Influence of Wall Conditioning on ADITYA Plasma Discharges

by ***Rakesh. L. Tanna***

Collaborators: K A Jadeja, S B Bhatt, P S Bawankar, C N Gupta, Y S Joisa, P K Atrey, R Manchanda, Nilam Ramaiya, J Ghosh, D Raju, P K Chattopadhyay, R Jha, Y C Saxena and the ADITYA team

Institute for Plasma Research, Nr. Indira Bridge, Bhat, Gandhinagar-382 428, Gujarat, India.

IVS Symposium, February 15 – 17, 2012, Kolkata, India

Outline of the Presentation

- Introduction to ADITYA Machine
- Recent upgradation in ADITYA Performance
- Experimental Conditions
- Various Wall Conditioning techniques at ADITYA tokamak
- Experimental results and Discussions of few experiments
- Summary

Introduction

ADITYA is ohmically heated limiter based tokamak and is regularly being operated with the transformer converter power supply.

- **Machine Parameters:**

  Major Radius : 75 cm

  Minor Radius : 25 cm

  Toroidal field : 0.75 – 0.9 T

  Peak loop voltage : 20 V

  Gas pressure : 8 x 10^{-5}–1 x 10^{-4} torr

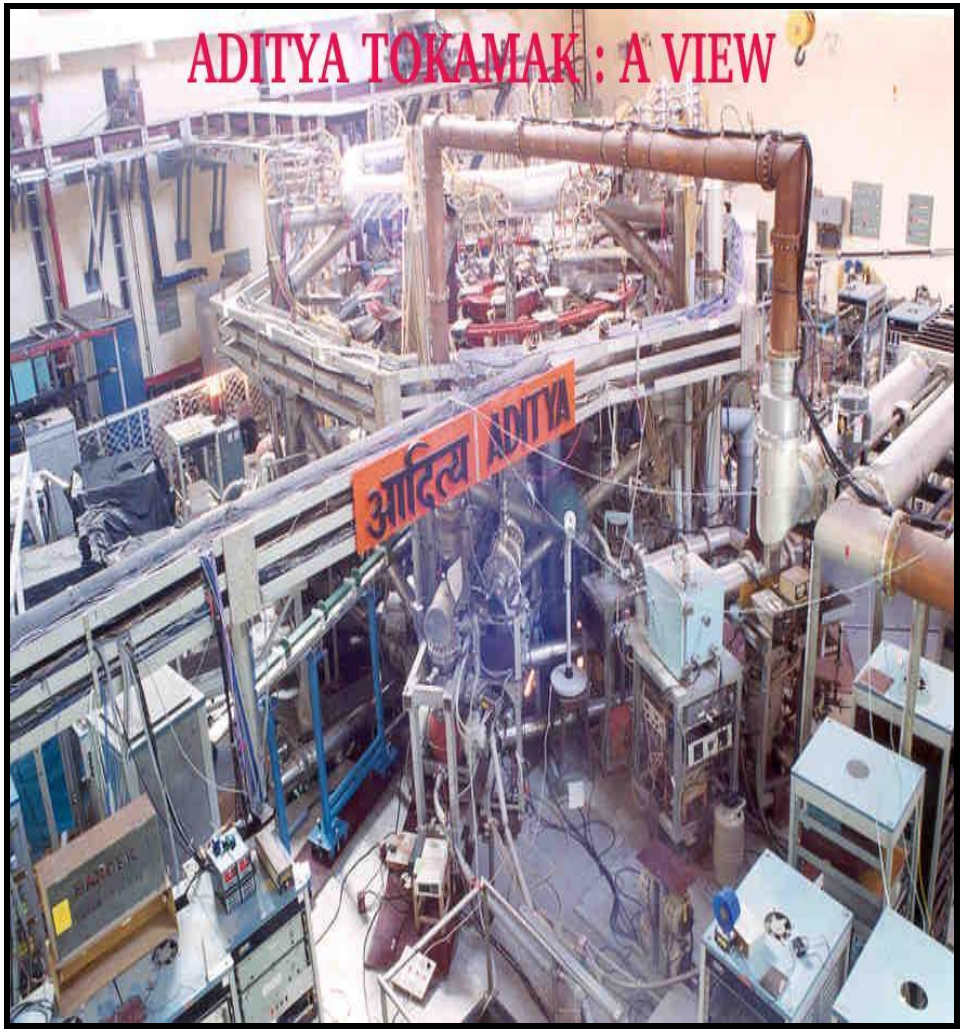
- **Plasma Parameters:**

  Plasma current : 70 – 100 kA

  Pulse Length : 100 – 275 ms

  Electron Density : 1.5 – 2 x 10^{13}/cc

  Electron Temp. : 400 – 600 eV



Recent upgradation in ADITYA Performance

- Recycling study with SiC and Graphite limier
- Low hard X-rays, high temperature Plasma Operation
- Application of Gas puff on ADITYA plasma discharges
- Plasma pulse length enhancement with negative converter
- ICRH pre ionization and assisted Start-up Experiment
- ICRH heating experiment
- ADITYA discharge operation: Helicity Experiment
- Electrode Biasing experiment

Experimental Conditions: Input Power

Toroidal (TF) magnetic field coils:

- 20 nos. of water cooled TF coils having rectangular shape are connected in series
- Max. current & field : 50 kA & 1.5 T
- Pulse length : 5 Sec.

