Michigan Tech

COMSOL Multiphysics® Based Inductance Estimation for Modeling Transformer Winding Faults in EMTP

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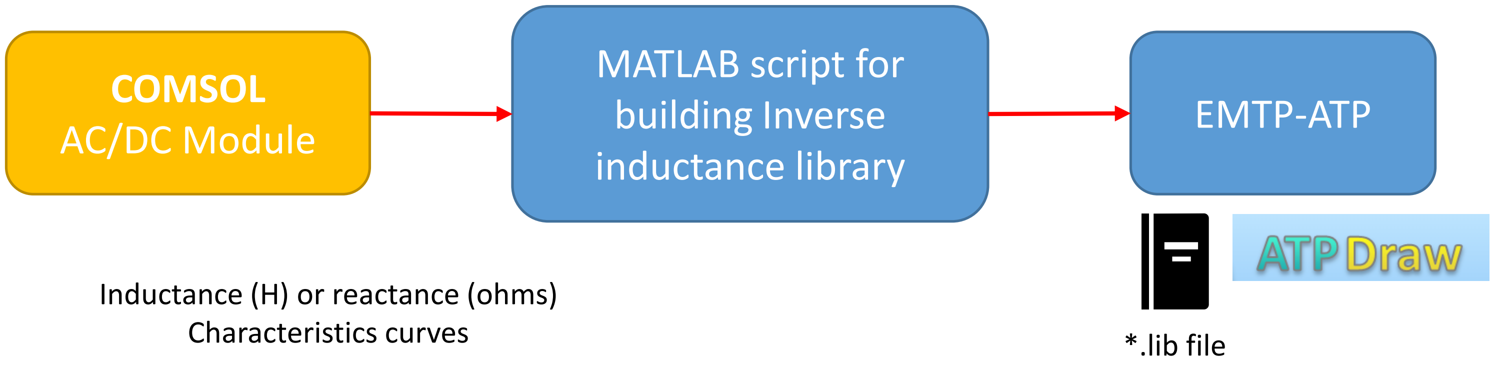
INTRODUCTION:

- ❑ Power Transformer are the most crucial element in power system network
- ❑ Protective systems are available to address the abnormality
  - Avoid relay mis-operation
  - Maintain reliability
- ❑ Inner winding faults produce minor current and are difficult to detect
  - Turn-to-turn winding fault (**T2T**)
  - Turn-to-ground winding fault (**T2G**)
- ❑ Transformer model is the key to study and analyze the behavior

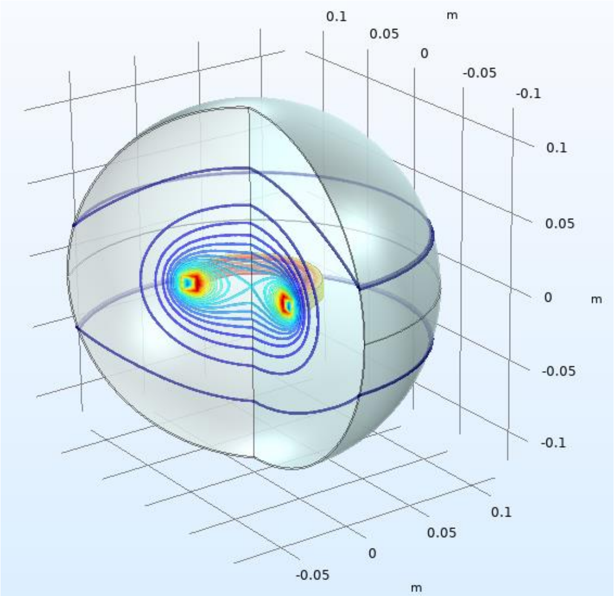
OBJECTIVE:

