

Open Phase Conditions in Transformers

Analysis and Protection Algorithm

Amir Norouzi

GE Digital Energy

Presentation for Texas A&M Conference for Protective Relay Engineers- April 2013

Agenda:

- 1- Introduction
- 2- Review of Transformer Construction
- 3- Open Phase in Transformers
- 4- Protection Algorithms
- 5- Conclusion
- 6- Questions

Introduction

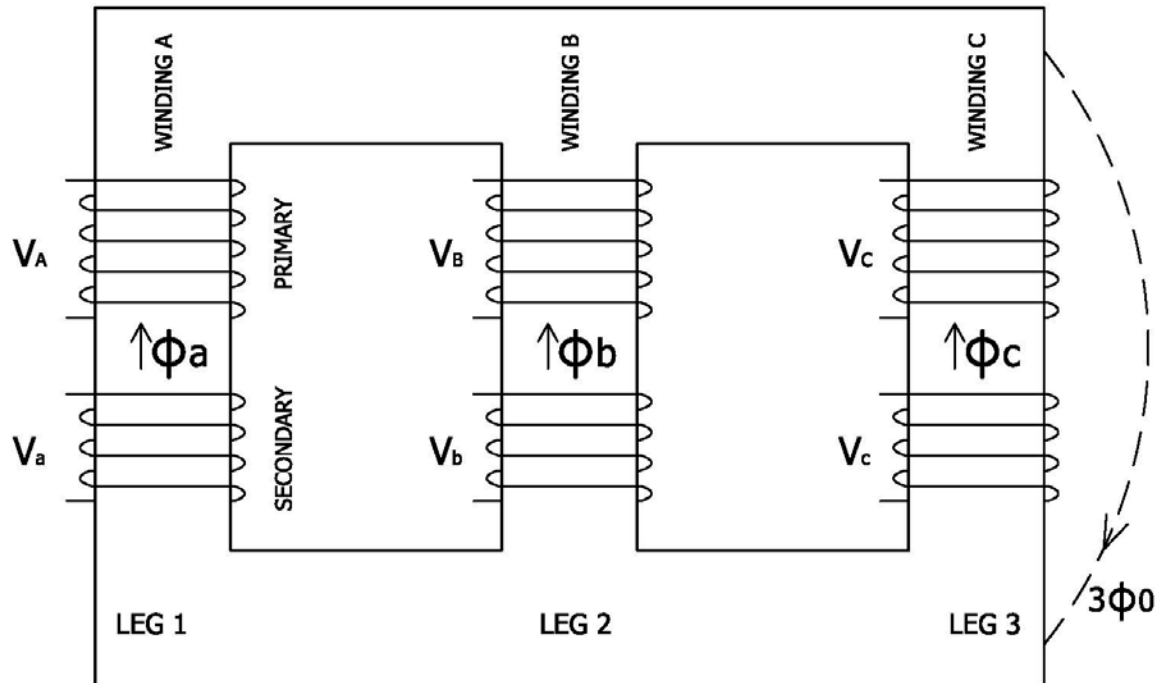
- Open phase: Broken conductor; blown fuse; defected breaker pole.
- More frequent in distribution networks, remote areas and industrial plants.
- Open phase is a series fault as opposed to shunt faults such as LG or LLG.

Introduction

- Conventional protection: Negative sequence overcurrent; Phase or ground overcurrent.
- Standard elements cannot always detect an open phase, particularly in lower transformer loading.
- Not able to identify the true cause of the fault; increase in down time.

