# Real Time Control of Electron Density on RFX-mod Tokamak Discharges.


Roberto Cavazzana, Cesare Taliercio, Gabriele Manduchi, Lionello Marrelli, Paolo Franz, Paolo Piovesan, and Chiara Piron

Consorzio RFX (CNR, ENEA, INFN, Università di Padova, Acciaierie Venete SpA), Corso Stati Uniti 4, 35127 Padova, Italy.



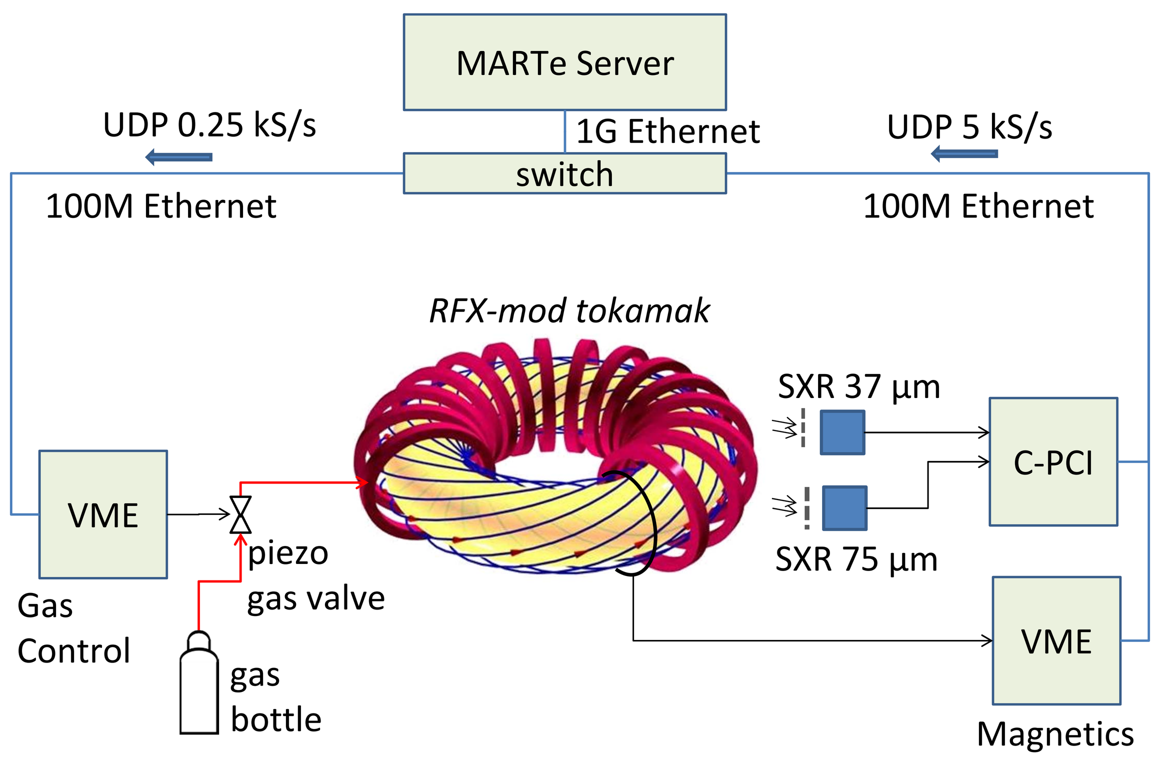
IEEE NPSS 20th Real Time Conference

P. 2 96


## 0. Introduction

A system for electron density control on tokamak plasma discharges of the RFX-mod experiment (R/a=2.0/0.46 m/m, toroidal field up to 0.55T, plasma current up to 150 kA) has been developed, implemented and subsequently routinely used during experiments.

