Liquid Phase Shifter for ICRH for Long Pulse Operation at SST-1

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Abstract. Plasma is a variable load. The plasma impedance varies over a wide range. This requires impedance matching with RF generator that is normally of 50 Ohm. The impedance matching network consists of stub tuner and phase shifter. Conventional phase shifter has moving arrangement for phase variation. At high power moving arrangement is not suitable because of high current. Finger contacts are used to make electrical contacts between different conductors. Because of the ovality present into the copper tubes, the pressure contact does not remain the same throughout the connecting periphery of the conductors. This gives uneven resistivity over the connecting periphery. Hence at some point current may be high while at some other point it may be low. Finger contact may burn due to high localized current. To avoid this problem, liquid phase shifter has been developed. Here there is no moving arrangement of electrical contacts. Changing the height of the liquid in the phase shifter varies the phase. Here we present the design detail, fabrication techniques of the liquid phase shifter. This is a $9\frac{1}{16}$ size phase shifter. This is the standard size of transmission line at SST-1 tokamak.

1. Introduction

Liquid phase shifter has been used at high power RF where sliding contacts for changing the phase are not advisable. At high power, the RF current is very high and hence the sliding contacts create uneven resistivity that in turn create uneven RF current. This in turn will produce localised high temperature and hence may burn sliding contacts. This problem is avoided in liquid phase shifter in which there in no sliding contacts. Phase is shifted by varying the height of the liquid in the phase shifter. The wavelength of the wave traveling in the liquid phase shifter changes by square root of the dielectric constant. Hence more the length the wave will travel through the liquid in the phase shifter more the phase shift it will achieve. So by varying the length of the liquid in the phase shifter, a phase shift may be achieved [1].

2. Working Principle

A liquid phase shifter schematic is shown in figure 1. In a matched line the conventional phase shifter does not change the impedance but in liquid phase shifter even in a matched line the impedance seen at the other end of the transmission line will be changed as will be shown shortly. So the liquid phase shifter not only changes the phase but also changes the input impedance at the receiving end of the phase shifter. In a medium with higher dielectric constant wavelength is reduced by the factor of square root of dielectric constant.
The schematic of liquid phase shifter is shown in figure 1. The total length of the liquid phase shifter is
\[ l = 2l_1 + l_2 \]
The total phase shift will be
\[ \theta' = \beta' l \]
where
\[ \beta' = \frac{2\pi}{\lambda'} \]
and
\[ \lambda' = \frac{\lambda}{\varepsilon_r} \]
so
\[ \theta' = \beta_1 \sqrt{\varepsilon_r} \]
= \( \theta \sqrt{\varepsilon_r} \)
So the phase will be changed by a factor of \( \sqrt{\varepsilon_r} \) higher than the phase change in a conventional phase shifter. Higher the dielectric constant, higher will be the phase change for smaller physical length of the phase shifter. This is a very good advantage for lower side of frequency band.

3. Characteristic Impedance
The characteristic impedance of the phase shifter will also change. If the impedance at point A is \( Z_L \), (figure 1) then the impedance at point B it will be
\[ Z_{in} = Z_0 \frac{Z_L + jZ_0 \tan \beta' l}{Z_0 + jZ_L \tan \beta' l} \] (1)

where \( Z_0' \) is the characteristic impedance of the liquid phase shifter. The value of \( Z_0' \) is given by

\[ Z_0' = \frac{\sqrt{\epsilon_r}}{Z_0} \]

where \( Z_0 \) is the characteristic impedance of the transmission line section from which phase shifter has been made.

4. Matching Requirement

In order to match the antenna with the generator, it is required to know the real and imaginary parts of the input impedance seen at the generator end of the phase shifter. Let the load at the phase shifter end is

\[ Z_L = R + jX \]

by putting this value of load impedance in eq. (1) and solving for real and imaginary parts, one gets

real part of input impedance as

\[ \text{Re}(Z_{in}) = Z_0' \frac{R(Z_0' - X \tan \beta' l) + R \tan \beta' l(X + Z_0' \tan \beta' l)}{(Z_0' - X \tan \beta' l)^2 + R^2 \tan^2 \beta' l} \] (2)

and imaginary part as

\[ \text{Im}(Z_{in}) = Z_0' \frac{(X + Z_0' \tan \beta' l)(Z_0' - X \tan \beta' l) - R^2 \tan \beta' l}{(Z_0' - X \tan \beta' l)^2 + R^2 \tan^2 \beta' l} \] (3)

By knowing the real and imaginary parts, one can choose the suitable length of the stub tuner to match the system. The phase should be adjusted in such a way that the real part of the input impedance at the stub location is 50 ohm. In equation (2) when the liquid is fixed, only one variable is left and that is the length ‘l’ of the phase shifter. This length is to be varied to get 50 Ohm impedance at the stub location. The stub length will be adjusted to cancel out the complex part.

Other than the conventional advantages of the liquid phase shifter, what has been observed is that there are certain other characteristics that make liquid phase shifter(LPS) a better option than conventional phase shifter(CPS). A computer program is written in C language and following conclusion has been drawn based on the results obtained from this program. To match a load of 1.0 + j1.0 Ohm, the electrical length required by LPS is 0.134 while that of CPS is 0.224. So the length required by the LPS is less than the length required by CPS to give same phase. Secondly it was observed that the change in impedance in more sensitive to length change in case of CPS than LPS. For example when the electrical length of CPS changes from 0.249 to 0.250 the impedance changes from 69 + j148 Ohm to 1.7 X 10^9 + j1.7 X 10^9 Ohm, while in the case of LPS the impedance changes from 44 + j77 to 7 + j35 when the electrical length varies from 0.151 to 0.152. These are the advantages that can be exploit while matching low impedances because in those cases the stub tuner length is very sensitive to the impedance.
5. Mechanical Design

This liquid phase shifter has been made from $9 \frac{1}{16}$ transmission line sections. Inner and outer conductor are both of 99.95% or better ETP copper. Humidity sensor and temperature sensor are installed in order to check the humidity and temperature of the system. The system can be operated locally or remotely. GUI is provided on the computer screen for remote operation. The variable physical length of the phase shifter is about 5.0 meter. The liquid used at present is transformer oil because this is the experimental phase of the system. Once the preliminary testing is over; the transformer oil will be replaced by silicon oil.

![Figure 2 Liquid Phase Shifter at Aditya Tokamak](image)

6. Conclusion

The phase shifter has been installed in the Aditya tokamak. It will be tested there for operational check. After testing, it will be connected to the main ICRH transmission line of Aditya for matching plasma impedance to the generator. At present in Aditya tokamak; there is one stub and one phase shifter. This matching network is being upgraded with two phase-shifters and two stub tuners. Along with the liquid phase shifter; one of the stub is also liquid stub. And Aditya tokamak impedance to be on smaller side, LPS will of great use looking at its characteristics in comparison to the CPS.

References

[1] Kumazawa R, Mutoh T, Seki T, Sinpo F, Nomura G, Ido T, Watari T, Noterdaeme J and Zho Y 1999 *Review of Scientific Instruments* **6** 2665-73