Ohmic transformer (TR) coils:

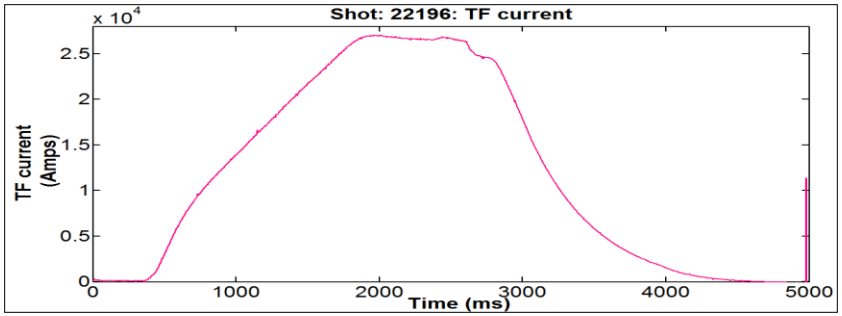
- Air core central solenoid with 4 pairs of auxiliary coils are connected in series.
- Max. current & voltage : ± 20 kA (2 kV)
- Wave shaping unit generates loop voltages
- Error field: 1 G / 1 kA current in OT coil

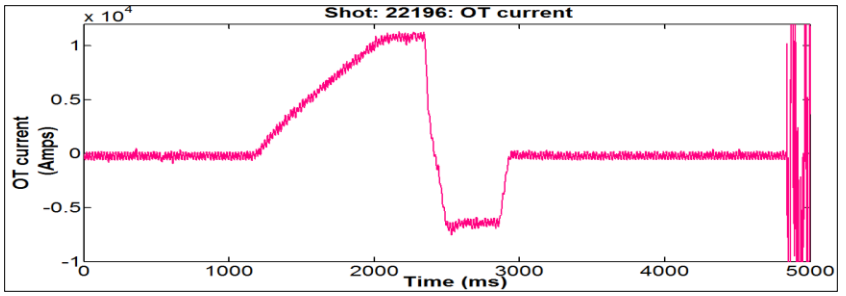
Vertical (BV) magnetic field coils:

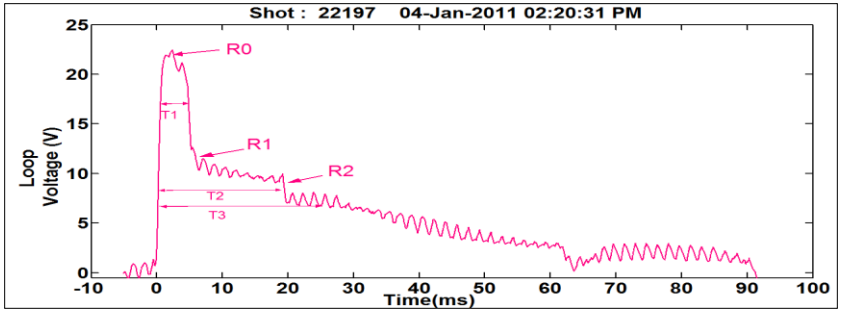
- 2 pairs of BV coils provide equilibrium field
- Max. current & voltage : 12 kA (2.2 kV dc)
- Max. field : 1000 G (4 G / 1kA of I_p)
- BV is in pre-programmed & Feed back control

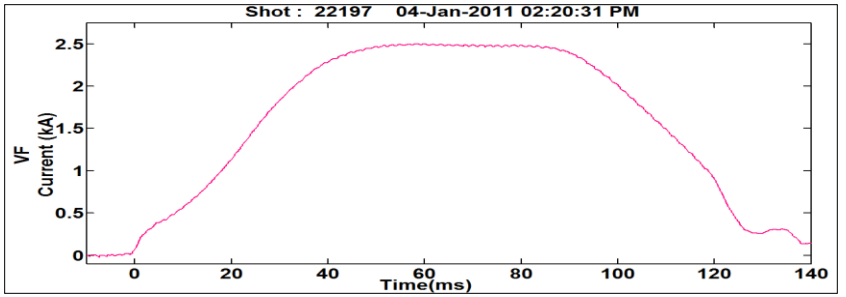
Fast Feed back (FFB) position control coils:

- 2 pairs of FFB coils are used for position control





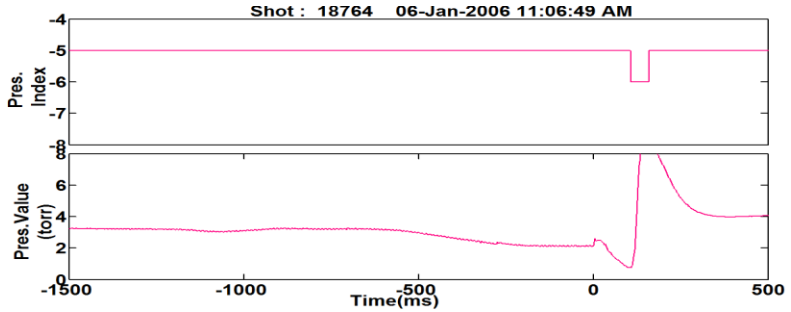




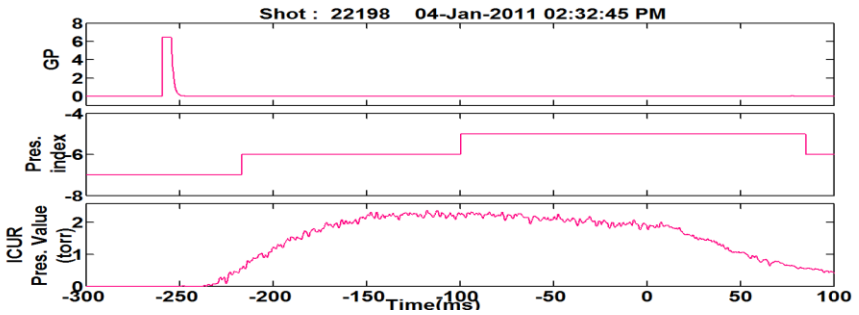
Experimental Conditions: Vacuum & Fueling

- **Pre ionization:** Filament pre ionization with filament current 19 A & Bias 150V
- **Pumping system:** 3 TMPS & 1 Cryo pump maintains base pressure ~ 1 x 10^{-7} torr
- **Gas Fueling System:** (1) Continuous (static) (2) Pulsed (Pre-filled) gas feed
- **Pressure measurements:** Ionization gauge (installed on pumping line) is used. Calibration factor: 2 (location calibration) x 2 (gas calibration)

Pressure measurement during Continuous gas feed



Ion current measurement during Pulse gas feed



- **Gas puff System:** A programmable Pulse Generator with software application is used to introduce multiple gas puff during the experiments
- **Impurity monitoring:** Partial pressure (P.P) of various Mass pieces, particularly water vapour (M#18) and $N_2/C_2H_4/CO$ (M#28) are regularly monitored with QMA. H_α & other low Z impurities viz., O-I, C-III and Visible-Cont. line radiations are monitored with Visible Spectroscopy diagnostic.

