Arc detection for the ICRF system on ITER

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The ICRF system for ITER is designed to respect the high voltage breakdown limits. However arcs can still statistically happen and must be quickly detected and suppressed by shutting the RF power down. The objectives of an arc detector are thus the prevention of damages to the actively cooled components, which could cause a leak in the vacuum vessel, threatening the tokamak safety, the protection of the generators against surges of reflected power and the support in damage diagnosis through spatial localization of arcs.

For the conception of a reliable and efficient detector, the analysis of the mechanism of arcs is necessary to find their unique signature. The issue of arcs physics for ICRF is twofold: first, the transient character of the arc and its strong coupling with the resonant part of the ICRF system requires a work on multiple time scales ranging from the nanoseconds for its ignition to the microseconds for its interaction with the transmission line and to the milliseconds for its extinction process. Secondly, the harsh environment makes the measurements with good Signal to Noise Ratios problematic. Indeed, arcs have to be detected while they only consume few watts of power, i.e. orders of magnitude lower than the power of the ICRF wave supplied by the generators. This wave is moreover made unstable by its coupling with the plasma, especially during ELMs or L-H transitions and its Voltage Standing Wave Ratio can mimic the behavior of arcs. The electromagnetic environment and the RF instabilities from the plasma like the Ion Cyclotron Emission (ICE) are additional sources of noise, which the detector has to be shielded against.

The latest generations of digitizers with sampling rates over the gigasamples/s, the construction and operations of test benches dedicated to RF breakdown production, the routine operations on present tokamaks have lead to a better knowledge of arcs, the detection of which can be summarized in two main topics: the difficulty to monitor the so-called "low-voltage arcs" and the discrimination against plasma instabilities (ELMs and ICE), which give the same signatures as arcs on some arc detection methods.

Numerous systems have been conceived to address these issues. VSWR-based detectors, RF noise detectors, sound detectors, optical detectors, S-matrix based detectors. Until now, none of them has succeeded in demonstrating the fulfillment of all requirements and the studies for ITER now follow three directions: improvement of the existing concepts to fix their flaws, development of new theoretically fully compliant detectors (like the GUIDAR) and combination of several detectors to benefit from the advantages of each of them. This last solution, however attractive, pinpoints the problem of justification of the reliability of an increasingly complex system with multiple interfaces: the trial and errors approach, presently used on the relatively fault-tolerant ICRF systems to test the arc detectors, will not be compatible with the ITER safety requirements; a rigorous approach is needed to demonstrate in advance the reliability of the detection and define the maintenance operations (inspections, tests, refurbishment) to assure the lifetime and availability of the detectors.

Together with the physical and engineering challenges, the development of an arc detection system for ITER raises methodological concerns to extrapolate the results from basic experiments and present machines to the ITER scale ICRF system and to conduct a relevant risk analysis. In this frame, this review presents the data gathered on the fusion facilities throughout the world: ASDEX-Upgrade, JET, Tore-Supra, DIII-D, Alcator C-Mod, LHD and on the test beds (like MXP), and sketches the possible ways to integrate them in a coherent work.