Study of electrode biasing in the edge and SOL regions of a Tokamak

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Abstract

An extension of the previous work (V. Shankar *et.al.*, 2022) has been done to study further the effect of the electrode biasing (EB) in the edge region on the interchange plasma turbulence. Both positive and negative EB biasing have been studied. It is found that EB modifies the power spectral density (PSD) of the density time series in the edge and SOL regions. PSD in the edge region before the position of the electrode is higher for the positive bias in the 5-70kHz frequency range, but PSD for the negative biasing decreases than the without (w/o) biasing. In the SOL region, PSD for both the biasing is lower in comparison to w/o biasing. Analysis of k_y spectrum for both the bias cases shows the reduction of k_y in the edge and SOL regions in comparison to w/o bias. The heat and particle loads on the plasma-facing components have been investigated as a function of biasing voltages. It is found that the SOL width related to the heat and particles decreases with the biasing.

1 Introduction

Edge and scrape-off layer (SOL) regions of a tokamak are dominated by the interchange plasma turbulence [1, 2, 3, 5, 4]. Biasing in the edge region can be done by putting an electrode there. EB can modify the turbulence so that the recycling, exhausts, confinement time, reduction of heat loads on the limiter plates, etc can be controlled. In earlier work [6], derivation of model equations in the presence of the interchange plasma turbulence had been done. These model equations consist of the electron continuity, quasi-neutrality, and electron energy equations. Analysis of the linear growth rates in the edge region in the presence of EB using a uniform electron temperature approximation and also using the finite electron temperature gradient had been done. Fully, nonlinear equations had been solved numerically using BOUT++ platform. From the simulation results, it was reported that the positive biasing lead to a larger increment in plasma density and temperature as compared to the negative biasing. It was found that the radially outward flux decrease mainly due to the decrease of cross-correlation between density and poloidal electric field fluctuations.

In the present work, we have extended the studies of EB in the edge and SOL regions using the two dimensional (2D) interchange plasma turbulence simulations. From the simulation results, it has been found that EB affects PSD of the density fluctuations obtained from the density time series. PSD label increases for the positive biasing in the 5-70 kHz range than the without (w/o) biasing in the edge region. In the SOL region, PSD is always lower than w/o biasing. Also we have presented k_y spectra in the edge and SOL regions. It is found the k_y spectrum shifts towards lower values with the positive biasing. The reduction of the SOL widths related to the plasma density and electron energy has been obtained from the biasing simulations.

2 Simulation Results

Here, we will discuss the results obtained from the fully non-linear solutions of the equations in the edge and SOL regions in the presence of edge biasing [6]. The equations have been solved in $128\rho_s \times 256\rho_s$,

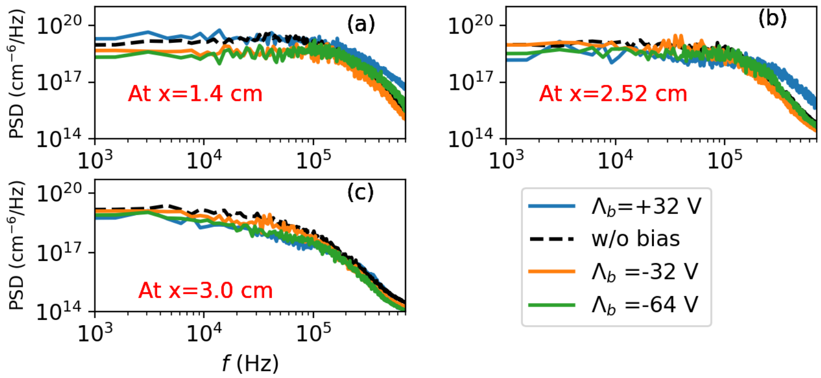

Figure 1: PSD vs f, before the electrode (a), between the electrode and LCFS (b), and in the SOL regions (c).

where $128\rho_s$ and $256\rho_s$ indicate the radial and poloidal dimensions. The edge region is represented by 0-$64\rho_s$ and the SOL region is represented by 64-$128\rho_s$. Here, ρ_s denotes the ion gyroradius. The biasing has been done at $42\rho_s$. Typical Aditya-U parameters have been used for the simulations. These are plasma density at the last closed flux surface $n_0 = 5 \times 10^{12}/\mathrm{cm}^3$, electron temperature $T_e \sim 16$ eV, toroidal magnetic field $B \sim 1$ Tesla, major radius $R \sim 100$ cm. Using these parameters, we get $\rho_s \sim 4 \times 10^{-2}$ cm [6]. The biasing voltages have been varied from $+64$ to -64 volts and assumed that the biasing is poloidally continuous.

