X-point potential well formation in diverted tokamaks

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Recent TCV experiments confirm, for the first time, the predicted formation of an electric potential well below the magnetic X-point in the unfavorable B_t direction, thereby substantially reshaping the typical divertor $E \times B$ flow pattern [1]. The presence of such a potential well may strongly influence the divertor performance for reactor operation with unfavorable H-mode access (e.g. reverse triangularity plasmas, I-mode…) or double null configurations in which one of the two X-points has the required ∇B direction to exhibit a potential well, regardless of the B_t direction.
The local charge balance $\nabla \cdot j = 0$ in the private flux region (PFR) of diverted tokamak plasmas has been previously argued (JET [2], DIII-D [3], AUG [4]) to be established by parallel currents and ∇B currents. This hypothesis is herein rigorously verified using SOLPS-ITER simulations of TCV discharges accounting for drifts and currents. Simulated parallel currents correctly predict TCV target current profiles measured with wall-mounted Langmuir probes whereas simulations without drifts fail. For low temperature (detached divertor) conditions the parallel electric field is dictated by the direction of these resulting parallel currents. In this contribution, we demonstrate, for the first time, that the electric plasma potential in the PFR becomes negative with respect to both target plates for detached operation with unfavorable H-mode access (ion ∇B away from the PFR). This implies a reversal of the parallel electric field in the PFR, a significant enhancement of the radial electric field close to the separatrix and a substantially altered $E \times B$ drift pattern with strongly enhanced poloidal flows in the vicinity of the separatrix. A simple analytical model, based on electron momentum balance and the leading order terms in the current continuity equation, provides insight into the underlying physics and generates a scaling of the potential well depth with divertor conditions and machine size. An experimental verification of the electric potential well is enabled following the recent installation of a reciprocating divertor probe array on TCV providing two-dimensional plasma parameter measurements in the divertor volume [5]. A stringent comparison between TCV measurements and SOLPS-ITER simulations, employing TCV's full range of edge-relevant diagnostics, will be presented.

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