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Rapid prototyping of advanced control schemes in ASDEX Upgrade

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[2]See the author list "*H. Meyer et al 2017 Nucl. Fusion* ***57*** *102014*"

Motivation

- Advanced control schemes are becoming more important as fusion research progresses.
- Fast testing and implementaion of control schemes for e.g. exception handling is desired.
- A new feature that allows the configuration driven integration of evaluated signals into the discharge control system (DCS) is shown.
- The implementation and execution of a disruption avoidance scheme for H-mode density limit disruptions is shown.

Overview

Advanced control schemes have to be developed and tested. The aim for large devices (such as ITER) is an integrated control system with a decision logic that allows for extensive exception handling.

ASDEX Upgrade is utilized to study the architecture and design of the control system as well as control and exception handling schemes.

The ASDEX Upgrade discharge control system (DCS) is a distributed control system which allows:

- behaviour definition via configuration
- functional extension using application processes (AP)
- Inclusion of distributed systems using the DCS satellite concept (e.g. diagnostics, actuators, computation nodes, …)

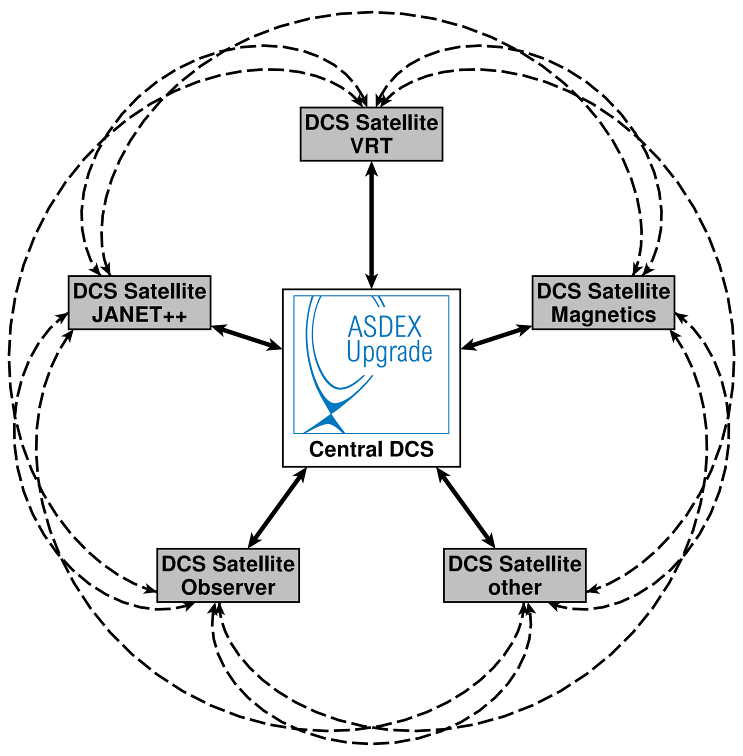
To enhance the capabilities of DCS an AP has been implemented which can parse expressions in run time and calculate signals during the real time phase:

- using constant parameters
- other run time generated signals (e.g. from diagnostics, …)

which are then published and can be used as input for other tasks (e.g. further signal evaluation, control, ...)

The configuration of where the defined signals are instantiated is done by the DCS operator.

Management of the signal communication for the real time phase is handled by the DCS framework.



Conclusions

The DCS capabilities have been extended to allow easy inclusion of the evaluated signals into the control system.

The C++ Mathematical Expression Library by Arash Partow was used to include flexible runtime expression parsing and evaluation into the DCS framework.

For H-mode density limit disruption avoidance the required signals were defined and instantiated. The control scheme to apply central heating power was successfully tested.

Testing of further control schemes is foreseen. Validated control schemes are foreseen to be implemented as dedicated AP to increase performance and the be available for exception handling

[1] *A.Partow, C++ Mathematical Expression Library*

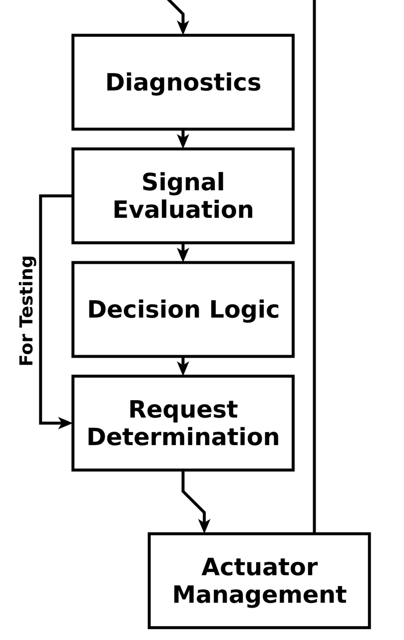
[2] *M.Bernert, et.al, PPCF,* ***57****, 1, 014038, 2014*