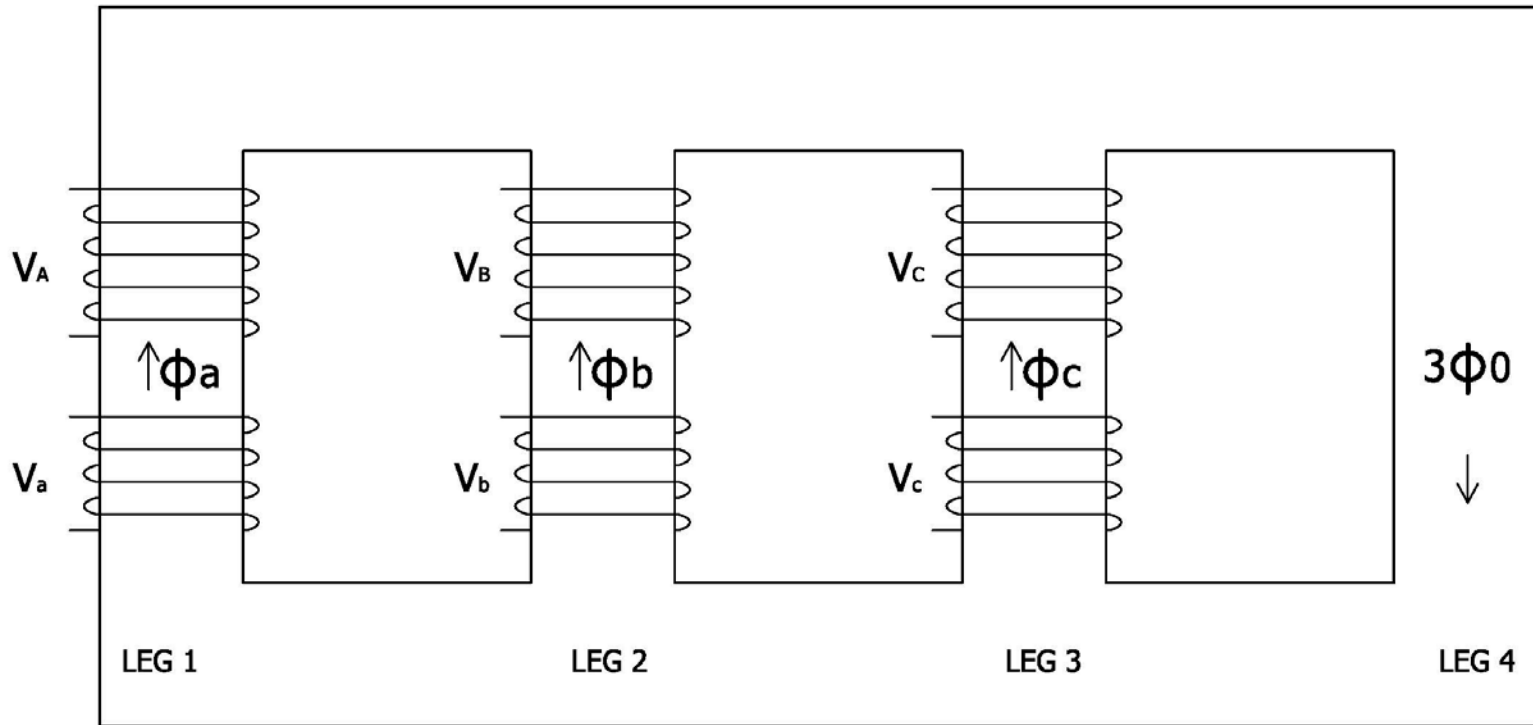
Transformer Construction

-Common core: three-leg; four-leg; five-leg or shell type.



