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Development and preliminary calibration of an off-normal warning system for SPARC

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This work explores the development and preliminary calibration of an off-normal warning system for SPARC, the aim of which is to minimize disruption loads and maximize operation time via the detection, interpretation, and pacification (i.e. avoidance and mitigation) of anomalous events. Similar systems have been implemented for existing tokamaks like DIII-D [1], NSTX [2], and TCV [3], but the preliminary calibration of this system will have it ready on day 1 of operation, and it is being designed to quickly adapt to the addition of SPARC data in its initial campaigns. It is expected that the preliminary calibration and subsequent intended day 1 implementation of this system will also be useful for informing the initial implementation of ITER's needed respective system. The detection and interpretation of this system will be facilitated via both physics-based warning thresholds as well as machine learning-based Proximity-to-Instability Algorithms, while the pacification will be handled by equilibrium steering, "soft-landings", and the disruption mitigation system, the choice of which will depend on the severity and type of the anomaly. The implementation of the system will initially focus on developing physics-based warnings, which are expected to be more reliable than ML-based alternatives early in operation and can provide more interpretable results to use in pulse-planning. The preliminary calibration of these warnings will be performed using a novel technique that trains individual warning modules targeted at specific off-normal events on both simulated examples of these events in a SPARC-like environment as well as events from the C-Mod database. The validation of warning modules for impurity accumulation, vertical displacement events, locked modes, and density-limits on C-Mod will be presented here, along with the first implementation of an impurity accumulation warning module trained within the DEFUSE [4] event-monitoring framework and on simulated impurity injections within the POPSIM simulation framework.

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[1] N.W. Eidietis *et al* 2018 Nucl. Fusion 58 056023
[2] S.P. Gerhardt *et al* 2013 Nucl. Fusion 53 063021
[3] T. Vu *et al* 2021 IEEE Transaction on Nuclear Science, vol. 68, no. 8
[4] Pau A *et al* 2023 A modern framework to support disruption studies: the EUROfusion disruption database 29th IAEA Int. Conf. on Fusion Energy (London, UK, 2023) (IAEA) p EX/4-1669

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