## 2. System Architecture Layout



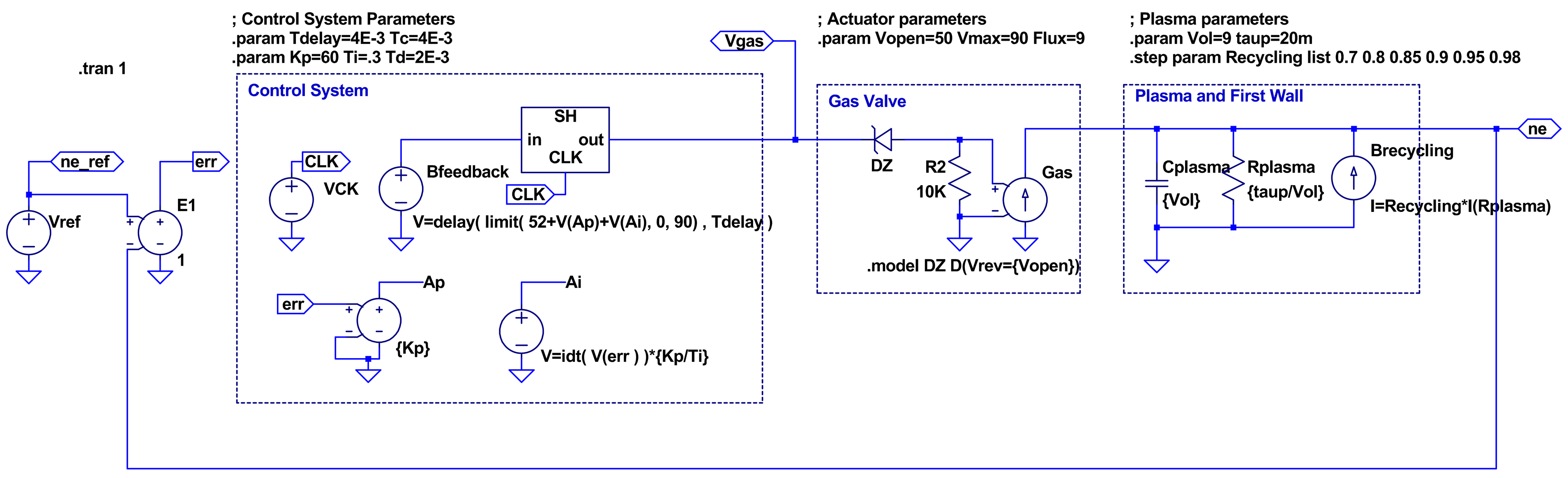

- The system integrates the existing infrastructure, without addition of new hardware.
- A new GAM module has been added to the MARTe real time framework to handle the density control.
- The software for the gas control system has been updated to receive commands from real time server.

## 1. Control System Model

**System Evolution Equation**
of the total number of principal gas particles *N*:

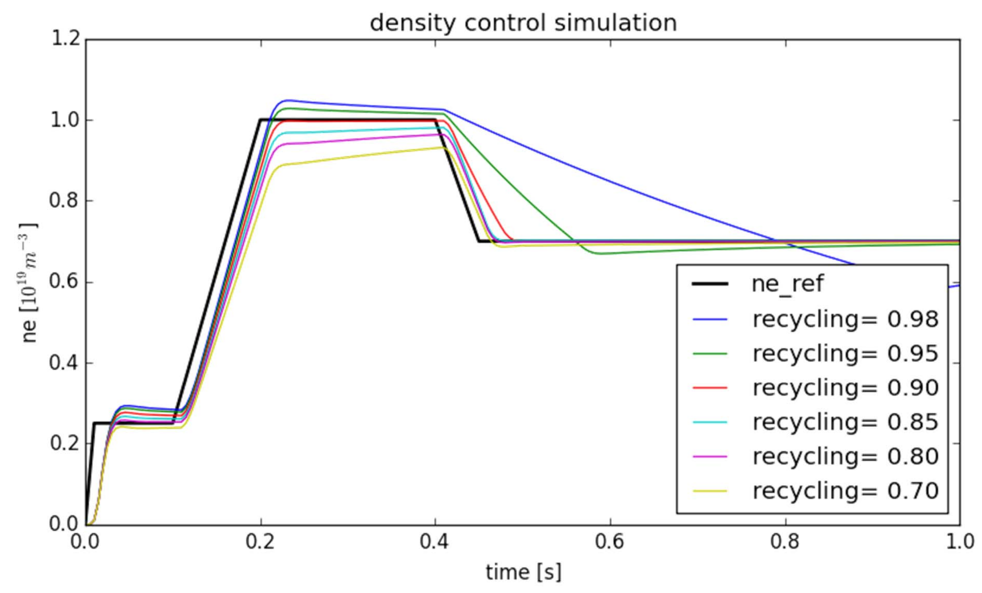
$$\frac{dN}{dt} = -\frac{N}{\tau_p} + R\frac{N}{\tau_p} + \Phi_{ext}$$

$n=N/Vol$ density.
$Vol$ plasma volume.
$\Phi_{ext}$ gas flux from by puffing valve.
$\tau_p$ particle confinement time.
$R$ Recycling factor, fraction of particles reflected back to plasma from wall (varies significantly).




