Equivalent Circuit and Electrodynamic Characteristics of Waveguide-Based Coaxial-Type Microwave Plasma Source

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INTRODUCTION

We present equivalent circuit of existing waveguide-based coaxial-type microwave plasma source (MPS) which was used to hydrogen production via methane reforming. This MPS is operating at frequency of 2.45 GHz, in gases at atmospheric pressure. The equivalent circuit cannot describe all electrical properties of the real MPS accurately due to some structural elements, which electrical lumped equivalents are difficult to find or are unknown. We used Comsol Multiphysics software to numerically investigate of the equivalent circuit which electrical lumped equivalents are difficult to find or are unknown.

FORMULATIONS

Normalized susceptance of iris:

\[ b_h = \frac{b}{b_0} = -\frac{\lambda}{l} \frac{c^2 g}{Z_0} \]

Transformation factors:

\[ k_z = \frac{g_z}{g_0} + \frac{g_i}{g_0} = k_z \]

Normalized movable plunger susceptance in output plane:

\[ Y = Z^{-1} (b_h + Z_0) \]

Admittance in discharge axis:

\[ Y_{\text{dis}} = \frac{Z_0}{Z} \]

Reactance of short coaxial line section:

\[ X_{\text{in}} = Z_{\text{sec}} \left( \frac{Z_{\text{in}}}{Z_{\text{sec}}} - 1 \right) \]

Characteristic impedance of coaxial line:

\[ Z_{\text{in}} = 60 \sqrt{\frac{\mu_0}{\epsilon_0}} \]

Plasma impedance transformed via coaxial line section:

\[ Z_{\text{plasm}} = Z_{\text{sec}} \left( \frac{Z_{\text{in}}}{Z_{\text{sec}}} - 1 \right) \]

Normalized input admittance:

\[ y_{\text{in}} = \frac{Z_{\text{sec}}}{Z_{\text{in}}} \left( Z_{\text{in}} X_{\text{in}} - 1 \right) + \frac{Z_0}{Z_{\text{in}}} \left( Z_{\text{plasm}} + X_{\text{in}} \right) + \frac{Z_0}{Z_{\text{in}}} \left( Z_{\text{plasm}} - X_{\text{in}} \right) \]

Tuning characteristic:

\[ P_1 = \frac{1}{T} \left( \frac{1}{K_1} \right) \]

Quantity Value

\( \lambda \quad 262.45 \text{ mm} \)
\( Z_0 \quad 357.5 \Omega \)
\( Y_{\text{in}} \quad 12.7 \text{ mS} \)
\( b_0 \quad -0.11 \)
\( a \quad 54 \text{ mm} \)
\( b \quad 54 \text{ mm} \)
\( Z_{\text{plasm}} \quad 35 \Omega \)
\( X \quad 112 \Omega \)

CONCLUSIONS

- The calculated results and results achieved in experiment are very similar for assumed plasma impedance \( Z_0 = 35 \Omega \) and reactance \( X = -X_0 \)
- The power reflection coefficient \( P_1 \) of the MPS with iris is small for wide range of normalized movable plunger position
- The presented equivalent circuit of the MPS can be helpful to improve any similar MPSs.

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