[3] *M.Maraschek, et.al, PPCF,* ***60****, 1, 014047, 2017*

[4] *O.Kudlacek, et.al, FED, In Press, 2019*

Strategy

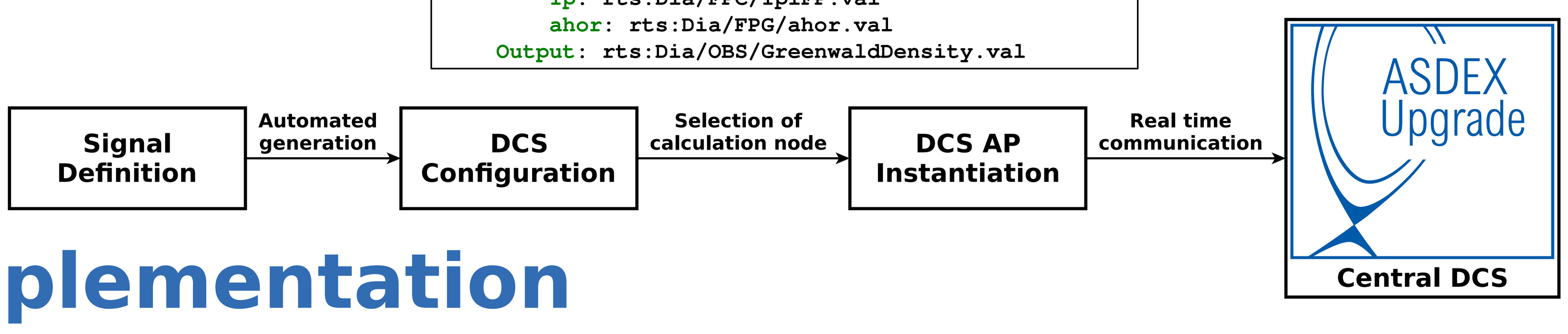
Diagnostics provide measurements which are evaluated to determine the current plasma state. The decision logic judges the information and prioritieses the different tasks. Based on this information the request is determined and issued actuator management. Actuator management maps the commands to the available actuators in the best way possible.



The aim is to implement the facilities into DCS to enable configuration based calculation of real time signals. The definition of signals is supposed to be easy without prior knowledge of DCS operation. The signal definition is done as a YAML configuration file, which is converted to DCS configuration by a DCS operator.

$$n_{GW} = 1\cdot 10^{14}\frac{I_p}{\pi a_{hor}^2} \longrightarrow$$

```
GreenwaldDensity:
    Expression: Prefactor * abs(Ip) / pi / (ahor^2)
    Parameters:
        Prefactor: 1.0e14
    Signals:
        Ip: rts:Dia/FPC/IpiFP.val
        ahor: rts:Dia/FPG/ahor.val
    Output: rts:Dia/OBS/GreenwaldDensity.val
```

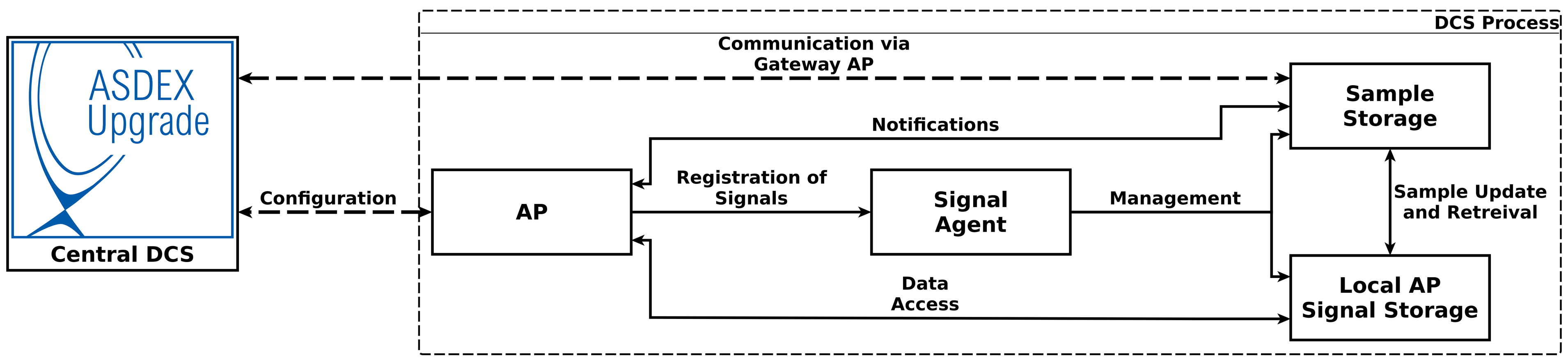


Implementation

The implementation has been included into the exisiting DCS framework (C++). The performance needs to be sufficient to handle the DCS cycle times (~1 ms), with evaluation times of each signals much shorter than the cycle time.