Implemented using *LTSpice* simulator:

- The voltage represents the particle density *n*
- The current represents the gas flow
- The charge in capacitor Cplasma the total particle *N*
- Gas valve with dead zone
- Discrete time control system with fixed delay



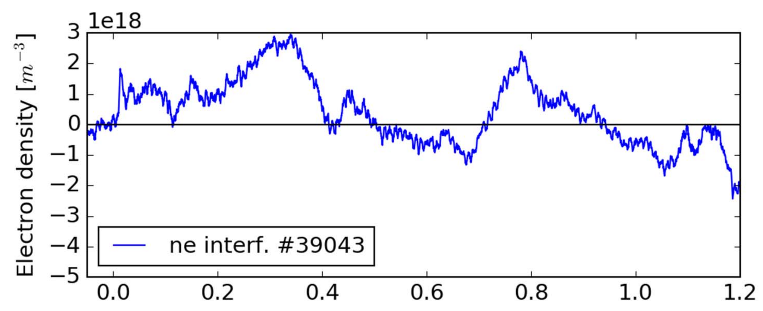

- A simple PI regulator gives satisfactory results for typical required evolutions.
- R > 0.95 is considered a situation that requires a first wall conditioning, even without control.

## 3. Density Measurement

**Reference measurements of the electron density are from microwave or laser interferometry**

- Good degree of accuracy.
- Require non-trivial processing.
- Errors from fringe jumps and vibrations: can be (not always) eliminated by data *post processing*.

*Require demanding efforts to make it suitable for real-time*



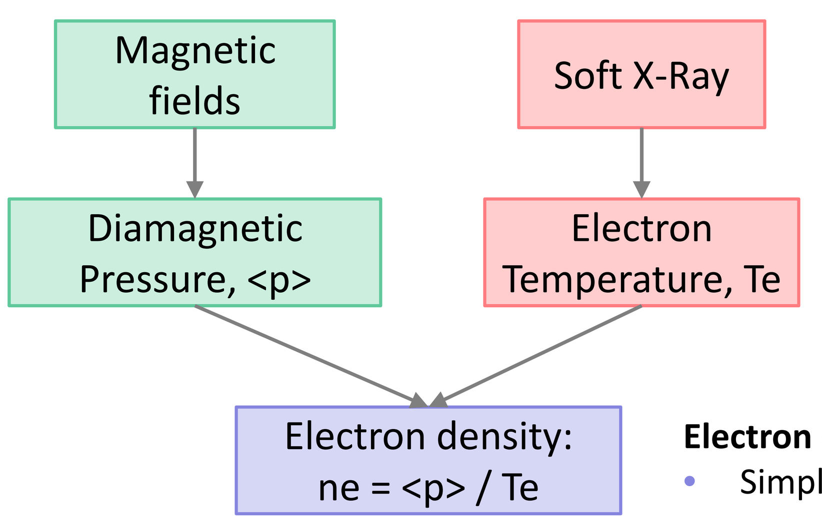

**A new technique for density measurement suitable for real time has been implemented**

- Reliable
- Easy to manipulate
- Less emphasis on precision

**Kinetic Pressure measurement**

- MHD equilibrium theory relates the reaction of plasma diamagnetic field to the kinetic pressure:

$$\langle p \rangle = \frac{1}{2\,\mu_0}\left(B_{ta}^2 - \langle B_t^2 \rangle - B_{\theta a}^2\right)$$