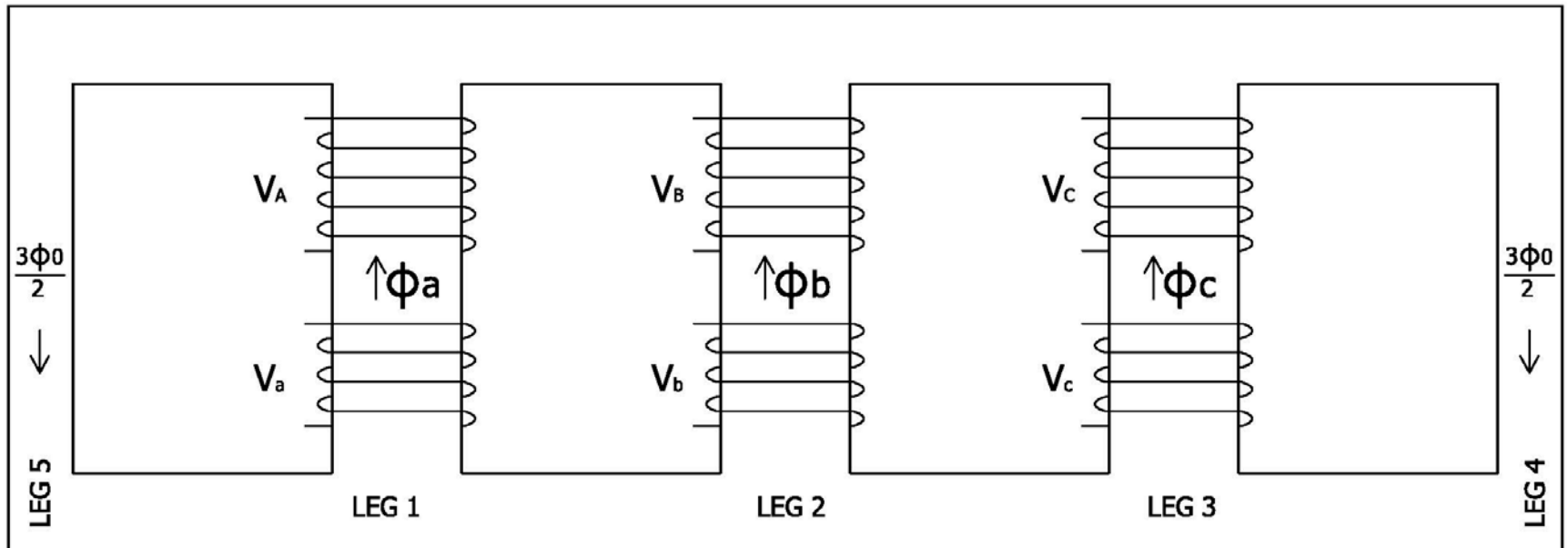
Transformer Construction

Four-leg construction



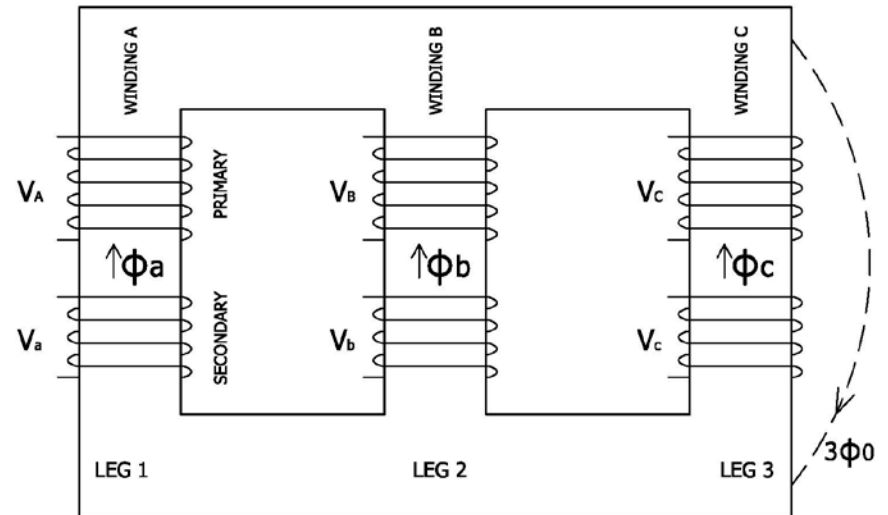
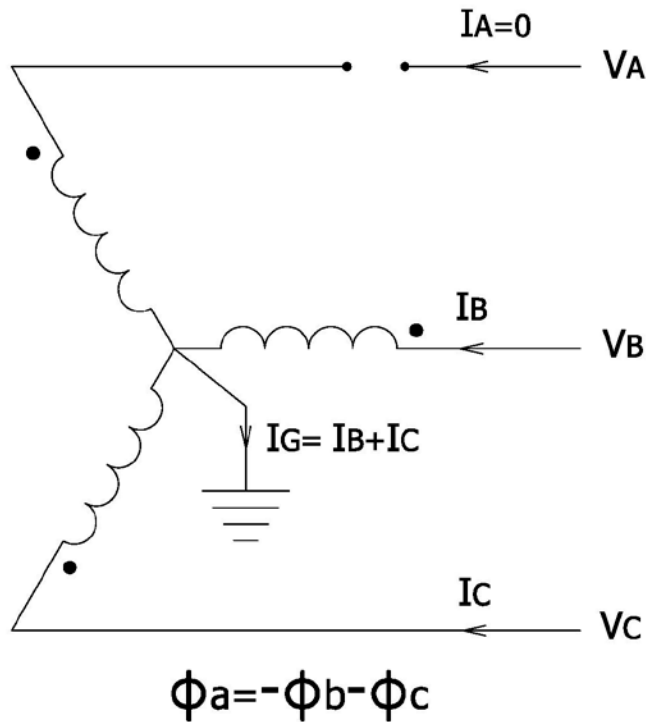
Transformer Construction