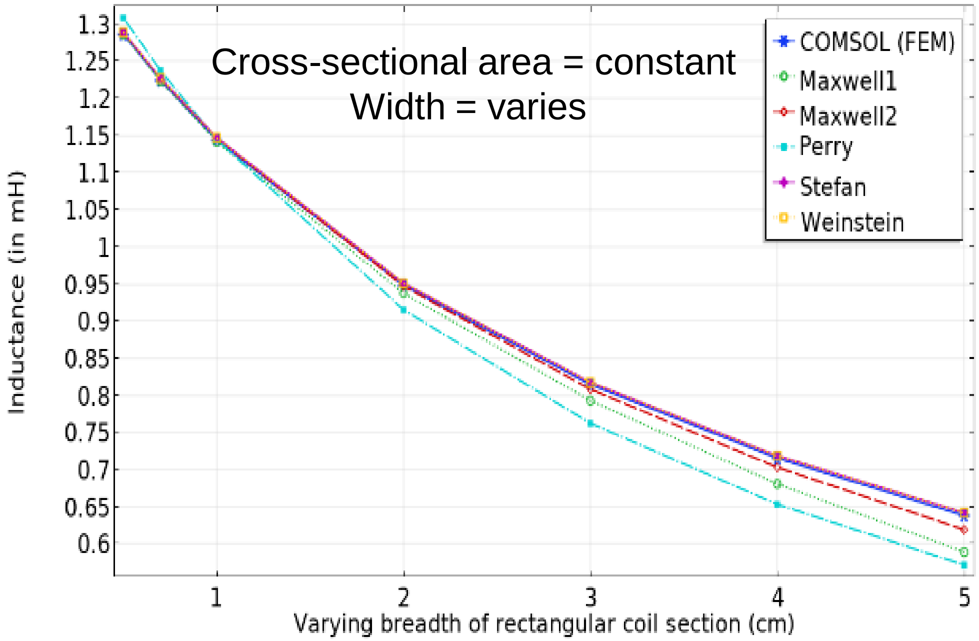
- ❑ Accurate representation of Transformer Winding fault
- ❑ Able to account minor effects
- ❑ Overcome simplification from Analytical Approaches
- ❑ Maintain user-friendly version of model for study and analysis
- ❑ EMTP-ATP Implementation worthy