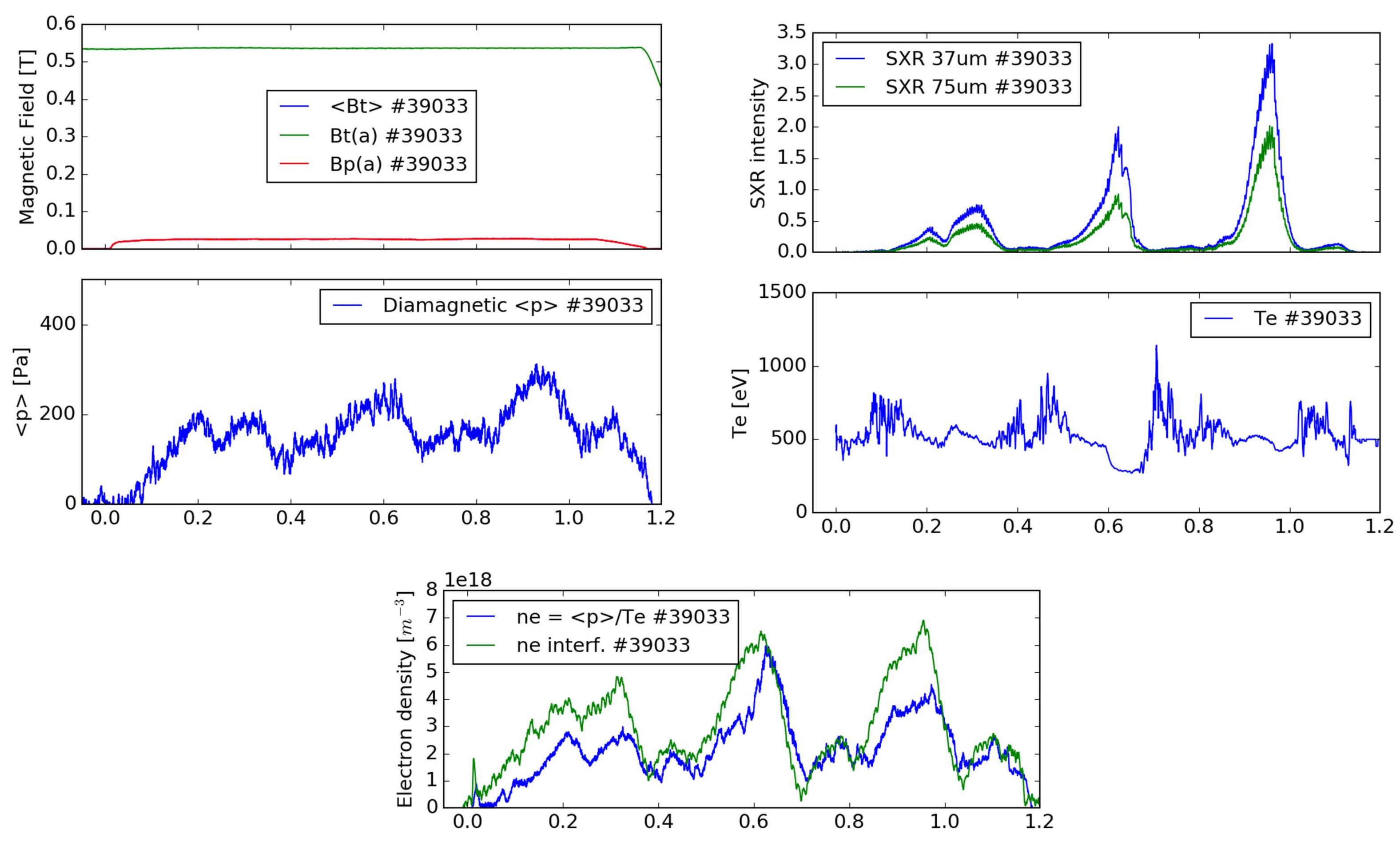



**Soft X-Ray measurement**

- Thin beryllium filters of are placed in front of different X-ray detectors.
- Energy threshold fixed by thickness .
- Ratio of filtered X-ray intensity is proportional to electron temperature.
- X-Ray intensity signals are a simple voltage output with a few kHz bandwidth.

**Electron density estimate**

- Simple ratio from ideal gas law.



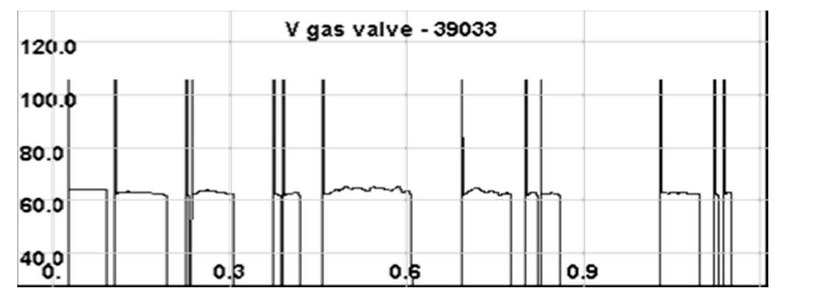

**Diamagnetic vs interferometric measurements**

- Discrepancies mainly come from X-Ray emission profile, drifts of magnetic measurement and plasma shape.
- Relatively reproducible, so can be compensated in the reference waveform by the operator.

