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

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Introduction

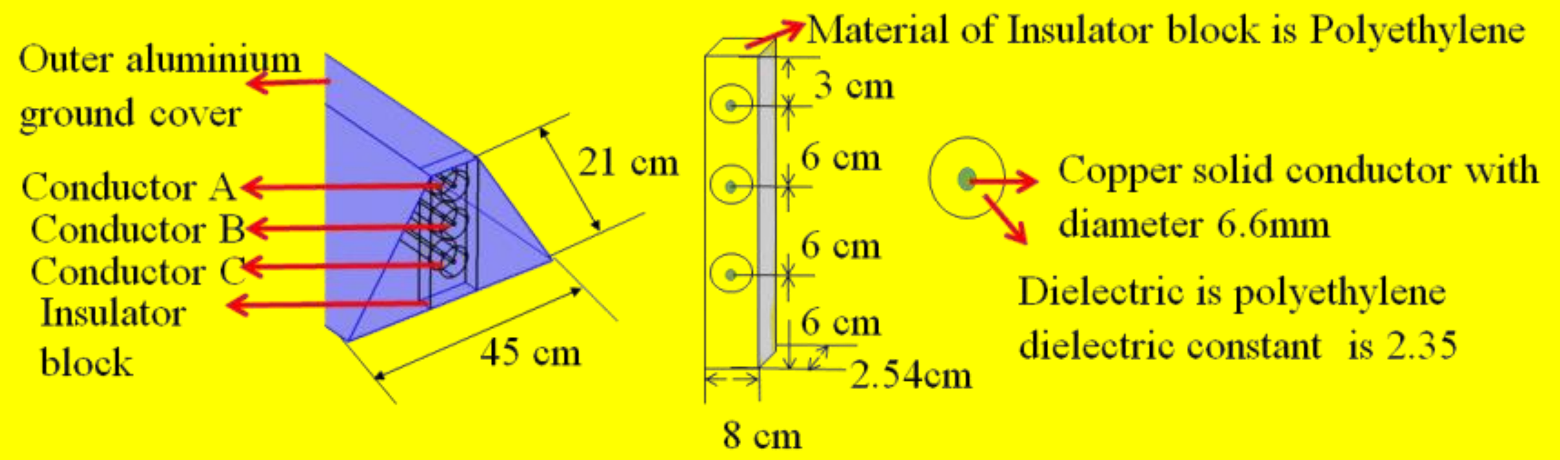
Neutral beam injectors inject multi megawatt neutral beams, several tens of amperes and energies from few 100 kV to MV, into the tokamak for heating and diagnostic purposes. As a result the gas density in the gaps is high and can lead to breakdowns often referred to as Paschen breakdowns. Another source 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.



Estimation of inter conductor stray capacitance in COMSOL platform

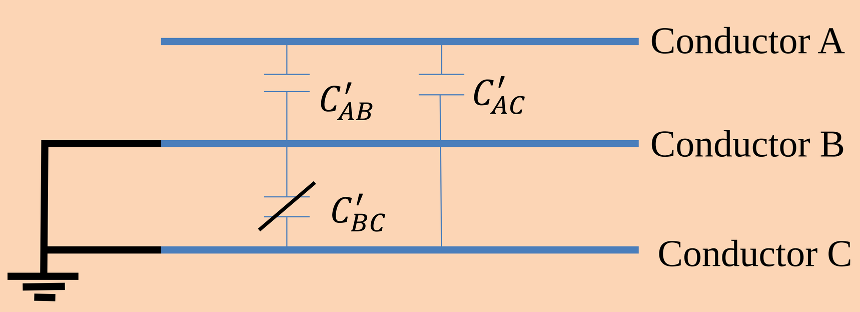
The COMSOL platform is used to estimate the inter conductor stray capacitance's of above mentioned configurations [5]. In COMSOL lumped parameters such as capacitance is calculated by energy method [6]. Equation below forms basis of calculation of capacitance C from integral of electric energy density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