Five-leg construction



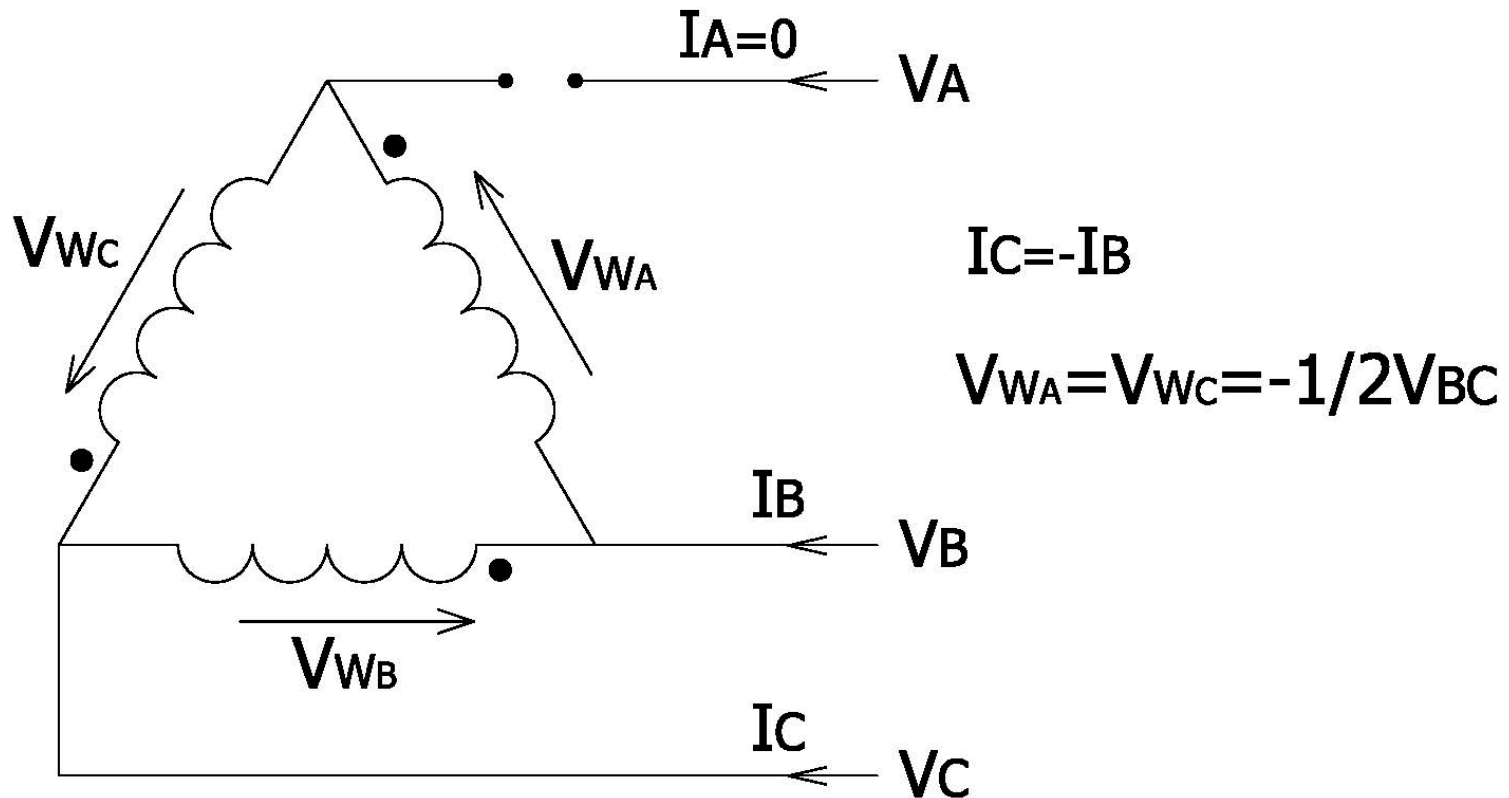
Open Phase in Transformers- Yg Winding

-Open Phase in Yg primary winding:
voltage re-generation in three-leg core.



