by the DCS framework [18]. Internally each DCS Satellite consists of one or more application processes (AP) which perform tasks required for the function of the DCS satellite. Each AP independently defines the configuration parameters and real time signals which it consumes and/or produces. In the DCS configuration, these parameters and signals are given names which uniquely identify them within the whole DCS. Within each AP the parameters and signals are identified by a name which is unique within the AP.

Table 1: DCS naming conventions. The internal name is used to identify the signal within an AP, the global name identifies the signal within DCS.

	Internal	Global
Parameter	p:arameter	par:Dia/.../parameter.val
Input	i:nput	rts:Dia/.../signal.(val, cmd)
Output	o:utput	rts:Dia/.../signal.(val, cmd)

The naming convention used at ASDEX Upgrade is shown in table 1. At the beginning of a discharge the DCS collects all information about the produced and consumed signals and then establishes signal connections between the DCS control and DCS satellite nodes. This includes the parameters required to configure the APs. Based on this information the DCS satellites then send the produced real time data to the systems which requested it. The default setting within DCS is that data is only sent over the network if another system has requested it. This is done to reduce traffic. However, it is possible to explicitly request specific real time data within the central DCS. In this case the real time data is sent to the central DCS. This can be used during development for diagnostic purposes. The data exchange is handled by the DCS framework and uses the corresponding communication paths between the sender and receiver (e.g. shared memory, network or reflective memory).

The sampling rate of the central DCS and the DCS satellites can vary. The cycle time of the central DCS varies during the discharge and is defined in the discharge program. Typically it is around half a second in the preparation time where the systems are prepared for the discharge, e.g. the ASDEX Upgrade flywheels are spun up. During the plasma discharge the cycle time of the central DCS, so far, can go down to 1 ms. A further decrease of the cycle time is envisioned in the future. DCS satellites themselves can either synchronize to the central DCS or provide their data with their own frequency. Even irregular sampling rates are possible, which could e.g. be used for event notification.

2.2. Magnetics

As an example, the internal structure of the new magnetics on ASDEX Upgrade is shown in figure 2. The magnetics DCS satellite consists of two types of APs. The first is the NI-RIO AP (dark grey) which each controls one NI-RIO FPGA card which connects to up to 64 integrators

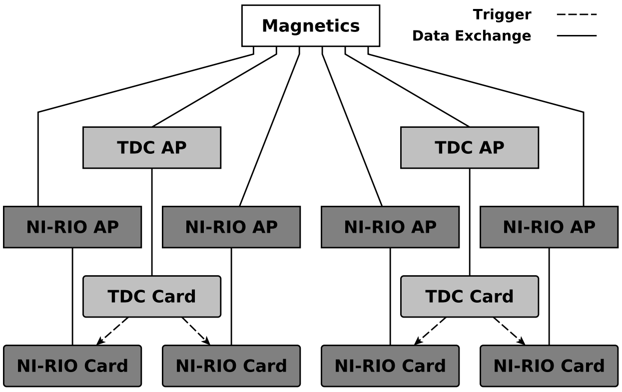

Figure 2: Illustration of the internal AP structure of the DCS satellite for the new magnetics on ASDEX Upgrade. The APs are indicated by the grey rectangles, the hardware is indicated by the grey boxes with rounded corners.

measuring the magnetic field. The second AP (light grey) is controlling a TDC2 timing device which is in charge of synchronized triggering of the data acquisition on the FPGA cards (dashed lines) [19]. The APs provide 20 kHz offline data as well as 1 kHz real time data to the DCS. In this case the measurements are used for equilibrium reconstruction, by e.g. JANET++ [16], which in turn provides data for other systems to be used for example for the control of the vertical plasma position.

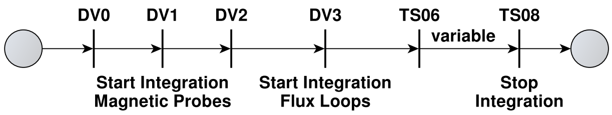

Figure 3: Illustration of ASDEX Upgrade time system events together with the start and stop of the magnetics integrators.

The magnetic probes measure the magnetic field by integration of the change of the magnetic field. The diagnostic has two type of sensors. The first kind are coils that measure the change of the magnetic field in a specific direction at the probe location. The second kind are diamagnetic flux loops which measure the change of the toroidal magnetic flux. For both probe types the signal is integrated by analog integrators to measure the absolute value of the magnetic field and flux.

During their idle phase, the integrators are on standby to avoid random pickup. During the ramping up and down phases of the toroidal magnetic field the diamagnetic flux loops pick up flux. This is not desired since only the flux change induced by the plasma is of interest for the equilibrium reconstruction [20].

The activity of the integrators is determined by time events distributed by the DCS. The ASDEX Upgrade time system events are illustrated in figure 3. The integrators of the magnetic probes are started at DV1 before the toroidal field is ramped up, the ones of the diamagnetic loops are started at DV3 to avoid undesired integration of the changing field during the ramping of the toroidal magnetic field.

With TS06, the plasma discharge is started and the measurement of the polodial magnetic field and the diamagnetic flux is conducted, which in turn is used for equilibrium reconstruction.

After the plasma discharge, TS08 indicates that the toroidal field is starting to ramp down. At this time the integration is stopped to avoid saturation of the probes.