We have calculated PSD of plasma density fluctuations with respect to frequency (f) as shown in Figs-1(a)-(c). Three radial positions have been used (x =1.4 cm, 2.52 cm, and 3.0 cm) as shown in Figs.1(a), (b), and (c), respectively for the biasing voltages +32 V, -32 V, -64 V, and w/o bias. In Fig.1(a), $x = 1.4$ cm ($35\rho_s$) is the radial position that lies before the biasing electrode. Here, in 5-70 kHz frequency range, the magnitude of PSD for biasing potential +32 volt, is higher than PSD obtained from w/o biasing, but for -32 V and -64 V PSD is lower than w/o biasing. At the higher frequency ($>$ 70 kHz) PSD obtained from -32 and -64 Volts is almost similar to w/o biasing but higher for +32 volt. Therefore, the positive biasing increases PSD but negative biasing decreases PSD in the edge region. In Fig.1(b), at $x = 2.52$ cm (region between the electrode and LCFS), PSD for the lower frequency (5-70 kHz) range remains slightly lower than w/o biasing for +32 V, -32 V , and -64 V. At the higher frequency ($>$ 70 kHz), the magnitude of PSD is higher for +32 V and almost similar to w/o biasing case for -32 V , and -64 V. In the SOL region, at $x = 3.0$ cm as shown in Fig.1(c) PSD for both the biasing cases is lower than w/o biasing. The modification of PSD in the presence of the biasing is mainly due to the modification of the zonal flows.

We have investigated k_y-power spectral density (k_y-PSD) at the same three radial locations (x =1.4 cm, 2.52 cm, and 3.0 cm) as a function of time. Figure-(2) indicates that k_y-PSD has maximum value in range $k_y \sim$ (7-24) rad/cm for w/o biasing caes. In the presence of positive biasing (Λ_b= +32 V) k_y-PSD moves towards lower k_y modes. The same tendency has been found for $\Lambda_b = -64$ volt also. But for the $\Lambda_b = -32$ V range of maximum value is almost similar to w/o bias with decrease magnitude of k_y-PSD. k_y-PSD at $x = 2.52$ cm has been shown in Fig.3. Here in the case of w/o, k_y-PSD becomes maximum at slightly lower range of $k_y \sim$ (7-20) rad/cm, but in the presence of biasing, shifting of k_y-PSD not that much, but the magnitude of k_y-PSD has been reduced. In the SOL region, at $x = 3.0$ cm similar tendency has been observed as at 2.52 cm with reduced magnitude of k_y-PSD.

The width of the SOL region is an important parameter for a tokamak as the plasma-facing components are present in this region. The plasma-facing components receive heat loads due to the transport of heat in the parallel direction. The intensity of the heat load (heat load per unit area) will be minimum if the radial width of the SOL is higher. Here, the SOL width is defined by the radial width where plasma density in the SOL region decreases to its e-folding value of the density present in LCFS, $n = n_{\mathrm{LCFS}}\exp(-x/\delta_s)$. We have calculated δ_s from the numerical data in the presence of biasing. It is found that the SOL width decreases with the biasing voltages as shown in Fig.5. The SOL widths related to T_e for different biasing cases behave similarly as shown in the red color plot. The SOL widths related to the plasma density and temperature indicate that the particle and energy load intensity may increase on the limiter/divertor material in the presence of higher biasing potentials. But the plasma

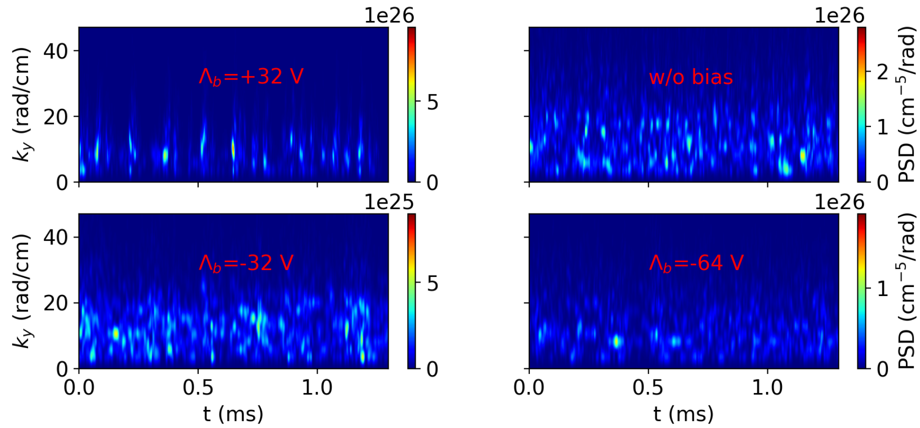

Figure 2: k_y-PSD for Λ_b = +32, −32, −64 volts and w/o bias in the edge region before the electrode (x=1.4 cm).

