Fundamental O-mode ECRH assisted Low-loop voltage plasma start-up in tokamak ADITYA-U

Braj Kishore Shukla, Joydeep Ghosh, R.L. Tanna, S.K. Pathak, P.K. Atrey, Mahesh Kushwah, Jatin Patel, Harshida Patel, D Purohit, Hardik Mistry, K.G. Parmar, Ranjana Manchanda, Devilal Kumawat, Umesh Nagora, V. Balakrishnan and ADITYA-U Team

Institute for Plasma Research
Bhat, Gandhinagar (Gujarat) India 382428

The EC assisted low-loop voltage plasma start-up experiments have been carried in Tokamak Aditya-U. The 42GHz ECRH system is used for off-axis breakdown in tokamak, which is operated at a toroidal magnetic field of ~ 1.2T to 1.4T. The EC power in fundamental O-mode is launched from low field side of the tokamak. The EC power and duration for breakdown are varied from 75kW to 150kW and from 50 ms to 100 ms respectively. The ECRH power is launched around 25ms before the start of the loop voltage and successful plasma start-up is achieved with 40% reduction in the peak loop voltage. In ADITYA-U, the gas breakdown and successful plasma start-up is normally achieved at peak loop-voltage of ~20V (Electric field ~ 4.5V/m). In these EC-assisted low-loop voltage plasma start-up experiments, the peak loop voltage is reduced to ~40 % (~12V) by reducing the resistance values in the ohmic circuit and successful EC-assisted plasma discharges with plasma current ~115kA and discharge duration of ~250ms has been achieved at ~12V loop-voltage.

1. Introduction

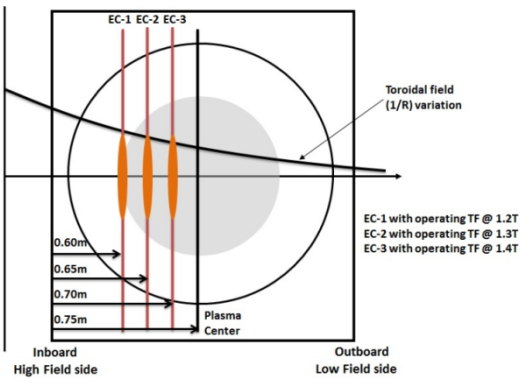
The 42GHz Electron Cyclotron Resonance Heating (ECRH) system has been re-commissioned on tokamak Aditya-U [1]. The tokamak Aditya-U has been upgraded with open diverter configuration [2]. The major radius of tokamak Aditya-U is 0.75m and minor radius is 0.25m. The toroidal magnetic field of tokamak is 1.5T but it is being gradually increased from 1.2T to 1.4T. The target plasma current for Aditya-U is 150 to 250kA with plasma duration more than 300ms. The diverter plasma is aimed to elongate with elongation of ~1.2 with triangularity ~ 0.45. The ADITYA-U focuses on the experiments like plasma heating, low-loop voltage start-up, generation and control of runaway electrons, disruption prediction and mitigation studies, along with plasma position control and confinement improvement studies with shaped plasma etc.

The normal loop voltage of Aditya-U is around 20V which corresponds to electric field around 4.5V/m. The Aditya-U operates with this loop voltage and normal plasma shots are achieved with plasma current ~ 150kA and duration around 250ms. The ECRH assisted low-loop voltage start-up saves the volt-seconds consumption and facilitates to extend the plasma shot duration. The 42GHz ECRH system is used to carry out EC-assisted low-loop voltage start-up. Several experiments have been carried out with successful low-loop voltage start-up

with extended duration plasma shots. The tokamak has been operated to 40% lower loop voltage and corresponding the plasma duration is increased as per the saved volt-seconds.

2. Off-axis ECRH experiments in Aditya-U

The toroidal magnetic field of tokamak Aditya-U is gradually increased from 1.2T to 1.4T, accordingly for 42GHz ECRH, the electron cyclotron resonance (ECR) layer shifted from inboard side to plasma centre. The ECR layers at different operating magnetic fields are shown in figure 1. Thus all the experiments of EC-assisted low-loop voltage start-up are carried out with plasma formation at inboard side.



