Estimation of Inter Conductor Stray Capacitances for HVDC Transmission Line of Negative Neutral Beam Injector

**Introduction**

Neural beam injectors inject multi megawatt neutral beams, several tens of amperes and energies from few 100 kV to MV into the tokamak for heating and diagnostic purposes. As a result the gas density in the gaps is high and can lead to breakdowns even if Paschen breakdowns. Another source of stored energy could be the inter conductor stray capacitance of the high voltage transmission line[1][2]. These breakdowns could lead to damage of the grid segments and thereby considerable down time of the injector.

One of the possible route to reduce the stored energy could be to lower the inter conductor stray capacitance by increasing the distance between the conductor and the outer ground cover. This will result in complex geometry of transmission line and direct estimation of inter conductor stray capacitance of such complex geometry is not possible. Hence a methodology is proposed to estimate the inter conductor stray capacitance of complex geometry transmission line.

High voltage transmission line[3] connects the acceleration and extraction power supplies to copper grid in NBI system. The same is estimated by electrostatic simulation in COMSOL platform[4]. The prototype of one such configuration is fabricated and capacitance estimation is done to verify electrostatic simulation results.

**Typical model of HVDC transmission line:**

- Insulator support block is of polyethylene material having dielectric constant 2.35. The placement of Insulator support at regular interval (at 1m) and dielectric cover of HV wire would in turn contribute to increase in capacitance of entire HVDC transmission line.

- High voltage transmission line involves HV wires (with polyethylene as dielectric) connected to grids of ion source.

- Aluminum ground cover would be provided surrounding all the three HV lines.

**Estimated value of inter conductor stray capacitance in COMSOL platform**

The COMSOL platform is used to estimate the inter conductor stray capacitance of above mentioned configurations [5]. In COMSOL lumped parameters such as capacitance is calculated by energy method [6]. Equation below forms basis of calculation of capacitance C from integral of electric energy W_e:

\[
C = \int \frac{W_e}{V} d\Omega
\]

V is the electric potential.

The estimation of inter conductor stray capacitance parameter involve obtaining the electrostatic energy of the system with known electric potential(V) applied to a conductor with rest of the system being grounded. Thus for three conductor system

\[
C_{AC} = \int \left[ \frac{W_e(A^+)}{V} \right]_{C_{AC}} \quad 0 \quad 1 \quad 0 \quad 1
\]

\[
C_{AB} = \int \left[ \frac{W_e(B^+)}{V} \right]_{C_{AC}} \quad 0 \quad 1 \quad 0 \quad 1
\]

\[
C_{BC} = \int \left[ \frac{W_e(C^+)}{V} \right]_{C_{AC}} \quad 0 \quad 1 \quad 0 \quad 1
\]

Where\( W_e(A^+) \) is electrostatic energy of the system when Conductor A is applied with potential and V is the applied potential. Inter conductor stray capacitance could be estimated from known electrostatic energy and electric potential.

**Results and Discussions**

- **Estimated values of inter conductor stray capacitances**

  - Difference in simulation and measured values could be due to the spacing of the conductors may not be uniform throughout the length of prototype.
  - Fair agreement between measured and simulation values[7] and are in range from 0.15% to 3% [8][9].

- **Electric field contour and electric potential contour**

  - Estimated values from COMSOL and measured values

<table>
<thead>
<tr>
<th>Inter conductor stray capacitance</th>
<th>Estimated values from COMSOL</th>
<th>Measured values</th>
</tr>
</thead>
<tbody>
<tr>
<td>C_{AC}</td>
<td>17.22</td>
<td>17.17</td>
</tr>
<tr>
<td>C_{AB}</td>
<td>18.45</td>
<td>18.42</td>
</tr>
<tr>
<td>C_{BC}</td>
<td>15.03</td>
<td>15.41</td>
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</tbody>
</table>

- **Next steps**

  - Analytical estimation for further validation
  - Variation of the inter conductor stray capacitance with length
  - Experimental validation by energy measurement.
  - Simulation in MATLAB with computed parameters for a grid breakdown.

**Summary**

- Methodology formulated
- Simulation in COMSOL platform and validation by estimation of capacitance for prototype

**References**

4. Jordi-Roger Riba et al, Analysis of Capacitance to Ground Formulas for Different High-Voltage Electrodes, Energies, 11, 1090, 2018
5. H.Lorenzen, et al., Calculation of Cable Parameter for Different Cable Shapes, Excerpt from Proceedings of COMSOL Conference Hannover, 2008
6. Comsol 5.2a, AC DC user guide