Wall Conditioning Experiments

- Lithium wall Conditioning
- Discharge with SiC and Graphite limiter

Wall Conditioning techniques of ADITYA (1/2)

1. Automated Glow Discharge Cleaning System (GDC):

Positive potential : Two UHV bellow driven movable electrodes

Negative potential : Vacuum Vessel

Discharge Voltage & current : 350 – 400 V DC and ~ 3.5 Amps

Fuel gas pressure : Hydrogen gas at ~ 8×10^{-4} to 1×10^{-3} torr

Duration : Automated for maximum 12 h

Electron Temperature : ~ 5 eV

Toroidal field (B_φ) : No

2. Pulse Discharge Cleaning system (PDC):

Ohmic charging voltage : 5 kV (V_L ~ 14 V)

Toroidal field (B_φ) : 900 G

Fuel gas pressure : Hydrogen gas at ~ 2 to 3 $\times 10^{-5}$ torr

Pulse duration & Repetition Rate : 4 ms and 900 pulse/hour

Electron Density &Temperature : ~ 1×10^{11} cm^{-3} and 5 –6 eV

Wall Conditioning techniques of ADITYA (2/2)

3. ECR Discharge Cleaning System:

Microwave Source with power : Magnetron (~ 1 kW)

Frequency : 2.45 GHz

Anode current : 200 mA

Toroidal field (B_φ) : 500 G

Fuel gas pressure : Hydrogen gas at ~ 2 to 3 $x10^{-5}$ torr

ECR Duty cycle : 66 %

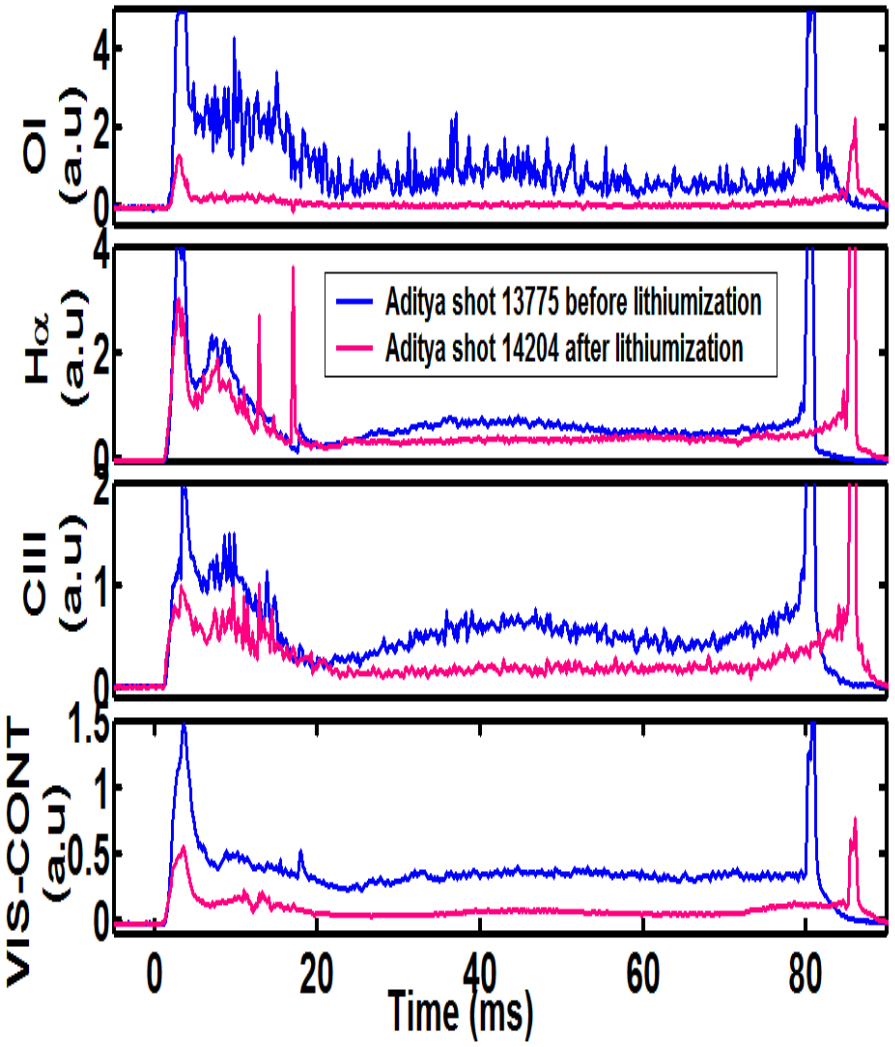
Electron density (ECR +PDC) : 6 x 10^{11} cm^{-3}

