AIP | Conference Proceedings

Proposal of an Arc Detection Technique Based on RF Measurements for the ITER ICRF Antenna

S. Huygen, P. Dumortier, F. Durodié, A. Messiaen, M. Vervier et al.

Citation: AIP Conf. Proc. **1406**, 21 (2011); doi: 10.1063/1.3664920

View online: http://dx.doi.org/10.1063/1.3664920

View Table of Contents: http://proceedings.aip.org/dbt/dbt.jsp?KEY=APCPCS&Volume=1406&Issue=1

Published by the American Institute of Physics.

Proposal of an Arc Detection Technique Based on RF Measurements for the ITER ICRF Antenna

S. Huygen[a], P. Dumortier[a], F. Durodié[a], A. Messiaen[a], M. Vervier[a], M. Vrancken[a], E. Wooldridge[b], and the CYCLE Team[a,b,c,d,e]

[a] LPP/ERM-KMS, Association EURATOM-Belgian State, Brussels, Belgium
[b] EURATOM/CCFE Fusion Association, Culham Science Centre, UK
[c] Associazione EURATOM-ENEA, Politecnico di Torino, Torino, Italy
[d] IPP-MPI, EURATOM-Assoziation, Garching, Germany
[e] Association EURATOM-CEA, DSM/IRFM, Cadarache, France

Abstract. RF arc detection is a key operational and safety issue for the ICRF system on ITER. Indeed the high voltages inside the antenna put it at risk of arcing, which could cause substantial damage. This paper describes the various possibilities explored by circuit simulation and the strategy now considered to protect the ITER ICRF antenna from RF arcs.

Keywords: ITER, ICRF, antenna, arc detection.
PACS: 52.50.Qt, 52.50.Fa

INTRODUCTION

High voltages and electric fields inside any ICRF antenna have the potential to create arcs and consequently damage it henceforth reducing the deliverable power. A fast and reliable arc detection system must therefore be developed.
A transmission line model of the full ITER ICRF antenna [1,2] and matching system [3,4] shown in Figure 1 has been used to simulate the response of potential arc detection techniques.
Various plasma profiles and antenna phasings have been tested and the outcomes remain similar.
A 20 nH parallel inductance simulating an arc is moved along the antenna to analyse its effect on the various measurements.

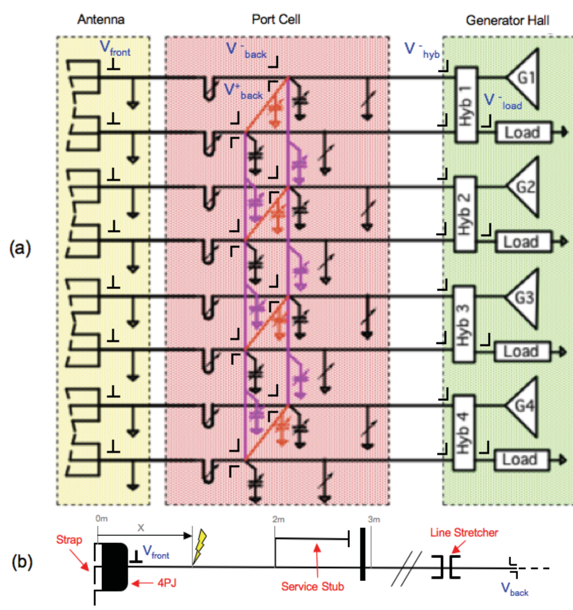


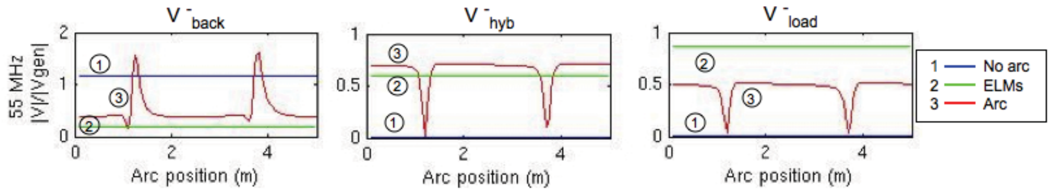
Figure 1: (a) Overview of the ITER ICRF system and (b) schematic representation of the antenna used for simulations.