Tool: C++ Mathematical Expression Library (ExprTk) [1]

- Developed by Arash Partow: http://partow.net/programming/exprtk/
- MIT License allows free usage
- Provides extensive expression parsing and evaluation features
- The library builds an abstract syntax tree (AST) which connects the expression with the C++ variables, which can be configured and evaluated at runtime.



In DCS parameters and signals are configured before the execution of the real time loop. After the configuration is completed the storage location of each APs local storage is fixed. The references to the storage location are passed to the ExprTk to generate to computation kernel. During the runtime phase DCS notifies the AP about updated signals. The AP then retreives the signals into the local storage, evaluates the computation kernel and notifies DCS about the updated provided signal. The evaluation scheduling between the different APs is done automatically by DCS.

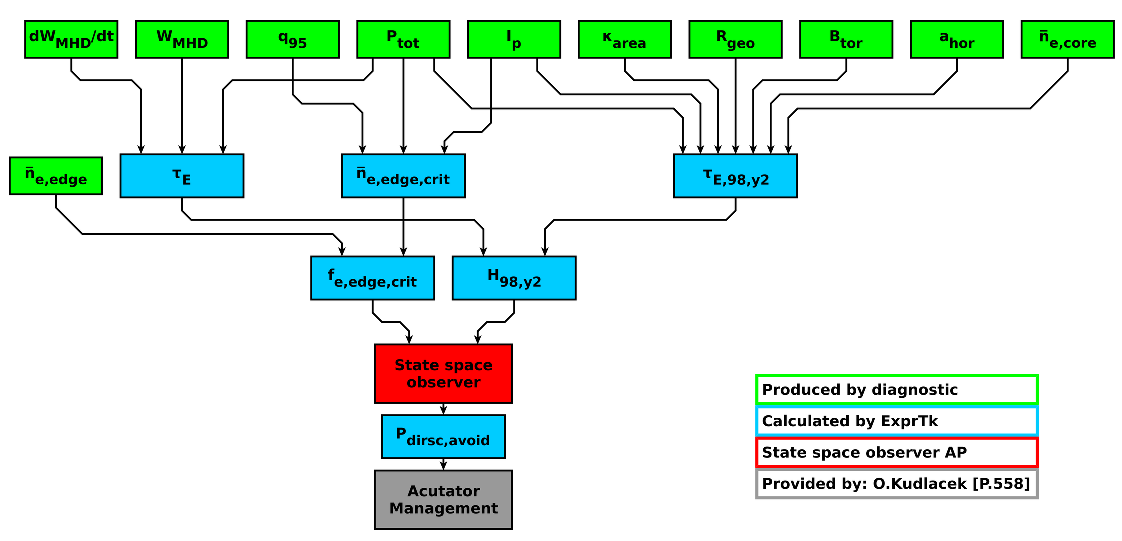
Disruption Avoidance: H-mode density limit