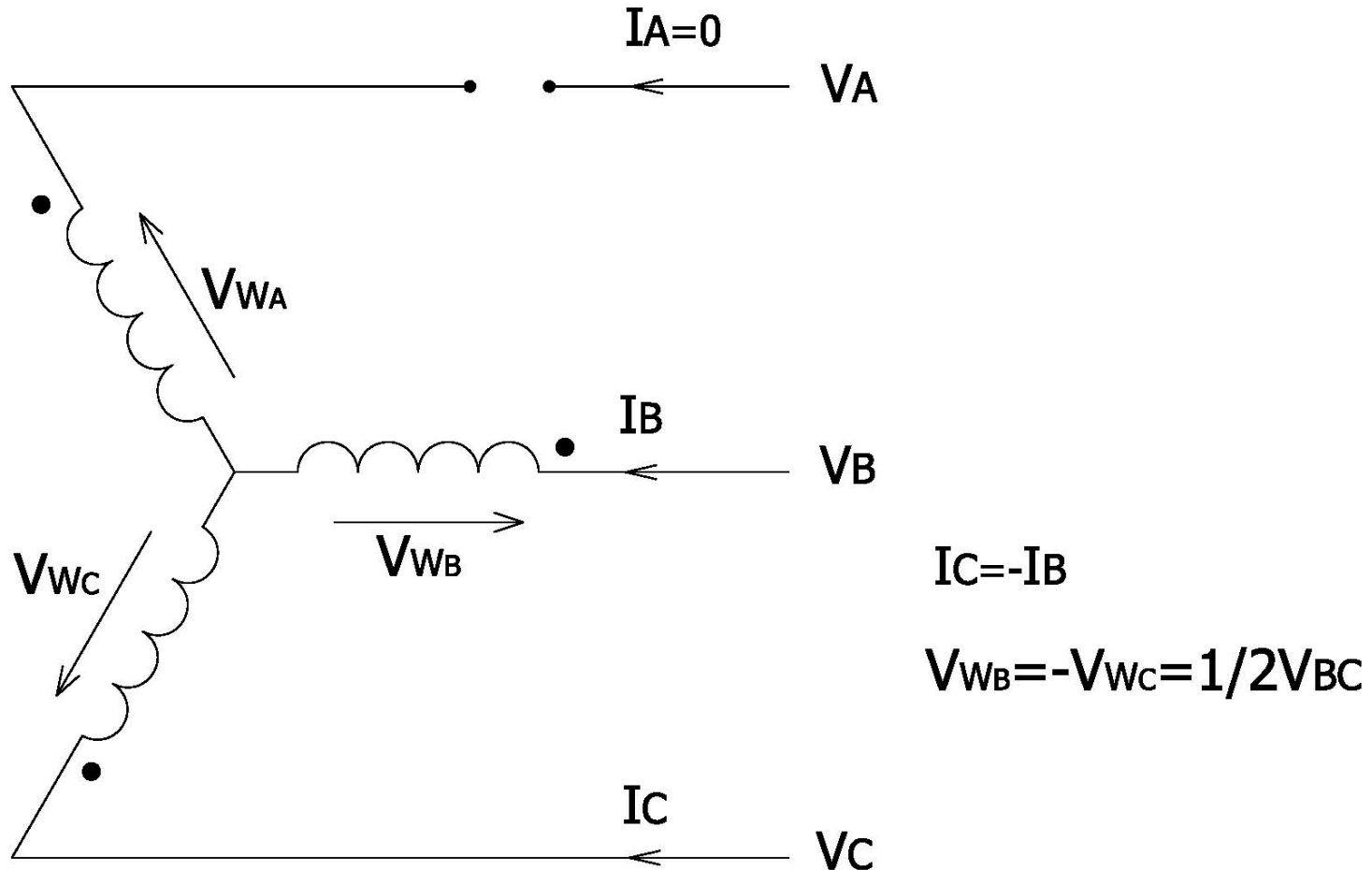
Open Phase in Transformers- Delta Winding

-Open Phase in Delta primary winding: No voltage re-generation.