Radio Frequency Power in Plasmas
AIP Conf. Proc. 1406, 21-24 (2011); doi: 10.1063/1.3664920

Edge Localised Modes (ELMs) are also simulated, according to the formula [5]:

$$Z_{ant,normal} = R_{normal} + j \times X_{normal} \Rightarrow Z_{ant,elm} = 5 \times R_{normal} + 0.9 j \times X_{normal}$$

Due to the load-resilience nature of the matching system, the usual voltage or Voltage Standing Wave Ratio (VSWR) measurements along the lines are not capable of detecting arcs or distinguishing between arcs and ELMs. Indeed, as depicted in Figure 2, the voltage variation at different measurement points due to an arc is similar to the one due to an ELM. Therefore, others techniques have to be investigated.



(a) (b) (c)

Figure 2: Reflected voltage (a) at V_{back}, (b) before the hybrid couplers and (c) to the load with (1) no arc, (2) ELMs conditions and (3) arcs along the antenna as a function of the arc position.

PHASE VARIATION

One of the systems considered is the variation of the phase of the Reflection Coefficient (ρ) measured at V_{back} (Figure 1). For matched conditions, $V_{back} = V_{max}$ [3,4], which makes the phase of ρ being zero in normal conditions without arc, as depicted in the dotted line in Figure 3(a).

In that same Figure 3(a), it appears that an arc (plain line) has a stronger influence on the phase of ρ than an ELM (dashed line), independently of the operating frequency, allowing differentiating between both. The Service Stub (SS) can also be partially protected (+ markers).

VOLTAGE RATIO ARC DETECTION

The other investigated system is the Voltage Ratio Arc Detection (VRAD). A VRAD signal is calculated independently for each Removable Vacuum Transmission Line (RVTL) according to the formula:

$$VRAD = \frac{|V_{front}|}{|V_{back}^{-}| + |V_{back}^{+}|}$$

with V_{front} measured as far forward in the antenna as possible

and $V_{back}^{+,-}$ measured near the voltage maximum, before the Decouplers.

Various combinations of measurements have been tested but these two come out as the most effective.

As shown on Figure 3(b), the VRAD is relatively insensitive to ELMs (dashed line), whatever the operating frequency but an arc (plain line) gives a clear signal change, which can easily be detected. This system can also detect arcs in parts of the SS (+ markers).

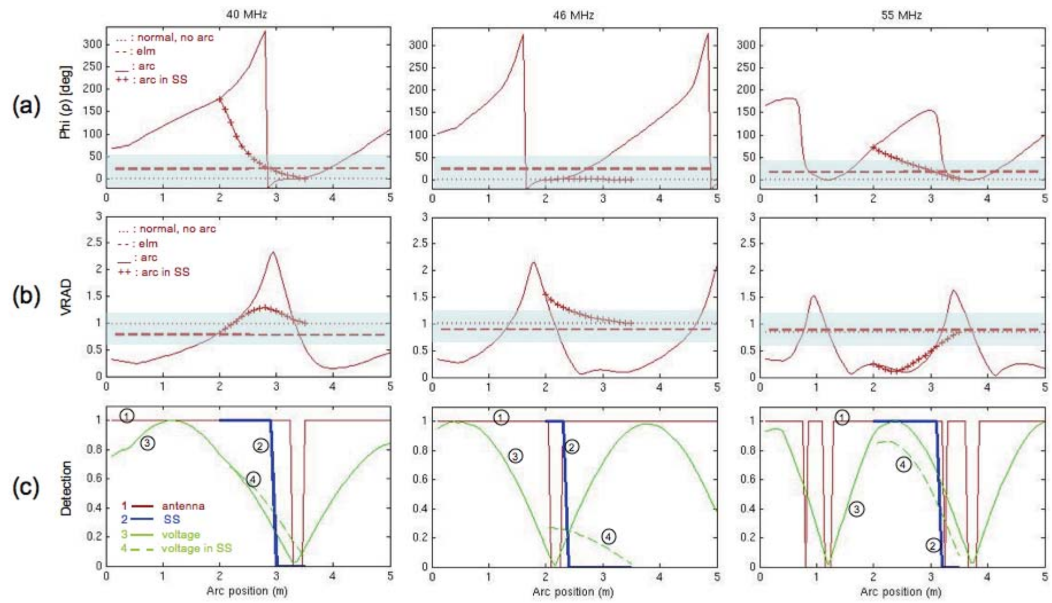


Figure 3: Magnitude (a) of the phase of the reflection coefficient (ρ) and (b) of VRAD, in various conditions and (c) an arc detection window of the combined systems for several frequencies as a function of the arc position.