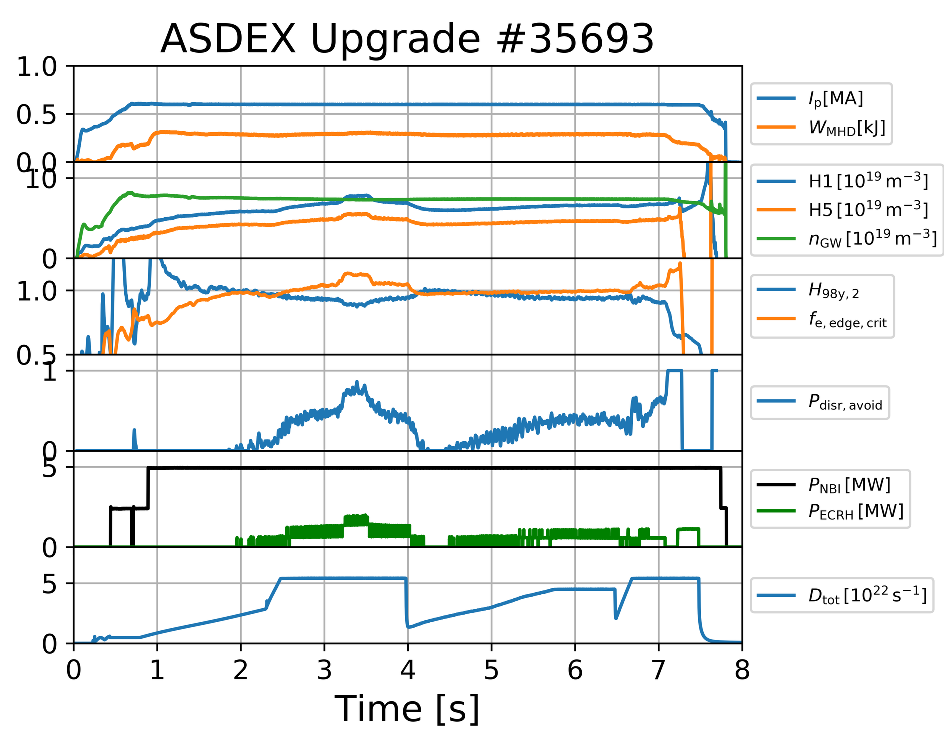
Disruptions pose a major threat for the operation of large fusion devices. Disruption avoidance aims at detecting an off-normal behaviour of a discharge and applying an action to return to the nominal path. Tokamaks encounter a disruptive limit at high density operation. An empirical boundary of the disruptive area was found [3] using the confinement factor $H_{98,y2}$ and the empirical critical edge electron density fraction [2]. The action for disruption avoidance is the application of central heating. For the demonstration ECRH was used.

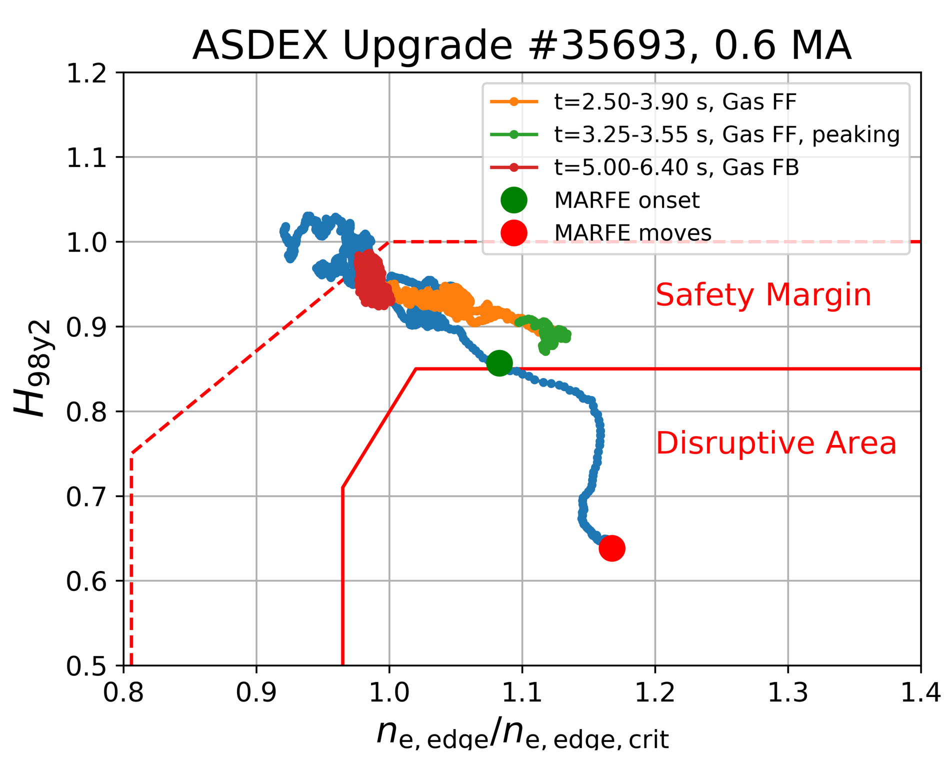
The required signals were defined and instanciated using the new DCS capability. The calculation of the heating power request to actuator management [4] was done using an AP which can calculate the distance to a configurable polygon, where negative values indicate that the point is inside the polygon.

For testing the decision logic to activate the controller was bypassed by enabling the controller via feed forward. The disruption avoidance scheme performed as expected during the experiments.

The discharge was kept outside the disruptive area while the controller was active and disrupted only after the controller was switched off and the heating power was reduced in feed forward to trigger the MARFE formation, which lead to the disruption.







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CODAC 2019, Daejeon, Republic of Korea

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