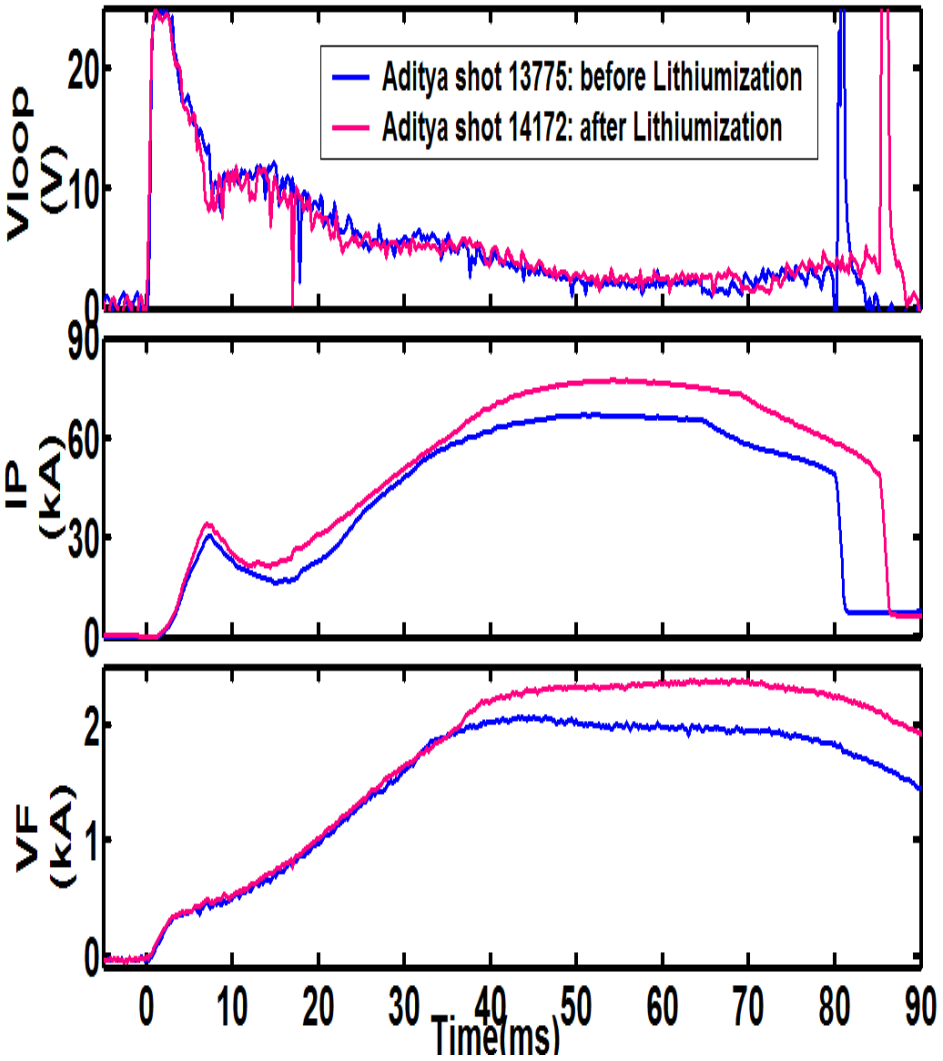
4. Lithium wall conditioning technique:

- Two Li rods of 12 mm diameter were inserted 20 mm inside the plasma volume.
- Lithium was exposed during ECR, PDC, GDC as well as actual plasma discharges.
- GDC assisted Lithiumization was found to be the most effective technique.
- Observed significant reduction in H_α & O-I, C-III, Vis. continuum line radiations.
- Plasma current rise rate becomes faster after Lithiumization.

Effect of Lithium Wall Conditioning

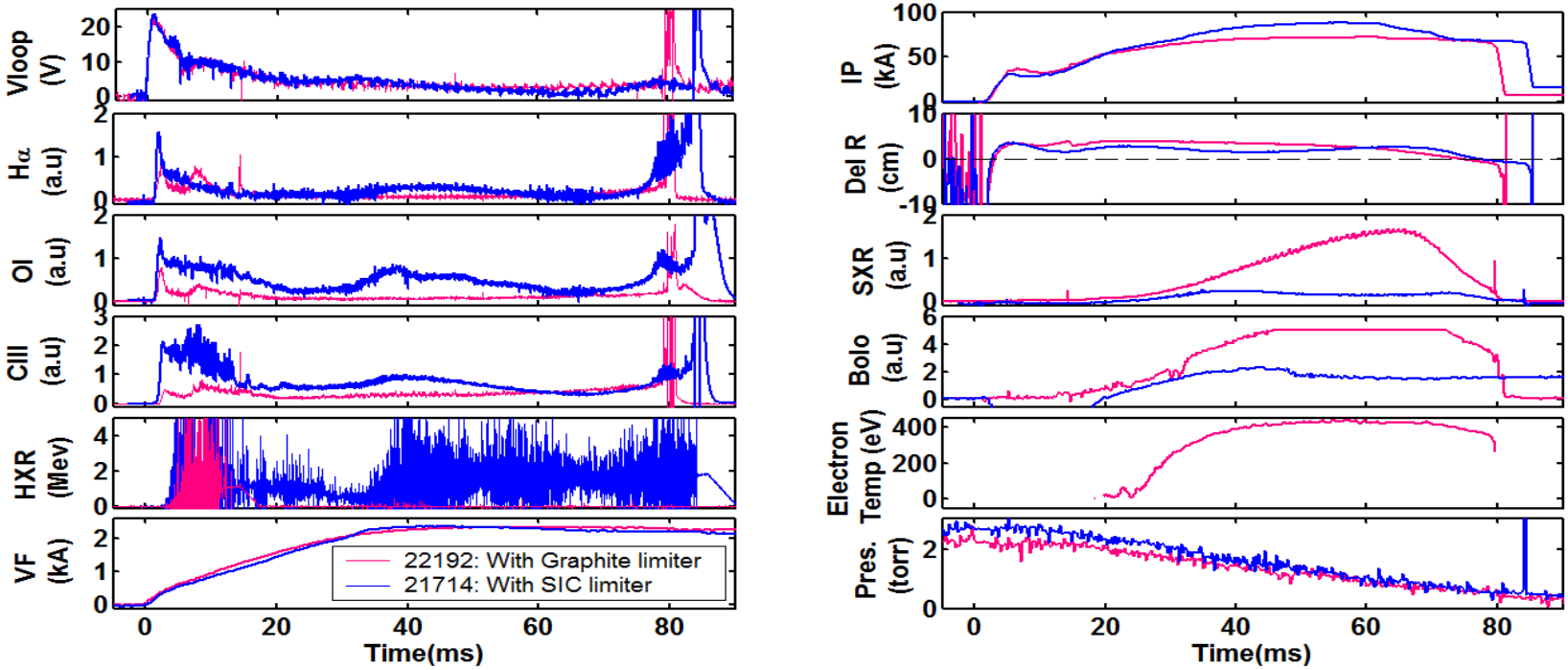
Discharge comparison before and after GDC assisted Lithiumization





Recycling Study with SiC and Graphite Limiter

Aditya discharge comparison with SiC and Graphite limiter



❖ Increase in H_α and C-III, O-I impurity line radiation restricts the electron temperature rise in the case of SiC coated graphite limiter based discharges.