Combining the detection zone of the VRAD with the one of the Phase Variation of ρ (when the signals are out of the normal operational zone represented in shaded grey in Figures 3(a) and 3(b)) allows maximising the window in which arcs are detectable, as shown in Figure 3(c). The blind zones for this arc detection technique appear around the voltage minimum along the antenna. This is due to the unfavourable ratio of the arc impedance compared to the local transmission line impedance. Unfortunately this is a known problem for every ICRF antenna and there is currently no successful solution based on voltage measurements.

Figure 4(a) shows the voltage distribution along the antenna for several frequencies. For the VRAD to be effective, the measurement at the front needs to be at a high voltage point and this for all frequencies. This is the case around the 4 Port Junction (4PJ) but the VRAD responses for three different measurement positions shown in Figure 4(b) prove that a probe located shortly after the 4PJ is also suitable. The advantage of the later location is that the probes can be incorporated in the RVTL and therefore replaced with the scheduled maintenance of this component. Unfortunately, incorporating a probe at this location may not be mechanically possible. The proposed probes are also designed to measure the current. An estimate of the voltage maximum on the RVTL section between the 4PJ and the SS can be approximated by $\sqrt{|V_{front}|^2 + |Z_0 \times I_{front}|^2}$ [6]. Therefore, the following formula may be the solution and needs to be further investigated:

$$\frac{\sqrt{|V_{front}|^2 + |Z_0 \times I_{front}|^2}}{|V_{back}|}$$

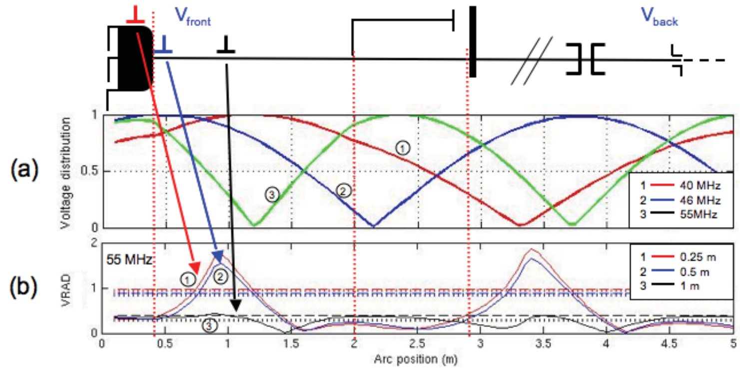


Figure 4: (a) Voltage distribution along the antenna and (b) magnitude of VRAD at 55 MHz for different front probe positions ((1): 0.25 m; (2): 0.5 m; (3): 1m from the front of the 4PJ) in various conditions (… : normal loading; ._: ELMs; __ : arc) as a function of the arc position.

CONCLUSIONS

The VRAD combined with the phase variation of the reflection coefficient appears to be a robust arc detection system, tolerant to load variation in the plasma independently of the antenna phasing. If positioning the probe just behind the 4PJ is technically problematic, combining local voltage and current measurements may provide a solution.

Unfortunately, arcs at low voltage points are still undetectable and their detection requires another system not relying on voltage measurements.

ACKNOWLEDGMENTS

The project F4E-2009-GRT-026 has been funded with support from Fusion from Energy. This publication reflects the views only of the author, and Fusion for Energy cannot be held responsible for any use which may be made of the information contained therein.

The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.

REFERENCES

[1] M. Vrancken et al., these proceedings.
[2] D. Hancock et al., these proceedings.
[3] M. Vervier et al., Proc. 18TH Top. Conf. RF Power in Plasmas, 297-300, June. 2009.
[4] A. Messian et al., NF 49(2009)055004.
[5] M. Evrard et al., Proc. 16TH Top. Conf. RF Power in Plasmas, 186-189, Apr. 2005.
[6] F. Durodie (private communication).