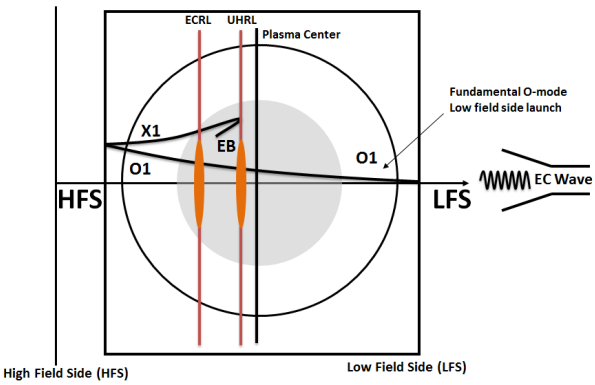


Figure 1 (Off-axis ECR layers at different magnetic fieldsFigure 2(Schematic of EC-wave in plasma)

The 42GHz ECRH system is used to carry out EC-assisted low-loop voltage experiments. The typical parameters for EC experiments in Aditya-U are shown in Table 1.

Table 1

ECRH parameters for Aditya-U	**Parameters**
Frequency	42GHz
ECRH Power	150 to 250kW
Pulse duration	70ms to 150ms
Mode	Fundamental O-mode (low field side)
EC pulse starting time	-30ms (30ms before the loop voltage)
Tokamaktoroidal magnetic field	1.2T to 1.4T

The fundamental O-mode is launched from the low field side. The EC wave absorbs with O-X-B conversion mechanism as the O-mode does not absorbs fully in its first pass especially in the case of pre-ionization when there is low density and temperature. This O-mode gets

reflected from the inner wall of tokamak and after the reflection it is a mixed polarization (O- and X-mode). This corresponds to fundamental X-mode launch from the inboard side, which in-principle absorbs fully in its first pass as it faces ECR layer first and then faces the upper hybrid resonance layer (UHR). At UHR again its mode converts from X-B (extra ordinary to Bernstein mode), which absorbs better. The schematic of EC wave trajectory inside tokamak is shown in figure 2.

3. Low-loop voltage EC-assisted experiments:

The normal peak loop voltage in Aditya-U is ~20V. For low-loop voltage experiments, the loop voltage is reduced by reducing the resistance in the primary of ohmic transformer. The resistances are reduced from 0.72Ω to 0.36Ω and finally 0.3Ω. The loop voltages at different resistance settings of ohmic is shown in figure 3, from the figure, it is seen that the saved volt-second stretches the loop voltage for around 30ms.

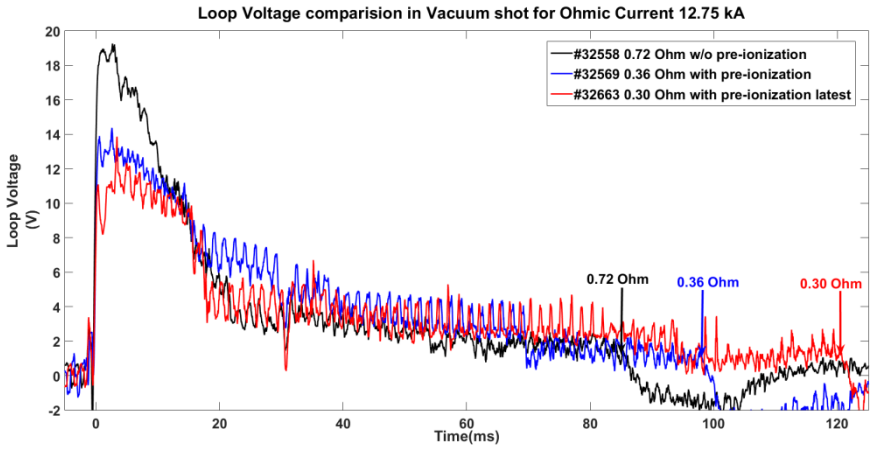


Figure 3 (Low loop Voltage setting for EC assisted start-up)

With reduced loop voltage, the plasma shots have been carried out with EC-assisted pre-ionization. Approximately 150kW ECRH power in O-mode is launched around 30ms before the loop voltage. The EC pulse duration is varied from 70ms to 100ms. Since, the EC-power is launched at fundamental harmonic, there is no delay in breakdown as Hα appears immediate with the EC-power. The standard Aditya-U plasma shot (shot no. 32710) at low-loop voltage assisted with EC power is shown in figure 4. In this shot, 178kA plasma current is achieved at 11V loop voltage. The plasma shot duration is more than 335ms. In figure 5, two plasma shots have been compared, shot no. 32528 at 20V loop voltage without EC power while shot no. 32584 at ~12V loop voltage with EC power. The shot 32584 shows the extended shot at lower loop voltage.