❖ In case of SiC coated graphite limiter, hard X-rays could not be controlled even with maximum gas pressure of 1 x 10^{-4} torr and lowest E/P up to 425 V/torr-cm.

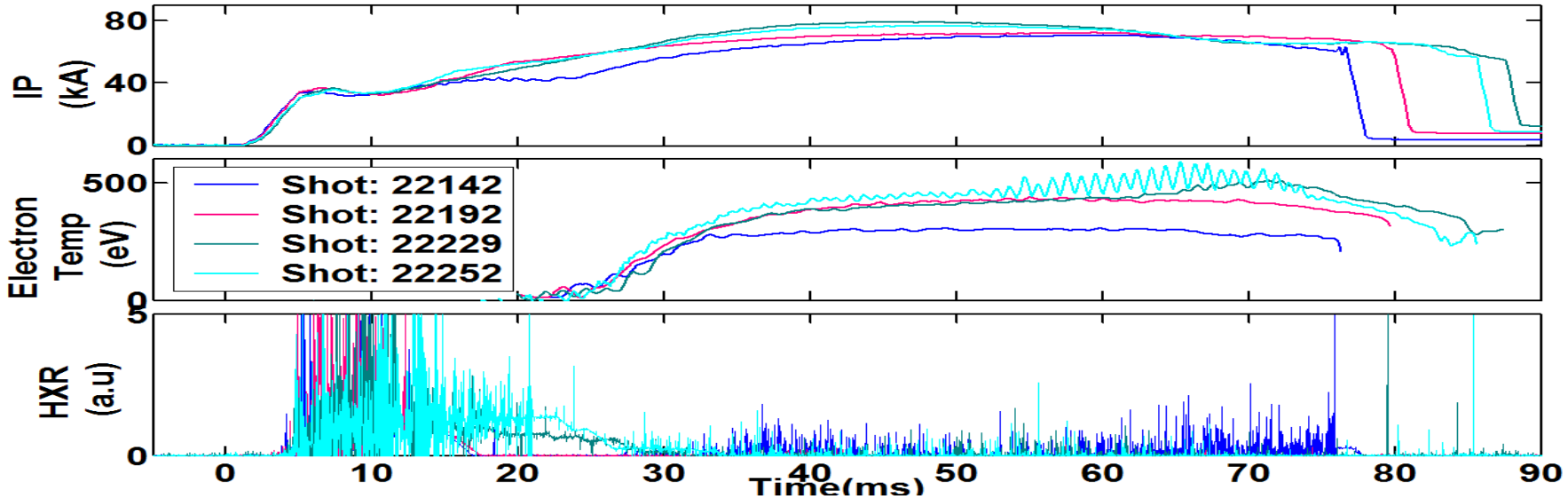
❖ Significant reduction in hard X-rays (except for first 10 ms) is observed with graphite limiter. This is also reflected in the plasma current driven by runaways.

Plasma heating Progress with Graphite Limiter

❖ Excellent plasma heating is observed in many discharges with graphite limiter. The electron temperature and wall conditioning progress is tabulated in Table 1.

Shot Series	Wall conditioning	Partial pres. (M# 18) (torr)	Partial pres. (M# 28) (torr)	Base pres. (torr)	Electron Temp. (eV)
22124 -22148	12 h GDC	6.7×10^{-9}	5.6×10^{-8}	3.6×10^{-7}	300 eV
22149 -22172	12 h GDC	5.8×10^{-9}	2.5×10^{-8}	3.4×10^{-7}	400 eV
22173 -22196	12 h GDC	4.4×10^{-9}	2.4×10^{-8}	3.1×10^{-7}	450 eV
22210 -22237	12 h GDC (limiter backing)	4.4×10^{-9}	2.1×10^{-8}	2.7×10^{-7}	500 eV
22238 - 22263	12 h GDC	3.0×10^{-9}	2.1×10^{-8}	2.9×10^{-7}	600 eV