*Note: diagnostic systems of RFX had been designed for Reversed Field Pinch configuration, and in this condition many signals are close to their noise floor level.*

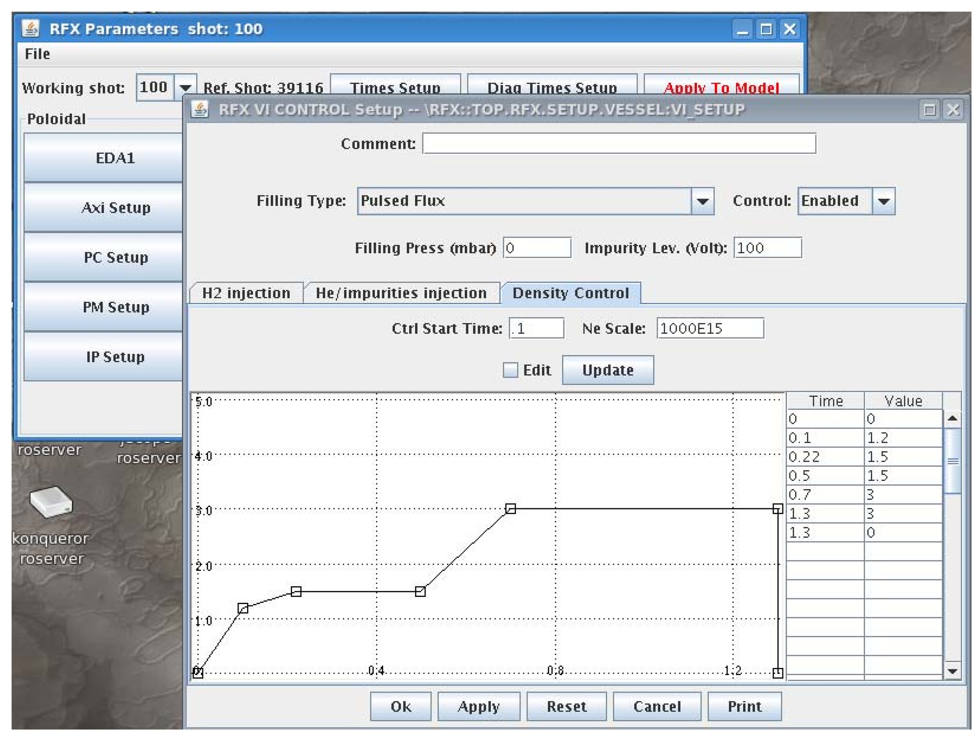
## 4. Gas Puffing Valve Control

- Asynchronous control, through UDP packets.
- The gas system accepts three parameters: V1, T1, V2.
- As the packet arrives the voltage is set to V1 for the duration T1 (0.1 ms resolution), and then to V2.
- If no packet is received before a timeout of 50ms, the voltage is set to 0 and the valve closed.

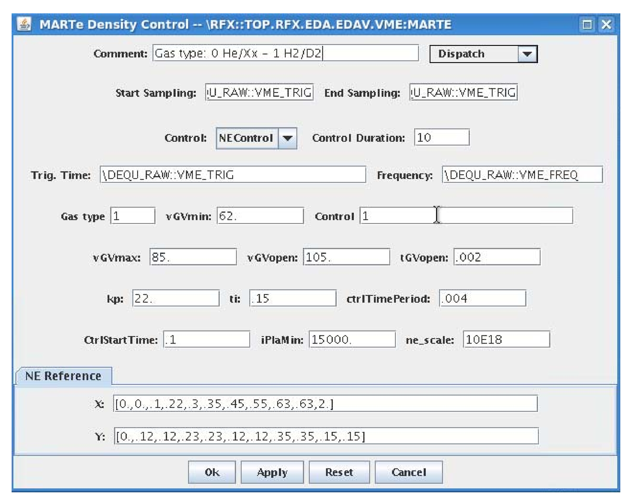



*The valve takes 50-100 ms to open if set at the typical voltage of operation (55-65V).*
*A fine tuned short higher voltage pulse (2ms@110V) is required to ensure its opening in few millliseconds.*