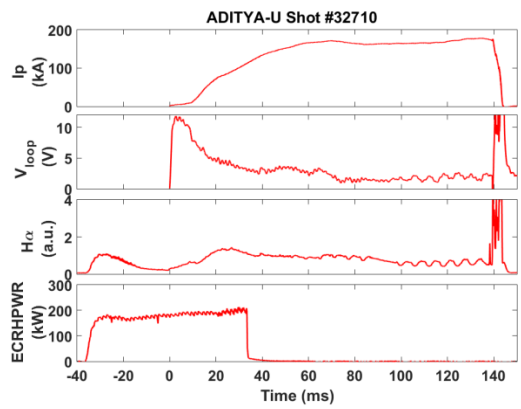


Figure 4 (EC assisted plasma shot at ~12V loop voltage)

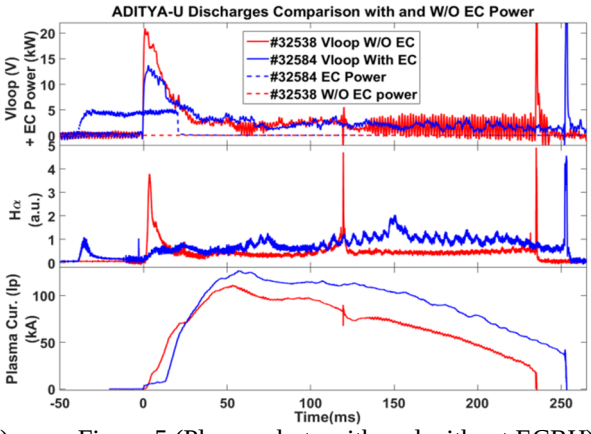


Figure 5 (Plasma shots with and without ECRH)

Since the tokamak is operated at lower magnetic field so ECR layer lies inboard side of tokamak. From the fast imaging diagnostics (Figure 6), we see the ECR layer is shining at pre-ionization stage and we can estimate the location of ECR layer is around 10cm away from the inboard limiter, which is expected at 1.2T operating toroidal magnetic field. The pre-ionized density of ECR plasma is ~$3x10^{-18}$ m^{-3}, which allows us for normal plasma discharges with plasma current ~150 to 170kA and duration ~300ms at 12V loop voltage.

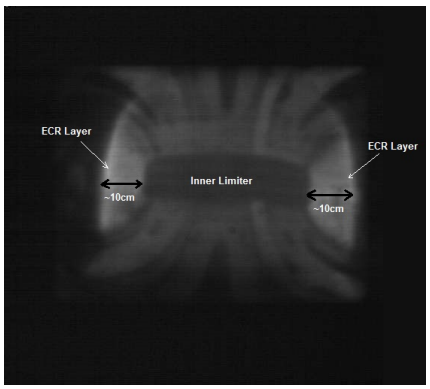


Figure 6 (Plasma shot with visible ECR layer)

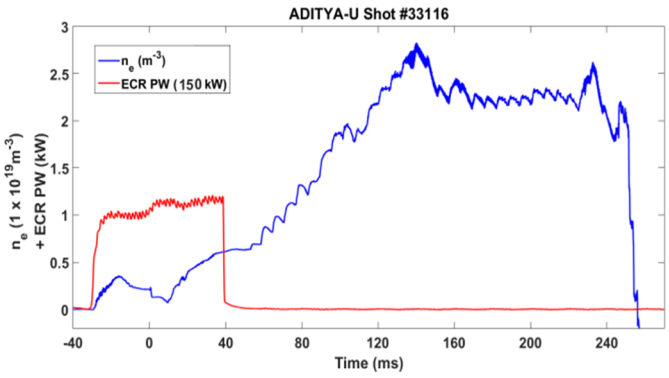


Figure 7 (Plasma density)

Summary: The ECRH assisted low-loop voltage start-up at fundamental harmonic has been achieved successfully in tokamak Aditya-U. The 42GHz ECRH power has been used at fundamental harmonic, the operating toroidal magnetic field of tokamak is increased gradually to 1.4T and off-axis breakdown is achieved with inboard side plasma formation. With the proper profiling of vertical field, the normal discharges (with plasma current up to 178kA) have been achieved at 12V loop voltage with extended duration up to 335ms.

References:

[1] “Commissioning of 42GHz Electron Cylotron Resonance Heating system on Tokamak Aditya-U” Braj Shukla et.al., Fusion Engineering and Design, March 2019

[2] “Overview of operation and experiments in the ADITYA-U tokamak” R.L. Tanna et.al. Nuclear Fusion, Vol. 59 (2019), 112006 (16pp)