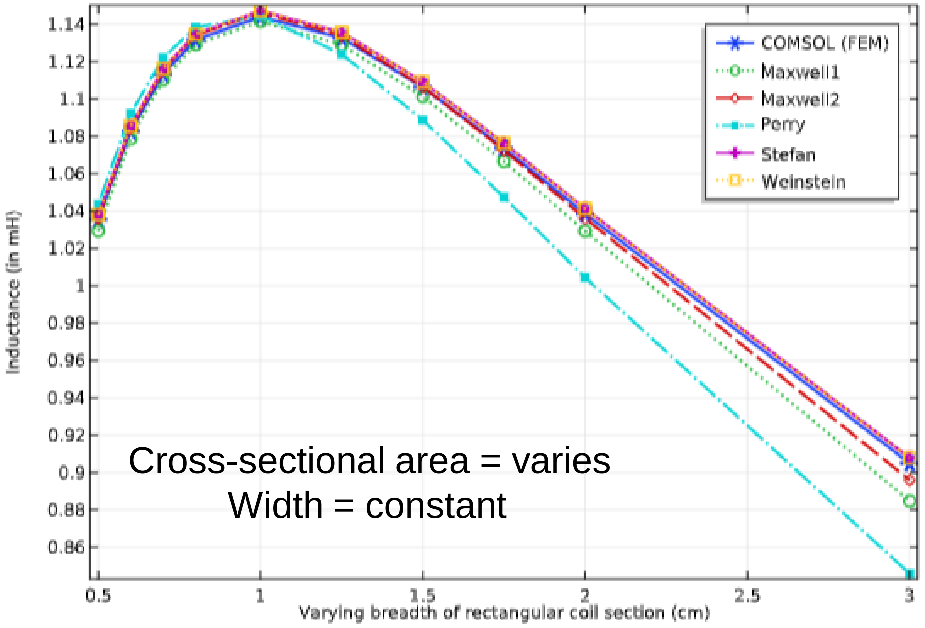


Significance of FEA based approach

Comparison of analytical approaches to estimate the inductance vs FEA method



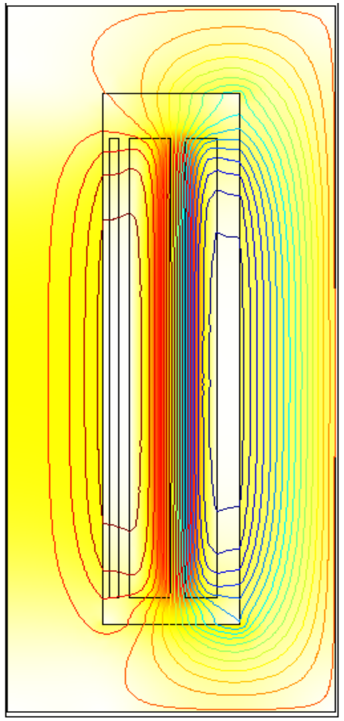




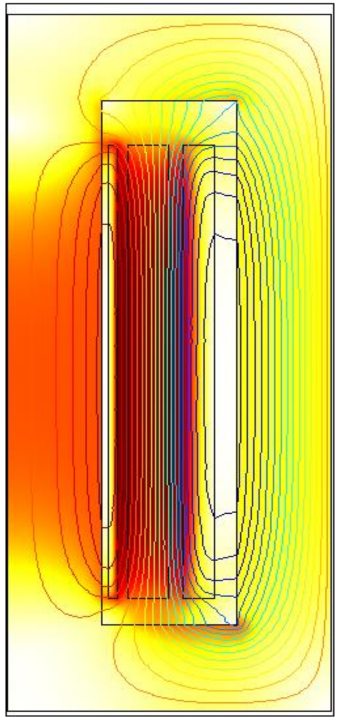
Method to estimate leakage inductances:

Case A: Healthy Transformer

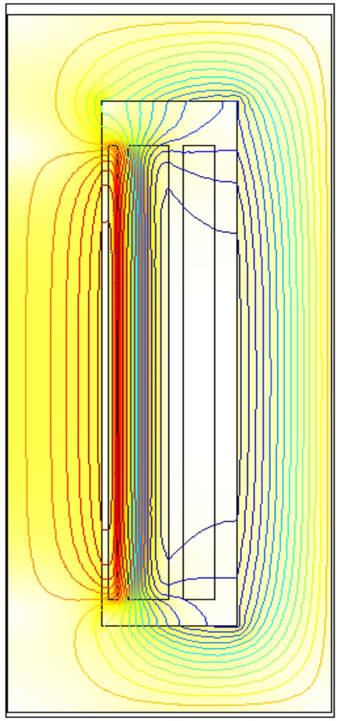
i.) Zps



ii.) Zpt



iii.) Zst



Leakage Reactance	Analytical formula based	COMSOL (FEA)
X_{sc}	21.2918	21.0572
X_{sd}	38.5627	38.1231
X_{cd}	11.7180	11.0950

Inductance calculation from simulation

Self and Mutual Inductance values

$$\mathbf{L}_{12} = \mathbf{L}_{\mathbf{self}1} - \frac{\mathbf{M}_{12}{}^{2}}{\mathbf{L}_{\mathbf{self}2}}$$

- One coil-pair at a time
- Coil 1 (source) = Current excitation (rated)
- Coil 2 (shorted) = Voltage excitation of 0V

↓

Mf.L_1_3 (H) [mutual inductances b/w 1 & 3]

mf.LCoil_3 (H) [Coil inductances]

Magnetic Solution Method

$$\mathbf{L}_{12} = \frac{2 * \mathbf{W_m}}{I^2} = \frac{2 * \mathbf{mf.intW_m}}{\mathbf{mf.ICoil\_1}^2}$$

- One coil-pair at a time
- Coil 1 = Current excitation (I1)
- Coil 2 = Current excitation (I2)
- I1 x N1 = I2 x N2 (AT balance)

↓

mf.Wm (J) [Magnetic Energy Density]