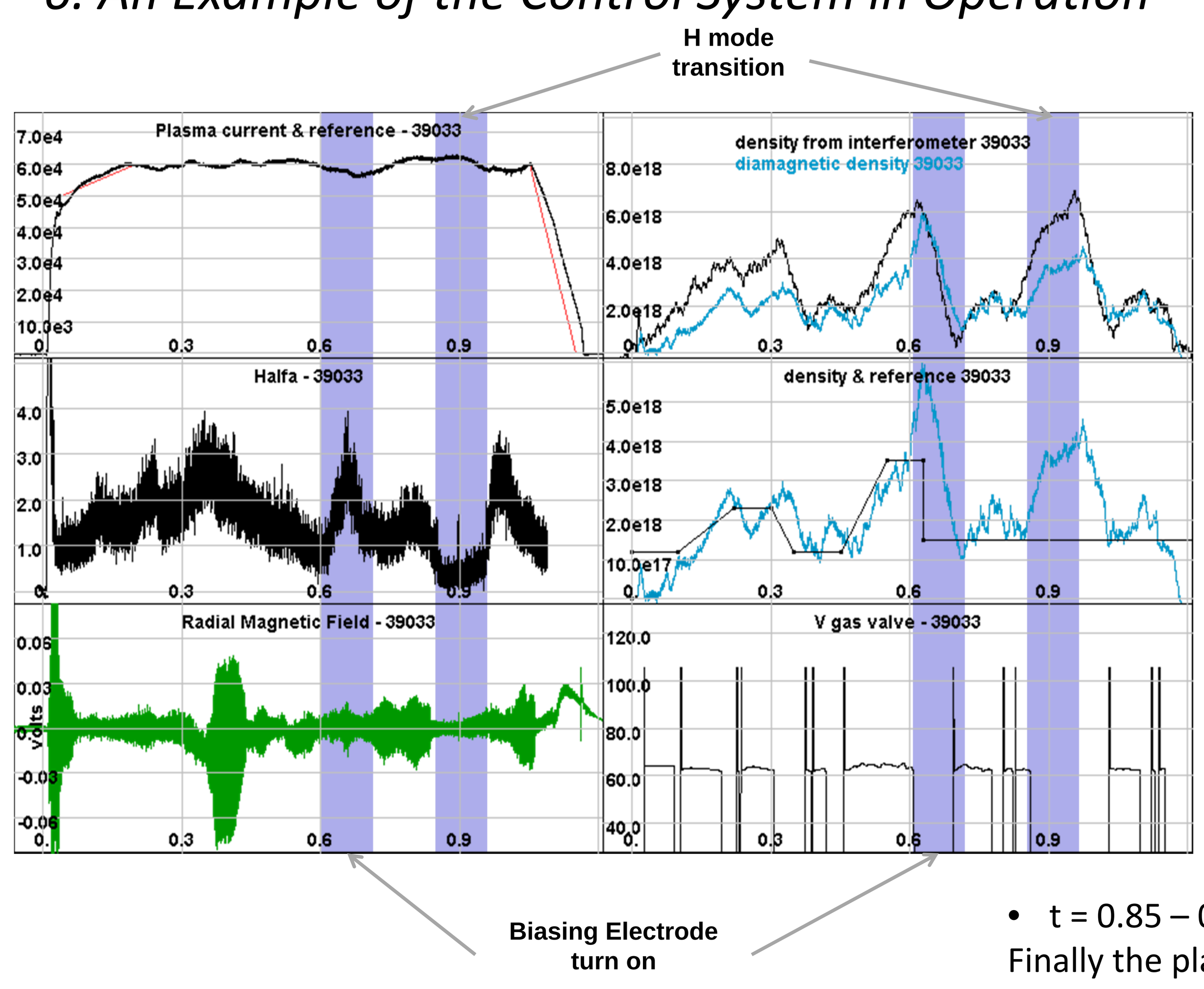
## 5. MDSplus User Interface



- The control system is managed through specific MDSplus devices.
- An user-friendly interface is exposed to the session leader of the experiment.
- Fine tuning parameters are accessed through a separate advanced interface dedicated to the technical operator.



## 6. An Example of the Control System in Operation




**An experiments with a biasing electrode applied to the plasma**

- t = 0.6 – 0.67

The bias voltage is applied (about 200A @400V ), an electric field is created and there is an increase particle flux form the wall to the plasma (Hα increases).
*The controller cuts off the gas*

- t = 0.67 – 0.85

An instability is triggered (radial field signal), the particle confinement is degraded and the density decreases.
*The controller restarts the puffing*

- t = 0.85 – 0.95

Finally the plasma enters the "H-mode" state, the instability is suppressed and the particle confinement is doubled (Hα drops). The density increases.
*The controller cuts off the gas*