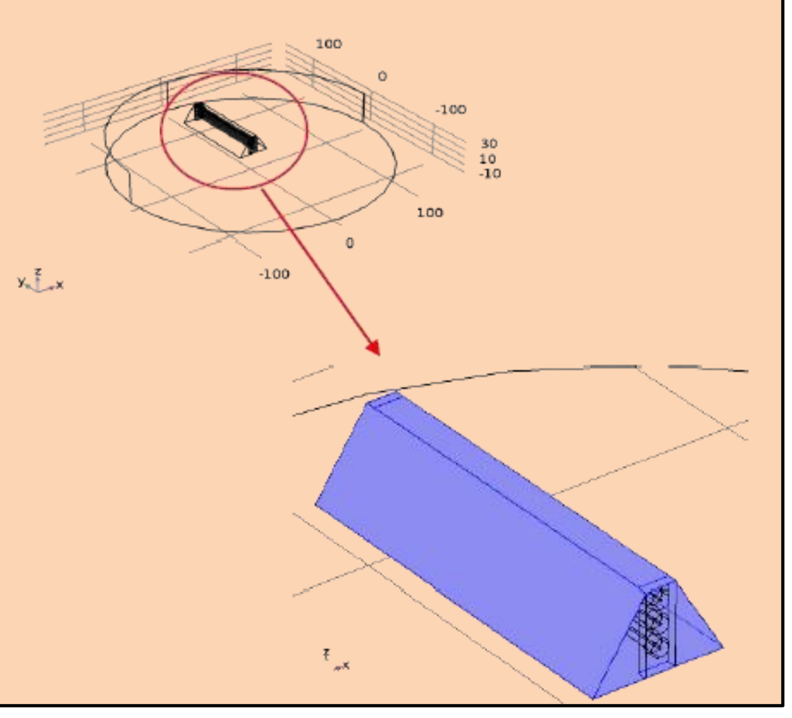
$$C = \frac{\int_{\Omega} W_e' \, d\Omega}{V^2}$$

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

$$\begin{bmatrix} C'_{AC} \\ C'_{AB} \\ C'_{BC} \end{bmatrix} = \frac{2}{V^2} \begin{bmatrix} W_e(A^+) \\ W_e(C^+) \\ W_e(B^+) \end{bmatrix} \begin{bmatrix} 1 & 1 & 0 \\ 1 & 0 & 1 \\ 0 & 1 & 1 \end{bmatrix}^{-1}$$

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 .



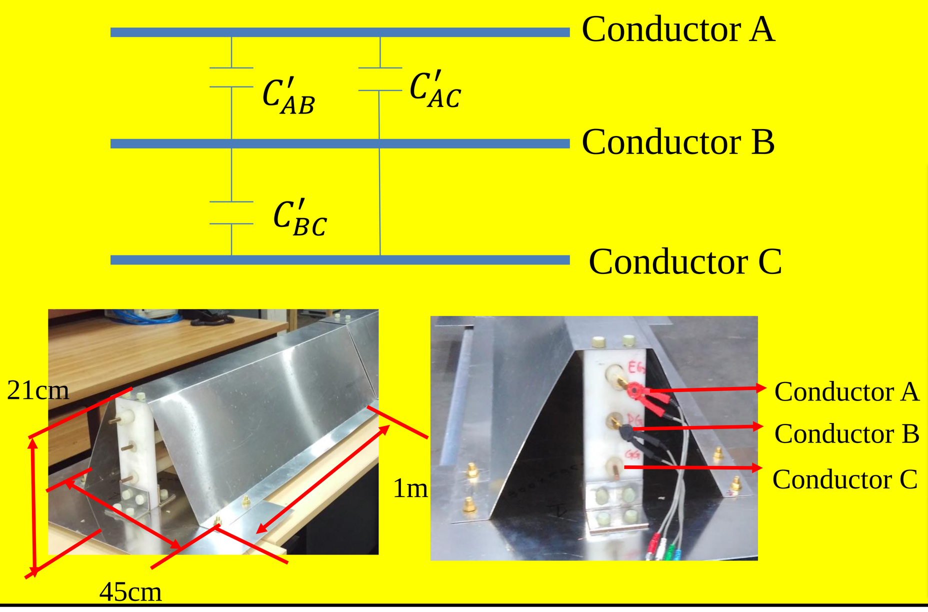


Inter conductor stray Capacitance	Outer trapezoidal ground cover(pF)
C'_{AC}	17.22
C'_{AB}	18.45
C'_{BC}	15.03