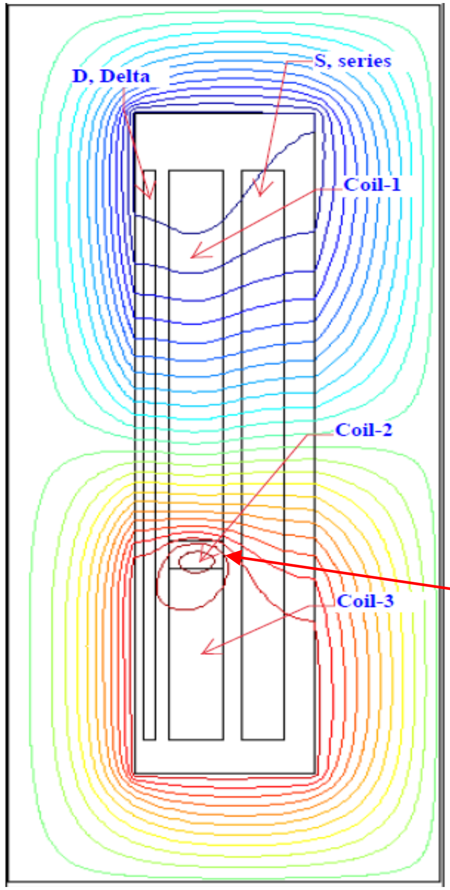
(user defined regions only)

or

mf.intWm (J) [Total Magnetic energy]

(covers all regions)

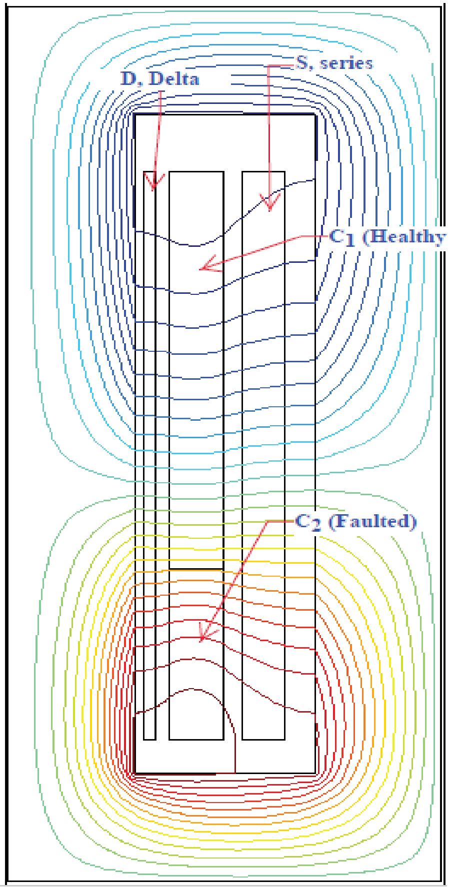
Winding Fault simulations



T2T

Conceptual overview of T2T and T2G fault modeling on common winding

3 coil segments with coil 2 indicating faulted turns



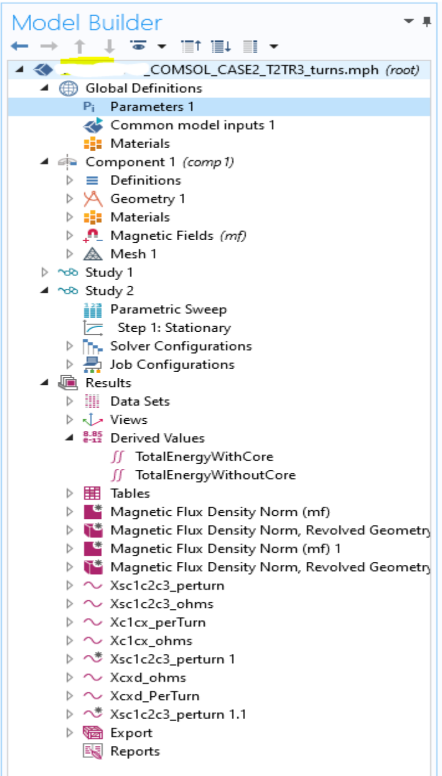
T2G

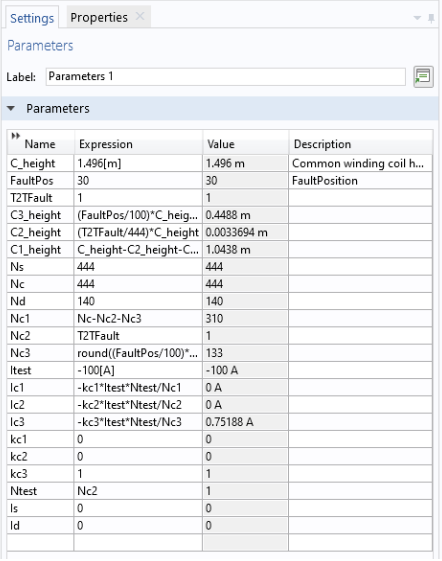
Challenge: To model for any range of fault progression

