Fusion Engineering and Design 105 (2016) 22–28

Contents lists available at ScienceDirect

Fusion Engineering and Design

journal homepage: www.elsevier.com/locate/fusengdes

0-D modeling of SST-1 plasma break-down & start-up using ECRH assisted pre-ionization

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HIGHLIGHTS

- Steady state superconducting tokamak (SST-1).
- Pre-ionization.
- ECRH.
- 0-D model.

ARTICLE INFO

Article history:
Received 29 September 2015
Received in revised form 22 January 2016
Accepted 11 February 2016
Available online 26 February 2016

Keywords:
Steady state superconducting tokamak (SST-1)
Pre-ionization
ECRH
0-D model

ABSTRACT

Electron cyclotron resonance (ECRH) assisted break-down and start-up is considered as useful tool towards the discharge initiation in superconducting tokamaks, where the vacuum vessels and the cryostats are usually electrically continuous with thick walls. ECH pre-ionizations are known to reduce the required central solenoid swing induced toroidal electric field, *E* significantly. The Steady state superconducting tokamak (SST-1, $R = 1.1$ m, $a = 0.2$ m) has achieved successful plasma break-down and subsequent current ramp-up with ECH pre-ionizations in both fundamental mode and second harmonic modes with $E \sim 0.35$ V/m. This work has discussed an appropriate simulation model and validated its results with experiments for the ECRH assisted breakdown and start-up, for both 1st harmonic ordinary mode (O1) and 2nd harmonic extra-ordinary mode (X2), in SST-1 for hydrogen plasmas, where the loop voltage is limited to 0.35 V/m. The simulation model is a zero-dimensional (0-D) model. In this model five temporal equations are solved for spatially-uniform plasma. The primary findings of this investigation has been the determination of the threshold ECRH power for successful pre-ionization of plasma in SST-1 and validations of the results with experimental findings in SST-1.

1. Introduction

By applying modest amount of electron cyclotron resonance heating (ECRH) power towards pre-ionization, the start-up voltage in a tokamak can be reduced by considerable amount even at a moderate error magnetic field. Such plasma start-up phenomenon have been explored and demonstrated experimentally in normal conducting tokamaks such as DIII-D [1,2], JT-60U [4] and ASDEX-U [5] as well in superconducting tokamak like Tore Supra [3] and KSTAR [6]. In superconducting tokamaks, the thick walled vacuum vessel and the cryostat are electrically continuous and conducting due to which eddy currents develop during the central solenoid swing, resulting in reduction of the available loop voltage. Thus, the loop voltage available in case of superconducting Tokamak is usually less. In ECH pre-ionization assisted break-down & start-up, ECH in presence of a DC toroidal field, ionizes the pre-fill gases in the resonance region inside the vacuum vessel and then the loop voltage assists in the start-up. The ECH can also assist in the start-up with finite current drives.

The steady state superconducting tokamak (SST-1) at Institute for Plasma Research has a resistive central solenoid placed in the bore of the cryostat. Thus, in case of SST-1 the flux has to penetrate through both the cryostat and vacuum vessel to be available as a loop voltage inside the vacuum vessel. The maximum ohmic electric field available in case of SST-1 was ≤ 0.4 V/m. In order to ensure reliable plasma breakdown, pre-ionization in SST-1 was facilitated through a 42 GHz, 500 KW electron cyclotron resonance heating (ECRH) Gyrotron. Although ECRH assisted start-ups in all machines [1–6] have been experimentally shown to be reliable, its theoretical modeling is both complex and complicated. Such a model

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http://dx.doi.org/10.1016/j.fusengdes.2016.02.031

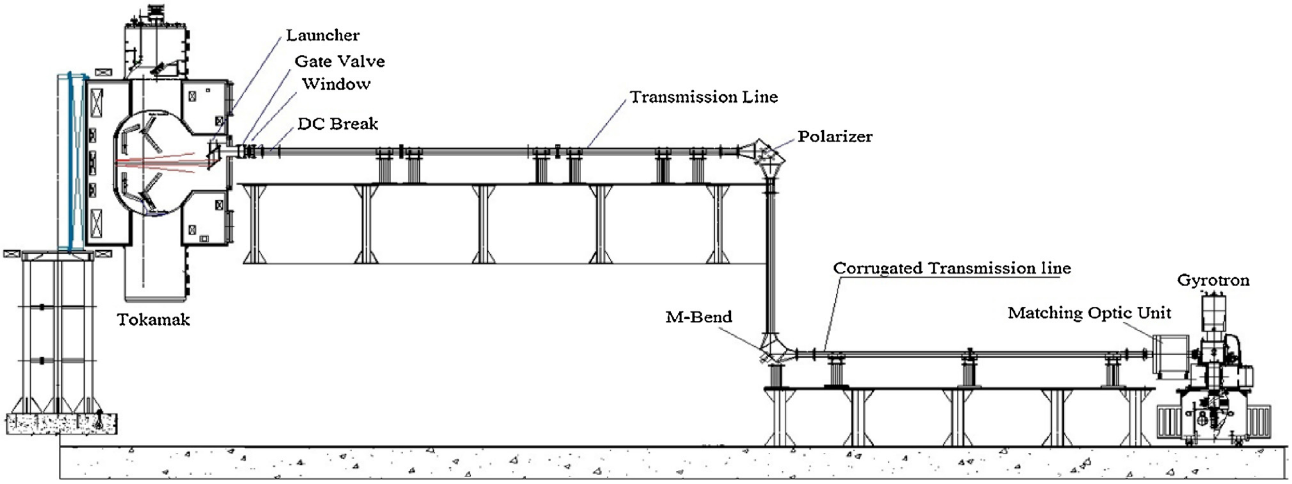

Fig. 1. ECRH Schematic with SST-1 interface.