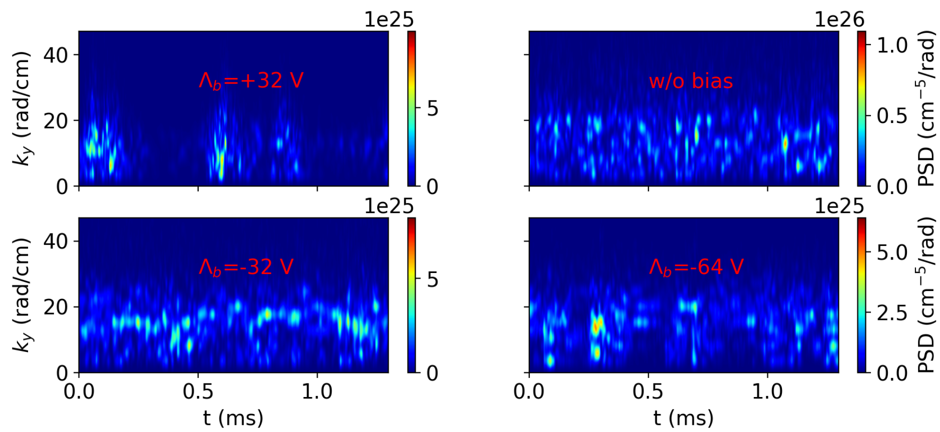

Figure 3: k_y-PSD for Λ_b= +32, −32, −64 volts and w/o bias in the edge region between the electrode and the LCFS (x=2.52 cm).

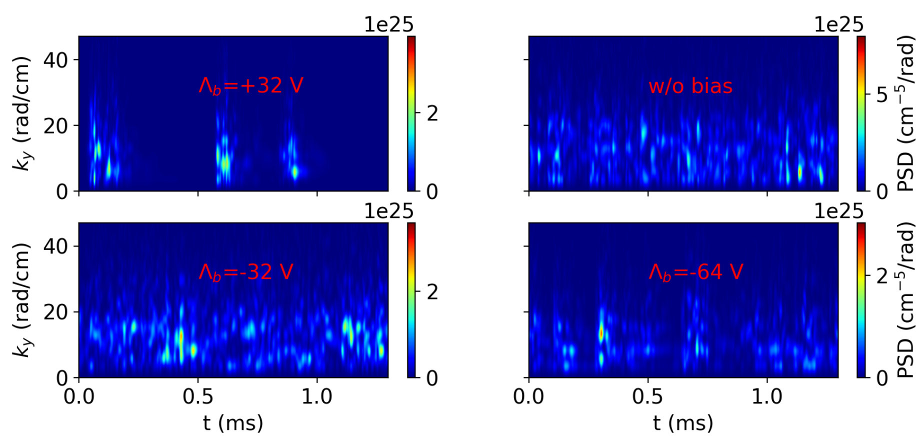

Figure 4: k_y -PSD for Λ_b= +32, −32, −64 volts and w/o bias in SOL region (x=3.0 cm).

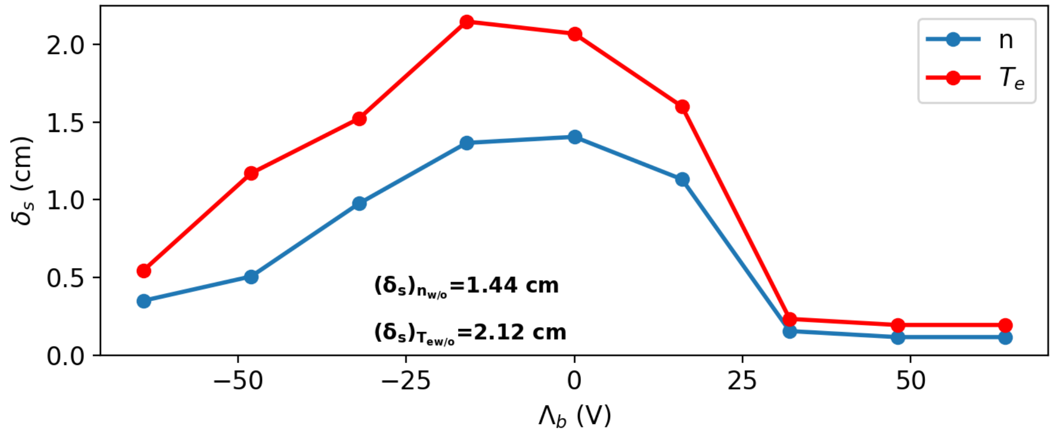

Figure 5: SOL width (δ_s) as a function of Λ_b. The SOL widths obtained from w/o biasing are 1.44 cm and 2.12 cm for T_e and n, respectively.

density and electron temperature in the SOL region decrease in the presence of the biasing, therefore, the overall change in these quantities may not be substantial.

3 Conclusions

The analysis of PSD in the three different regions (in the inner edge before the electrode, between electrode and LCFS, and in the SOL regions) has been done. An increased/decreased PSD for positive/negative biasing has been found in comparison to w/o biasing in the inner edge region. In the same region at higher frequency (> 70 kHz), PSD for the positive biasing is higher but for negative biasing it is almost similar to w/o bias. The positive biasing increases the poloidal flows that is related to the increase of PSD. PSD in the region between electrode and LCFS has lower magnitude for both the biasing cases for the lower frequency (5-70kHz) range. In the SOL region, magnitude of PSD is always lower for both the biasing cases. Analysis of k_y spectrum show that k_y-PSD shifts to lower k_y for both the biasing cases in comparison to w/o biasing in the inner edge region. In the SOL region, shifting of k_y-PSD is not that much, but the magnitude of PSD has been reduced. The e-folding SOL thickness decreases in comparison to w/o biasing in both the biasing cases.

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