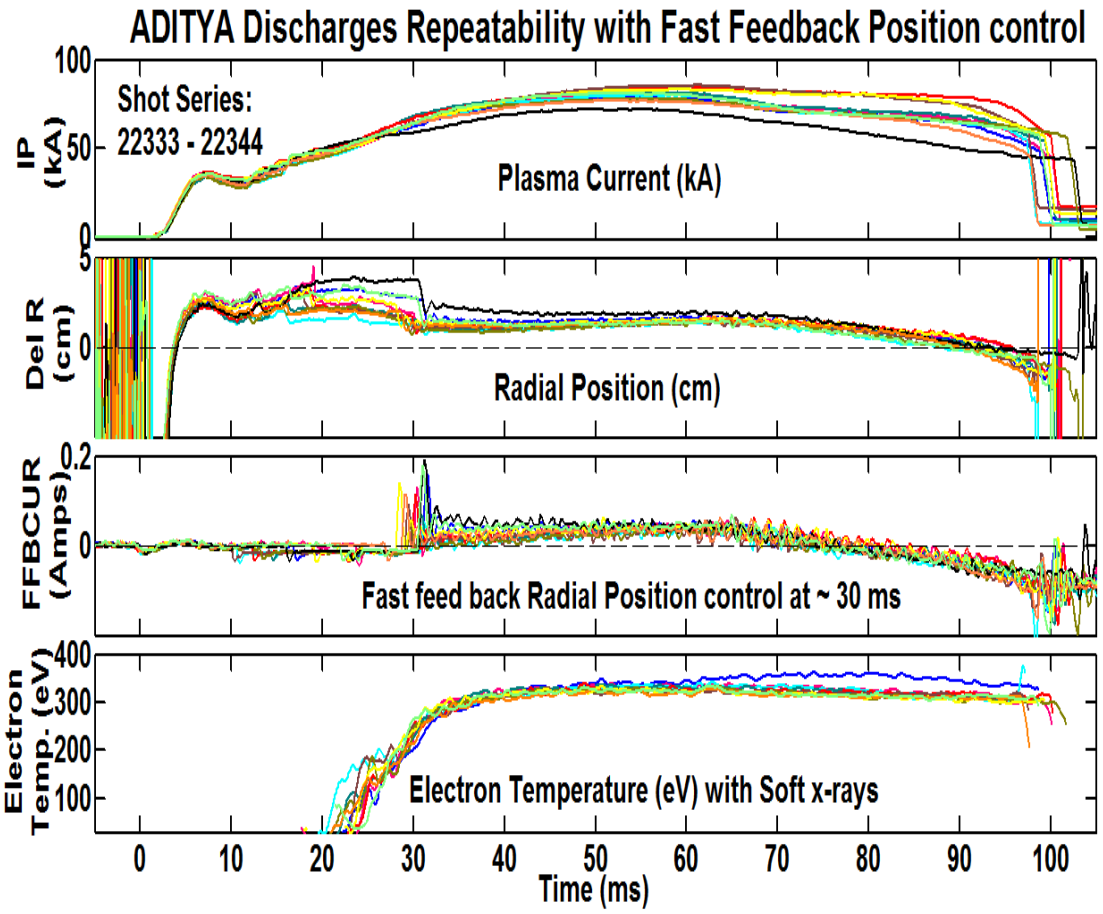
Discharges with plasma heating progress after installation of Graphite limiter



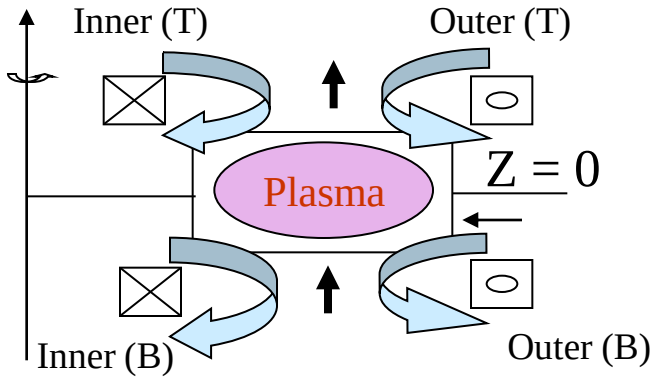
Performance improvement Experiments

- Discharge Repeatability
- Gas puffing experiment
- Application of Negative converter

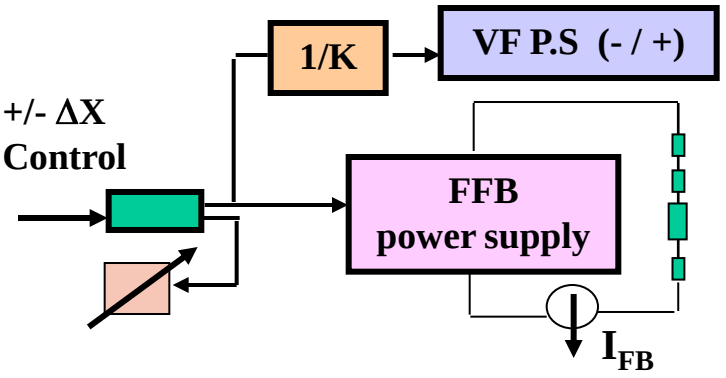
ADITYA Discharges Repeatability



Vertical cross-section view of FFB coils



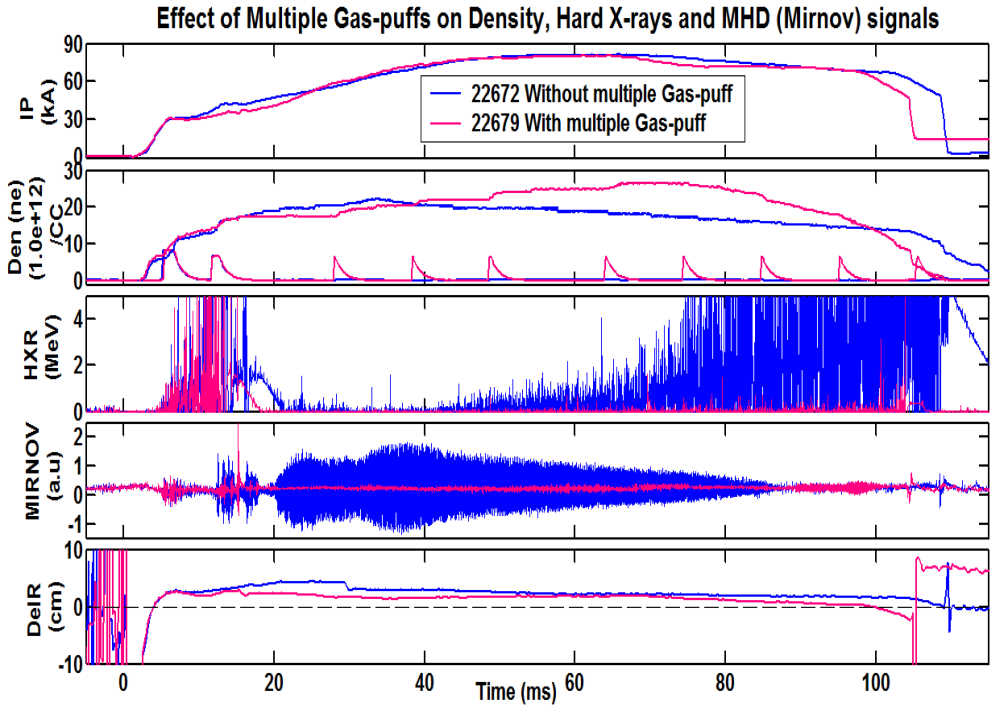
Block diagram of FFB power supply



- Achieved 13 repeatable discharges with good heating and stable electron temperatures with plasma position feedback control and limiter baking.
- Sufficient pumping time was provided between two consiquitive shots and Partial pressure of water vapour and nitrogen was monitored before each shot.