The timer events are distributed by the central DCS to the DCS satellites. The data acquisition is triggered by a 20 kHz clock provided by the TDC2 cards, which are synchronized to the absolute time of a central timer. To synchronize the triggering between multiple TDC2 cards, to ensure simultaneous data samples, the cards are given a start time. The time of DV0 is obtained by the DCS, after DV0 has triggered, and the TDC2 cards are then configured to start the 20 kHz clock 100 ms after DV0.

For the real time data the magnetics are synchronized with the control cycles of the central DCS. When the acquisition is running the magnetics sends the latest available measurement at the beginning of each new control cycle.

2.3. Video Real Time Protection

Another example for a DCS satellite is the video real time (VRT) protection system. For machine protection the plasma facing components of ASDEX Upgrade are monitored by near infra red cameras. As a replacement for the existing system, a new system using the DCS satellite concept is implemented.

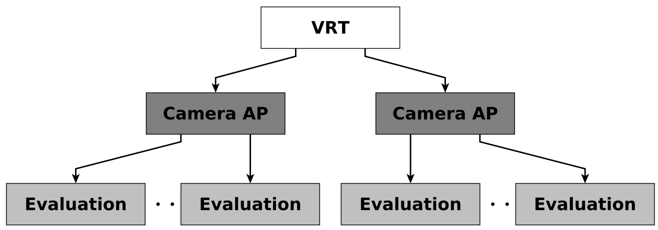

Figure 4: Illustration of the internal AP structure for the VRT DCS satellite.

The internal AP structure of the VRT DCS satellite is shown in figure 4. Each camera has a separate AP which itself can have several evaluation tasks. Each evaluation task evaluates a region of interest (ROI) with a specific algorithm. These algorithms are implemented in the DCS framework and can then be set via configuration. The cameras operate in a so called free run mode, which means they are continuously acquiring frames which are sent to the camera link frame grabber cards. The evaluation tasks are registered with the frame grabber software as callback functions. These functions are executed as soon as a new frame is acquired. The arrival of each frame is tagged with a TDC time stamp, which is used when the results are sent to the DCS. In contrast to the magnetics described

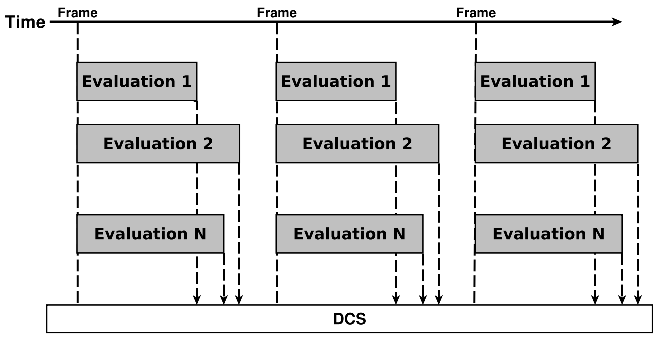

Figure 5: Illustration of the VRT evaluation timing. All evaluations for a camera are executed when a new frame has been acquired. The result for each evaluation is send to DCS as soon as it becomes available.

above, the cameras are not synchronized amongst each other, it is not even required that the cameras have the same acquisition rate. The VRT DCS satellite just sends the evaluated data when it becomes available, with the TDC time stamp when the frame has been acquired. An illustration of the evaluation timing is shown in figure 5. The central DCS, by configuration, is aware that it cannot expect synchronized data and accordingly either waits for next or uses the newest available data sample, depending on the purpose required.

In the central DCS, the information from the VRT systems is used to avoid overheating of the plasma facing components. So far, a trigger of the VRT systems immediately triggered a soft shutdown of the plasma. In the future, it is planned to use the information for more sophisticated exception handing, which will try to protect the machine by e.g. changing of heating schemes, change of plasma shape, etc.

The requirements for each diagnostic, actuator and evaluation satellite can vary significantly. For example diagnostics and actuators might require communication with special hardware. DCS satellites performing data evaluation (e.g. TORBEAM [21, 22], RABBIT [23]) might set a requirement on the performance of the computer.

3. Interplay with DCS

The most obvious and probably most common interaction with DCS is the delivery of real time data on which the control system acts. However, the possibility to exchange information between all connected systems enables more flexible and complex control scenarios.

An actuator DCS satellite for example can react on input from either the central DCS or another DCS satellite. In case of evaluation codes which are computational demanding it is trivial to add a dedicated computer into the whole control system. This also enables evaluations that would not be possible on a single system. Systems that require configuration that is dependent on the discharge type can obtain this information prior to the execution of the discharge. This allows automated configuration of the diagnostic which reduces the possibility of human error and ideally increases data quality. In case of the magnetics, for example, the acquisition duration is dependent on the discharge type. In combination with sophisticated control mechanisms like actuator management [24, 25] the possibility to combine data from multiple producers enables more complex control schemes.

4. Conclusions

The DCS satellite concept introduces a promising way to include heterogeneous systems into the control system of ASDEX Upgrade. The concept provides a unified way how to include systems into the control system whilst allowing enough flexibility to consider the various system specific requirements. All existing real time systems on ASDEX Upgrade will be ported to DCS satellites, with new systems be designed as DCS satellites from the beginning. Utilizing this concept, the capabilities of ASDEX Upgrade to develop and test complex control strategies will be improved and can serve as a test bed for ITER and DEMO control.

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