Estimation of inter conductor stray capacitance of 3 Conductor system for 1 m prototype

- The effective inter conductor stray capacitance between three conductors is estimated from the equivalent capacitance with electric potential(=1V) being applied to one conductor and other being grounded. Consider 3 conductors A, B, C as given in below figure, the effective inter conductor stray capacitance between conductor A and B is C'_{AB}. Similarly effective inter conductor stray capacitance C'_{AC} and C'_{BC} exist between other two conductor. When conductor B and C are grounded ,the effective capacitance $C_{eqvt}(A^+)$ is $C'_{AB} + C'_{AC}$. Hioki Impedence analyzer IM3570 is used to measure the capacitance

$$\begin{bmatrix} C'_{AC} \\ C'_{AB} \\ C'_{BC} \end{bmatrix} = \begin{bmatrix} C_{eqvt}(A^+) \\ C_{eqvt}(C^+) \\ C_{eqvt}(B^+) \end{bmatrix} \begin{bmatrix} 1 & 1 & 0 \\ 1 & 0 & 1 \\ 0 & 1 & 1 \end{bmatrix}^{-1}$$



Inter conductor stray Capacitance	Estimated values from COMSOL	Measured values
C'_{AC}	17.22	17.17
C'_{AB}	18.45	18.42
C'_{BC}	15.03	15.41

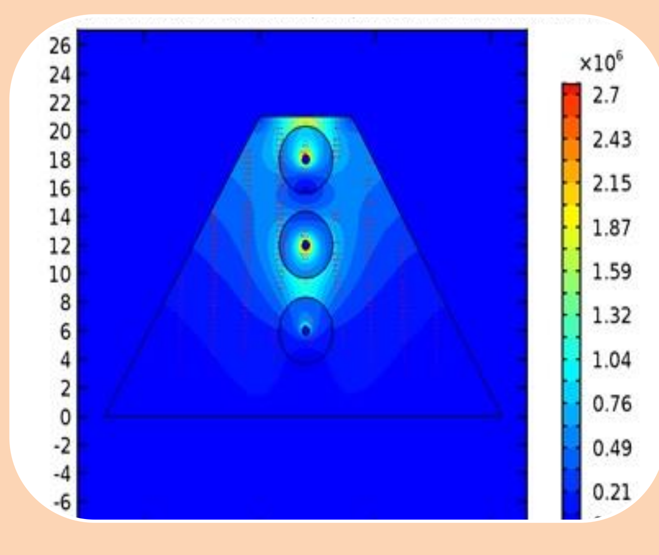
Results and Discussions

Estimated values of inter conductor stray capacitances

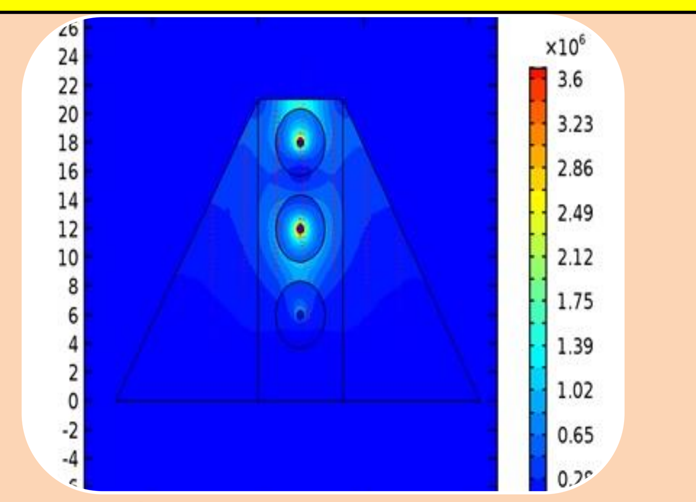
- Difference in simulation and measured values could be due to the spacing of the conductor may not be uniform throughout the length of prototype
- Fair agreement between measured and simulated values[7] and are in range from 0.15% to 3% [8][9].