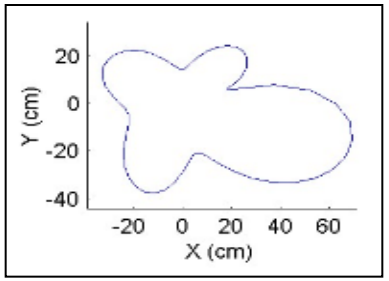
Effect of Gas puff on ADITYA Discharges

Effect of multiple gas-puff on hxr, density and MHD

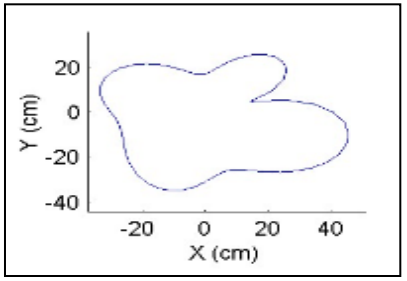


Mirnov Data Analysis for Shot: 22672

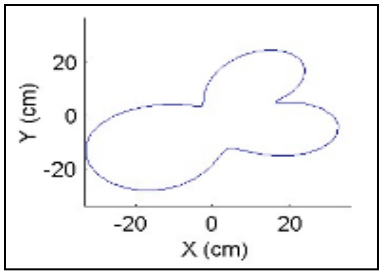
32 – 34 ms, m = 4 mode



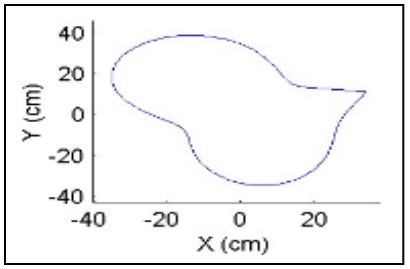
46 – 48 ms, m = 4 mode



72 – 74 ms, m = 3 mode



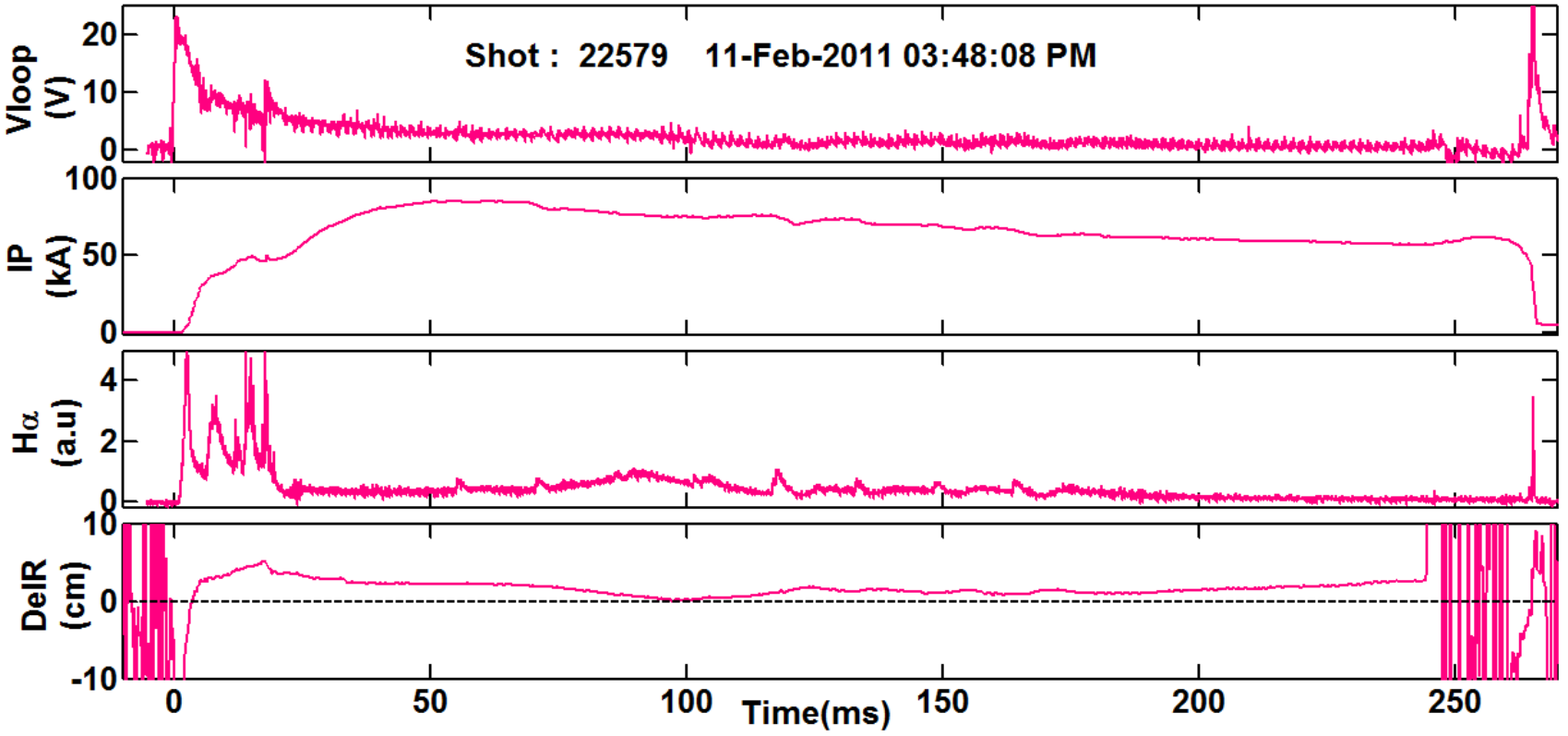
82 – 84 ms, m = 2 mode



- In absence of Gas puff, plasma column shifted towards outer wall interacts with impurity that strikes the MHD mode. Chord average electron density falls, which brings lots of runaways.
- Hydrogen gas pulses of 10 nos. with typically P.W ~ 0.2 ms and amplitude ~ 100 V raised electron density max. up to 2.8 x 10^{13}/ cc as well as control MHD and hard X-rays. Stable plasma position is observed in discharge with multiple gas puff .