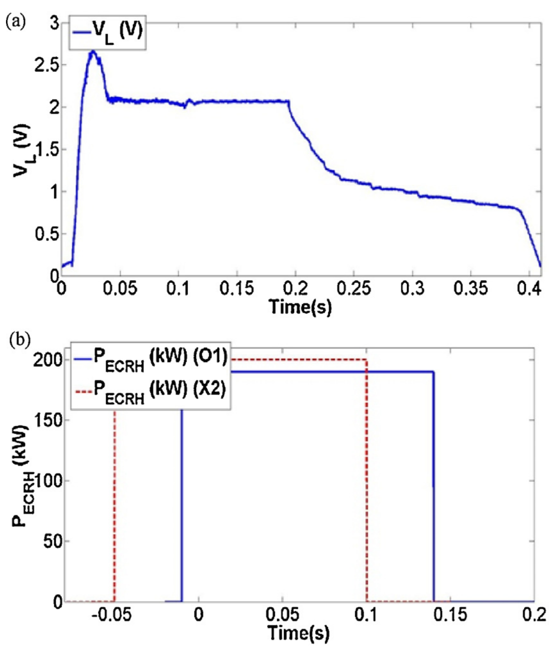

Fig. 2. (a) Experimental loop voltage. (b) Temporal behavior of the absorbed ECRH power for O1 and X2 mode.

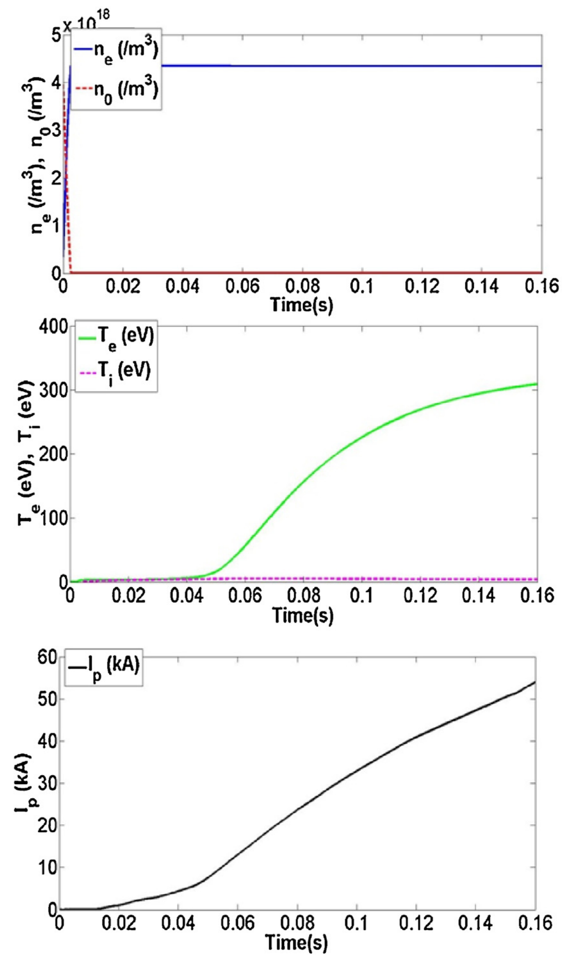

Fig. 3. Temporal behaviors of plasma parameters with initial conditions: $P_{ECRH} = 190\,kW$, initial seed electron density $n_e = 3 \times 10^{17}$, initial neutral density $n_0 = 4 \times 10^{18}$, $B_{err} = 0.5\,mT$.

necessarily needs knowledge of the electron velocity distribution and so on. Further, the complexities of the device specific of start-up physics makes detailed modeling of this phase of the discharge extremely difficult. In this work, an attempt has been made to explain and validate the experimental observations of SST-1 through a theoretical model especially the threshold power needed for successful start-ups, the effect of field errors etc.

Based on the work carried out by Kulchar et al. [7] to describe the ECRH-assisted start-up in ISX-B and on more advanced model developed by Lloyd et al. [8], which includes the effects of impurities and on the work carried out by Kim et al. [14,15], a zero-dimension (0-D) model has been developed to study the effects of various plasma parameters on the start-up and computation of threshold ECRH power for successful pre-ionization in SST-1.

2. Experiment set-up

SST-1 is a circular cross section tokamak ($R = 1.1\,m$, $a = 0.2\,m$) with a very wide toroidal magnetic field range (0.75–3.5 T) [9]. The ECRH system [10] in SST-1 as shown in Fig. 1, consists of a 42 GHz gyrotron, generating 0.5 MW power that usually operates at −50 kV beam voltage, 20A beam current and +19 kV anode voltage. The