<u>Derive Characteristic curves</u>

Parametric Sweep approach:

- Magnetic solution method
- T2T or T2G
- Fault position progression from bottom to top
- Faster output
- Ability to post-process multiple simulation cases into a table



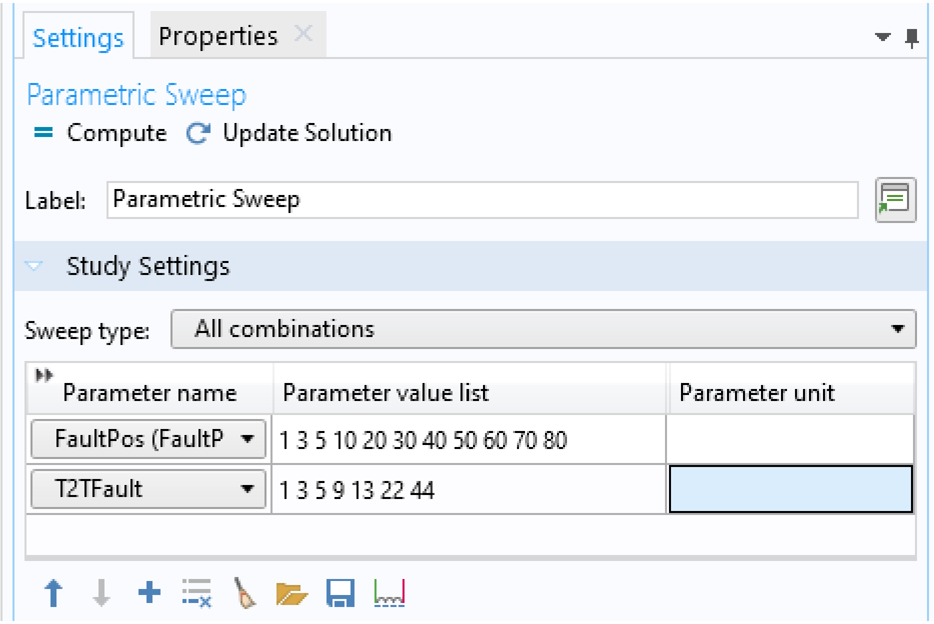

Settings Properties

Parameters

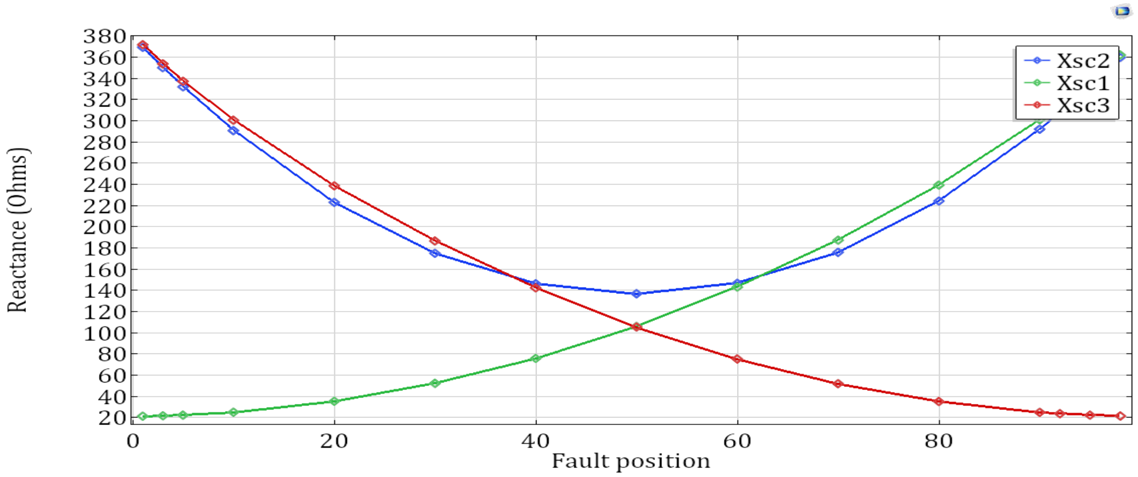
Label: Parameters 1

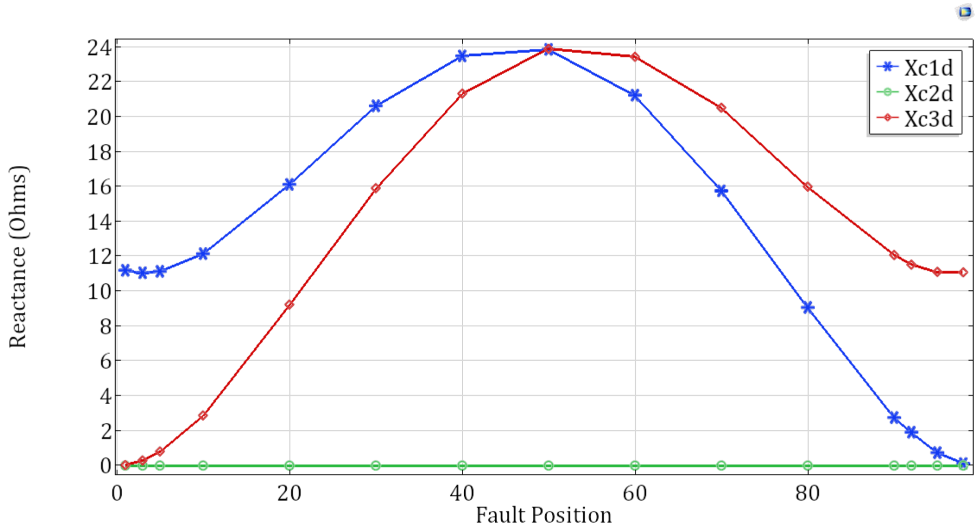
Parameters

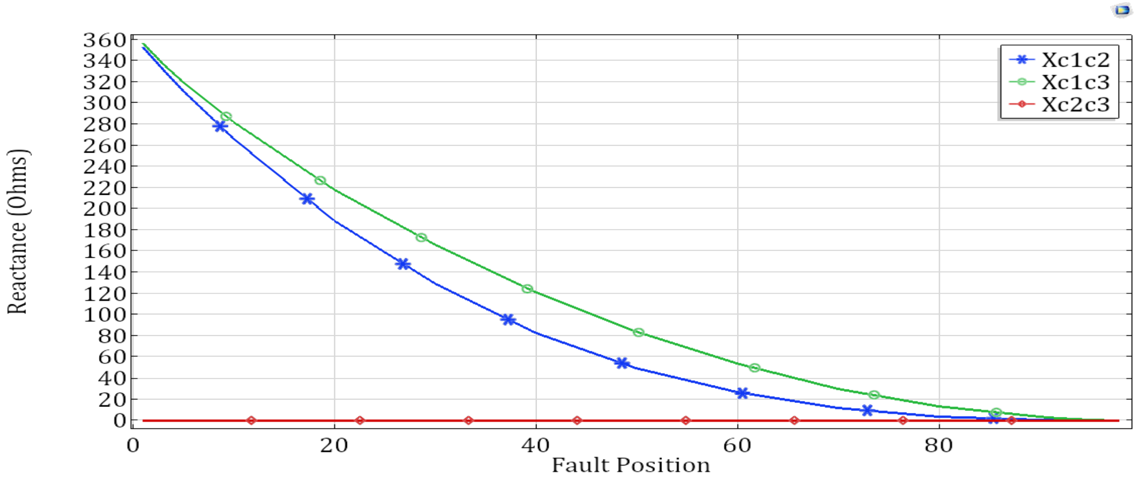
Name	Expression	Value	Description
C_height	1.496[m]	1.496 m	Common winding coil h...
FaultPos	30	30	FaultPosition
T2TFault	1	1	
C3_height	(FaultPos/100)*C_heig...	0.4488 m	
C2_height	(T2TFault/444)*C_height	0.0033694 m	
C1_height	C_height-C2_height-C...	1.0438 m	
Ns	444	444	
Nc	444	444	
Nd	140	140	
Nc1	Nc-Nc2-Nc3	310	
Nc2	T2TFault	1	
Nc3	round((FaultPos/100)*...	133	
Itest	-100[A]	-100 A	
Ic1	-kc1*Itest*Ntest/Nc1	0 A	
Ic2	-kc2*Itest*Ntest/Nc2	0 A	
Ic3	-kc3*Itest*Ntest/Nc3	0.75188 A	
kc1	0	0	
kc2	0	0	
kc3	1	1	
Ntest	Nc2	1	
Is	0	0	
Id	0	0	