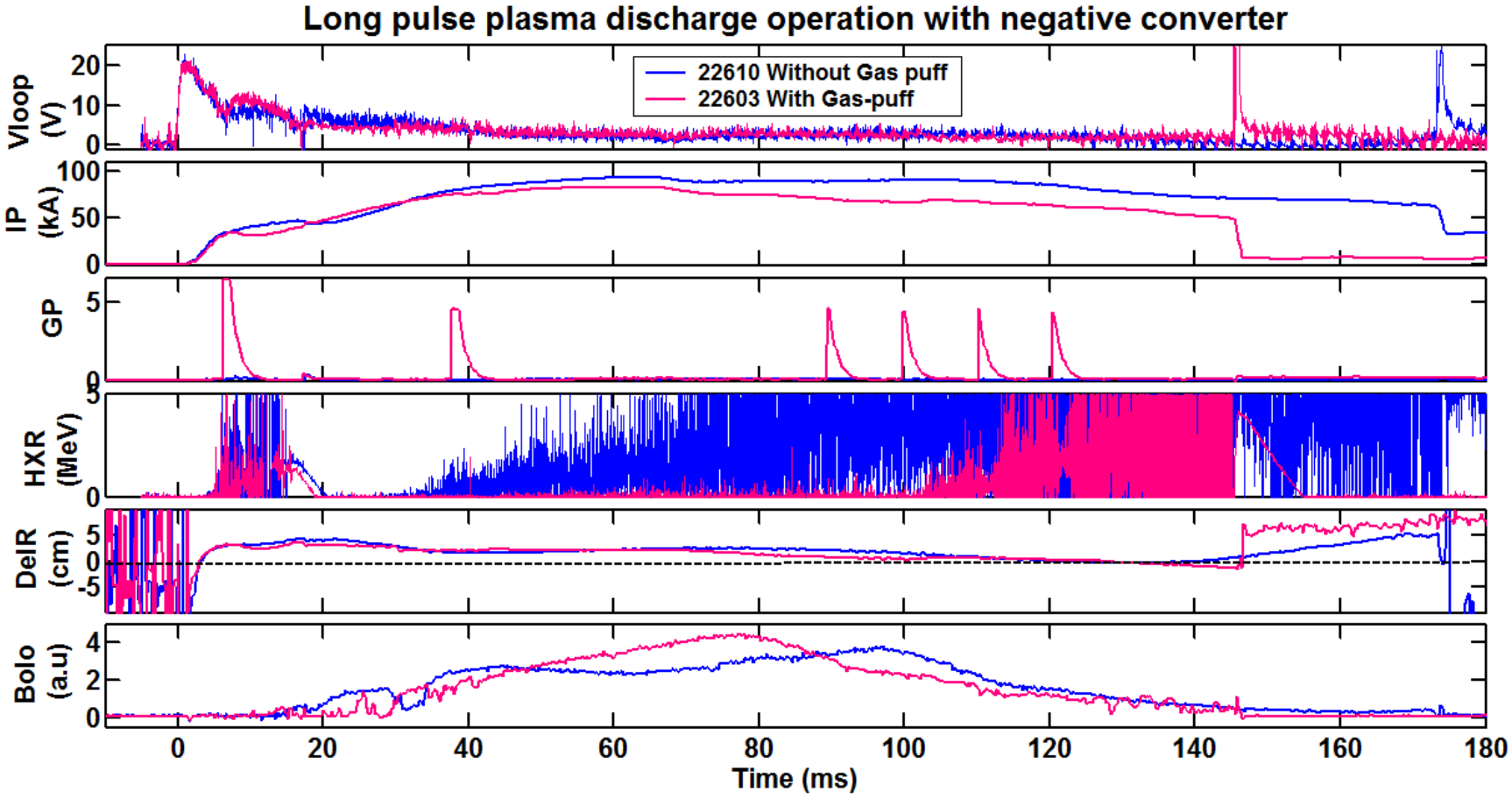
Pulse length enhancement with Negative converter

Long Pulse Plasma Discharge Operation with Negative converter



- Ohmic current swing was extended in the negative direction to generate loop voltage up to 275 ms. Discharge duration of 270 ms is obtained through tuning of parameters.
- Plasma current starts falling in auxiliary phase (~ 100 ms) due to decreasing loop voltage during that phase and remains at lesser value during negative converter phase.

Effect of Gas puff during long pulse operation



- Multiple gas-puff were introduced during the middle of the discharge helps in control the hard X-ray up to some plasma length.
- The max. electron density of the order of 3 x 10^{13} /cc and electron temperature of the order of 500 eV was observed.

Summary

- In recent operation campaign, ADITYA machine has been successfully operated for various performance improvement experiments.
- GDC assisted Lithiumization was found to be the most effective wall conditioning technique for significant reduction of impurity line radiations.
- The experiment on recycling study with SiC coated graphite limiter and graphite limiter, revels significant reduction in H_α and CIII, O-I impurity line radiation in discharges with graphite limiter.
- The excellent plasma heating improves the electron temperature up to 500 to 600 eV after installation of graphite limiter.
- Optimum parameters tuning, better wall condition and FFB position control provide excellent repeatability of ADITYA discharges.
- Application of multiple gas puff during the course of a discharge raised electron density and controls MHD activities as well as hard X-rays.
- Plasma pulse length enhanced beyond 250 ms is achieved with the application of negative converter. The drops in plasma current nearly around ~ 100 ms is because of slightly lower loop voltages during auxiliary converter phase. This issue will be resolved in near future.

Thank you very much for your kind attention