§10. Impedance Matching in Wide Range of Resistance in Conjugate Antenna System

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The conjugate antenna system was introduced in the previous annual report of 2007–2008. In this section the characteristics of the conjugate antenna system are further examined. The impedance at the T-junction is expressed in the following equation,

\[ Z = Z_0 \frac{R_N^2(1-2R_{NO}) + R_{NO}(2-R_{NO})}{2R_N(1-R_{NO}^2)} = Z_0 E \]  

(1)

It is easily found that when \( R_N = R_{NO} \), \( E \) becomes one and therefore the reflected RF power fraction \( R_{ref} \) becomes zero in the above equation. The above equation is a quadratic equation for \( R_N \) for \( E=1 \). Therefore there is another solution and the other solution of \( R_{N1} \) can be derived using \( R_{NO} \) in the following relation,

\[ R_{N1} = \frac{2 - R_{NO}}{1 - 2R_{NO}} \]  

(2)

For example when \( R_{NO} = 0.26 \), \( R_{N1} = 3.625 \), that is, there are two impedance matching conditions. On the other hand the reflected RF power fraction \( R_{ref} \) is calculated using the following equation,

\[ R_{ref} = \left( \frac{E - 1}{E + 1} \right)^2 \]  

(3)

It is thought that \( R_{ref} \) is fairly increased between two impedance matching conditions. Here the normalized resistance \( R_{Nm} \), where \( R_{ref} \) becomes the maximum can be found between \( R_{NO} \) and \( R_{N1} \). Using a differential of \( R_{ref} \) by \( R_N \) becomes zero when \( R_{ref} \) becomes the maximum in the following way.

\[ \frac{dR_{ref}}{dR_N} = 0 \rightarrow R_{Nm}^2 = R_{NO}R_{N1} \]  

(4)

The value of \( R_{Nm} \) is a geometric mean of \( R_{NO} \) and \( R_{N1} \). Then the local maximum \( R_{ref_m} \) is calculated using the equation (3) and derived in the following equation,

\[ R_{ref_m} = \left( \frac{R_{Nm} - 1 + R_{NO}^2}{R_{Nm} + 1 - R_{NO}^2} \right)^2 \]  

(5)

Dependences of the local maximum reflected RF power fraction \( R_{ref_m} \) on \( R_{NO} \) are plotted in Fig.1. It is found that \( R_{ref_m} \) is decreased with \( R_{NO} \) and becomes the minimum value of 12% at \( R_{NO} = 0.26 \).

The reflected RF power fraction is plotted against \( R_N \) in the case of \( R_{NO} = 0.26 \). When the allowable reflected RF power fraction is employed as \( R_{ref} = 5\% \), the normalized resistance \( R_N \) ranges from 0.18 to 0.45 as also shown in Fig.2. It was reported that the antenna resistance was changed from 2Ω to 8Ω during the H-L mode transition seen in JET [1]. If this conjugate antenna system is applied to the H-L mode transition plasma, the low characteristic impedance of the transmission line such as \( Z_0 = 8\Omega \) should be employed. When it is assumed that the maximum RF stand-off voltage is proportional to the clearance between the inner and the outer transmission line, the maximum RF power to be transmitted for the characteristic impedance \( Z_0 \) is assessed in the following equation:

\[ P_{RF} \propto a^2 \ln \left( \frac{b}{a} \right) \]  

(6)

Here \( a \) and \( b \) are an inner and an outer radius of the transmission line, respectively. The maximum \( P_{RF} \) is obtained in the case of \( b/a = 2.72 \), i.e., \( Z_0 = 30\Omega \). Then \( P_{RF} \) at \( Z_0 = 8\Omega \) is calculated to be reduced to less than 50% of that at \( Z_0 = 30\Omega \). It is thought that the method of employing the low impedance transmission line is not appropriate for a high power ICRF heating system.

Fig.1 Dependences of reflected RF power fraction, \( R_{N1} \) and \( R_{Nm} \) on \( R_{NO} \).

Fig.2 Dependence of Reflected RF power fraction on \( R_N \) in the case of \( R_{NO} = 0.26 \). The reflected RF power fraction can be suppressed to less than 5% in the range of 0.18 50 0.43 in \( R_N \).