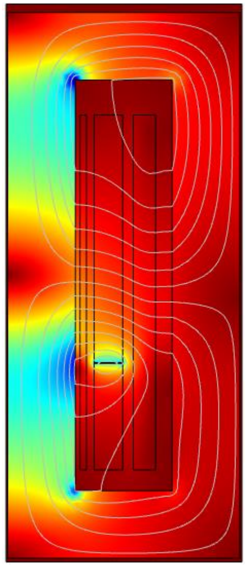


Leakage reactance between coil segments: S, C1, C2, C3 and D





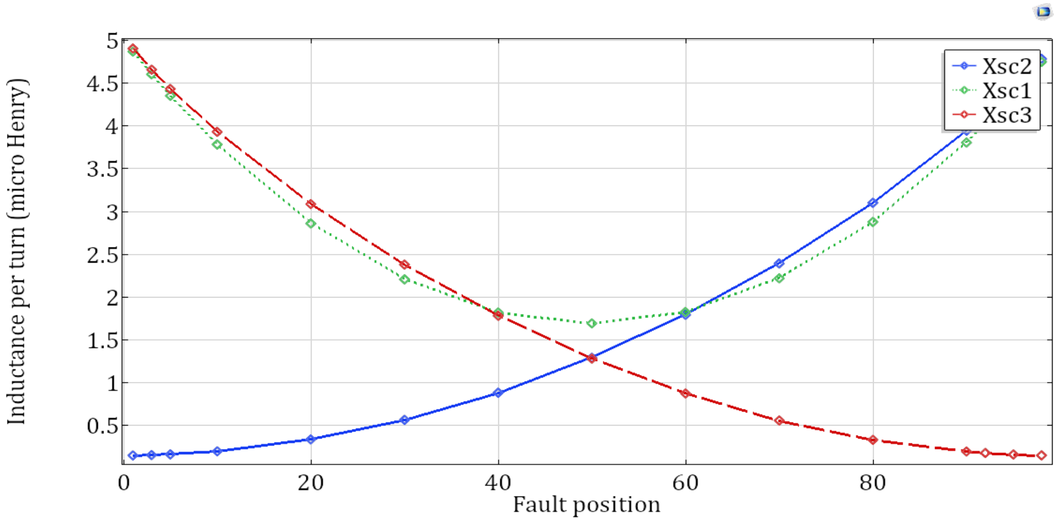


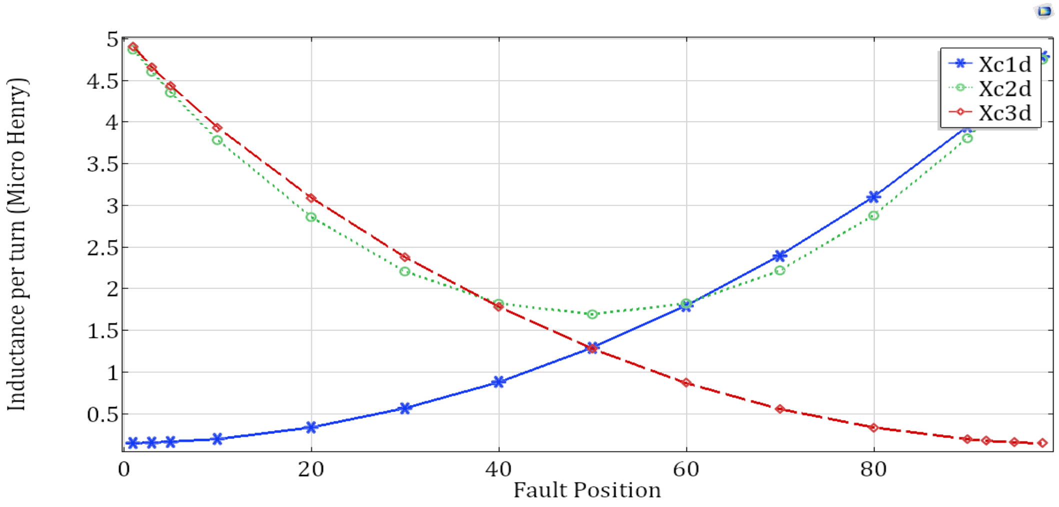


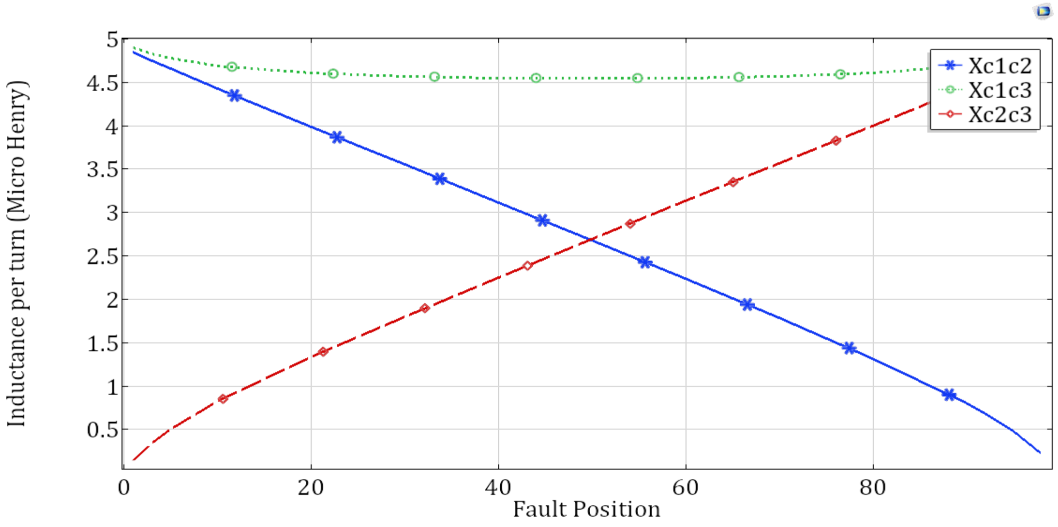
T2T fault on Common winding

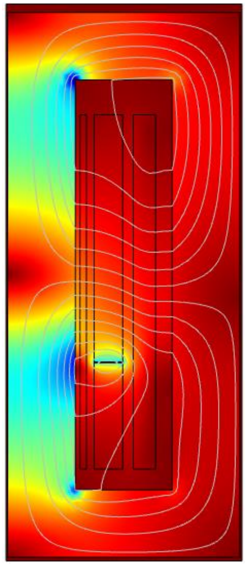
- Reactance profile doesnot provide trend to simplify the curves

Leakage inductances (1-turn basis) between coil segments: S, C1, C2, C3 and D









T2T fault on Common winding

- These curve are reduced to set of equation by fitting and supplied ad input to MATLAB codes

Simulation Result in ATP:

	Expected [A]	Simulation [A]
Primary (A-ph)	3717.7	3710.29
Secondary (A-ph)	237.0	240.65
Tertiary (A-ph)	3121.6	3001.9
Primary (B-ph)	247.5	251.00
Secondary (B-ph)	644.6	644.22
Tertiary (B-ph)	3121.6	3001.8

Conclusion:

- Accurately estimated the values of leakage reactance for healthy and faulted winding transformer
- Characteristic curve is exported or simplified by fitting the values
- The coefficients are then supplied to developed matlab code to generate library for near-real time
- Enhanced the ATP model for studying the Transformer protection

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