Electric field contour and electric potential contour

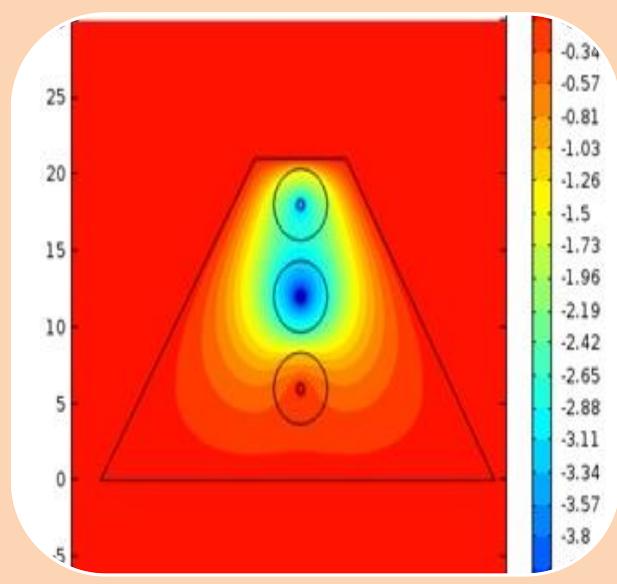
- Below mentioned figure represent the electric contour and electric potential contour with Acceleration power supply system(APSS , -35kV 15A) and Extraction power supply system (EPSS -11kV ,35A) of Twin source[10].
- For analytical estimation of inter conductor stray capacitance only top and bottom ground planes are needed to be considered for inter conductor stray capacitance estimation



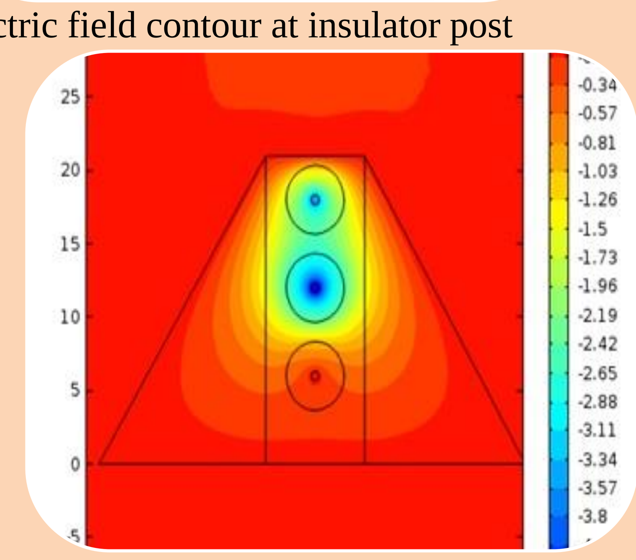
Electric field contour in between insulator posts



Electric field contour at insulator post



Electric potential contour in between insulator posts



Electric potential contour at insulator posts

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

1. H.M. Owren, et al,, *The effect of capacitive stored energy on neutral beam accelerator performance*, 12th Symposium On Fusion Technology, Julich, 1982.
2. M. Bigi , et al, *Protections against grid breakdowns in the ITER neutral beam injector power supplies*, Fusion Engineering and Design,2007.
3. Deepak Parmar, Vishnudev, et al, *Design and development Of electrical system for Twin Source* , SOFE,2015
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*
7. R. Gokul Raj, Chitti Venkata Krishnamurthy, *Relative permittivity of dielectrics from scaling relation of capacitance*, Measurement 151 (2020) 107174
8. João Peresc et al, *Accurate numerical method to evaluate the capacitances of multi-conductor power cables*, Electric Power Systems Research 103 (2013) 184– 191
9. Xingliang Liu et al, *Analytical Estimation Method of Winding Parasitic Capacitance for High-Frequency High-Voltage Application*, IEEE Access VOLUME 8, 2020
10. M Bandyopadhyay, et al, *Two RF Driver Based Negative Ion Source Experiment*, IEEE Transactions on Plasma Science, 42:624,March(2014)