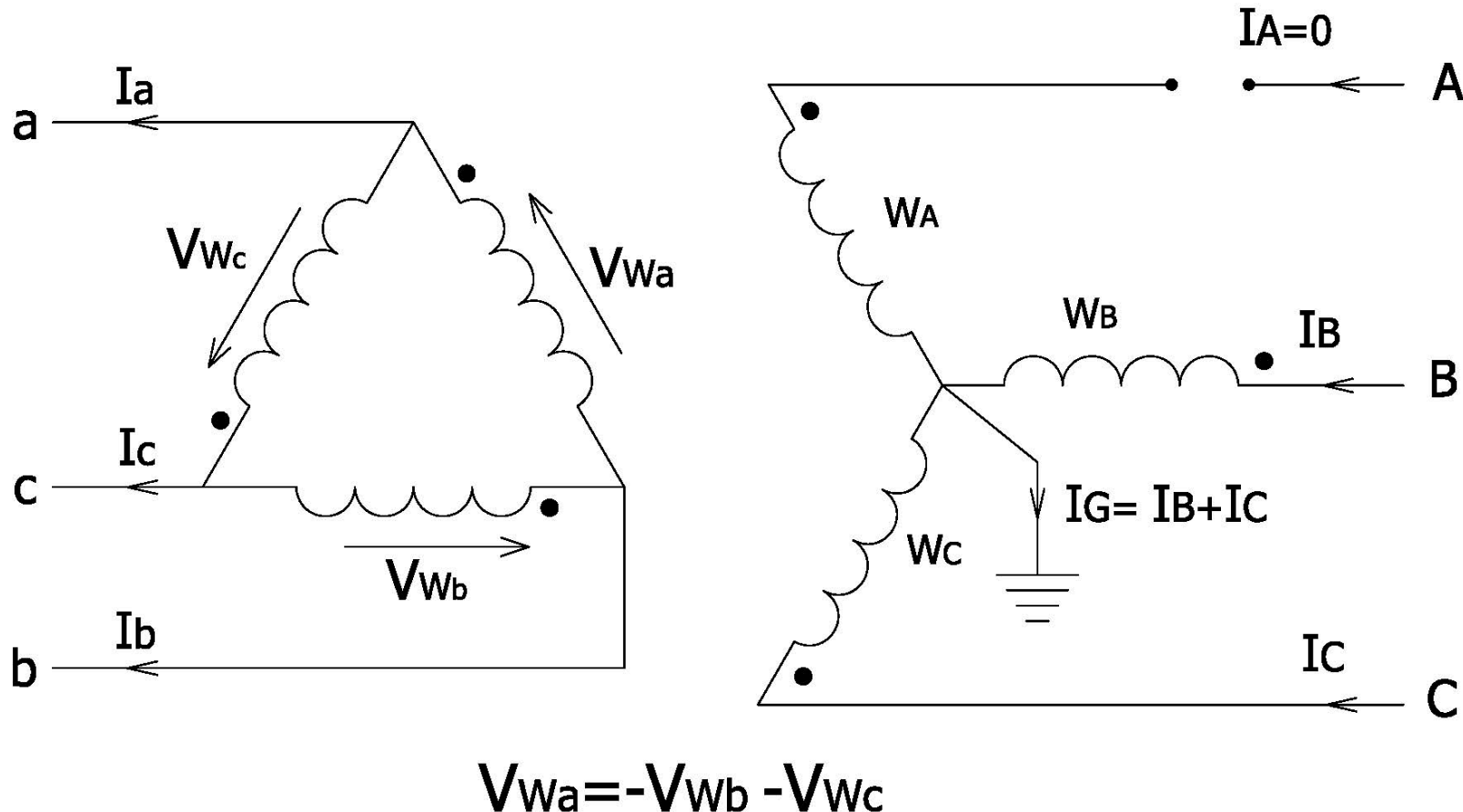
Open Phase in Transformers- Y Winding

-Open Phase in Y primary winding: No voltage re-generation.



Open Phase in Transformers- Yg-D

-Open Phase in Yg-D transformers: lost phase always re-generated regardless of core type



Open Phase in Transformers- Yg-D

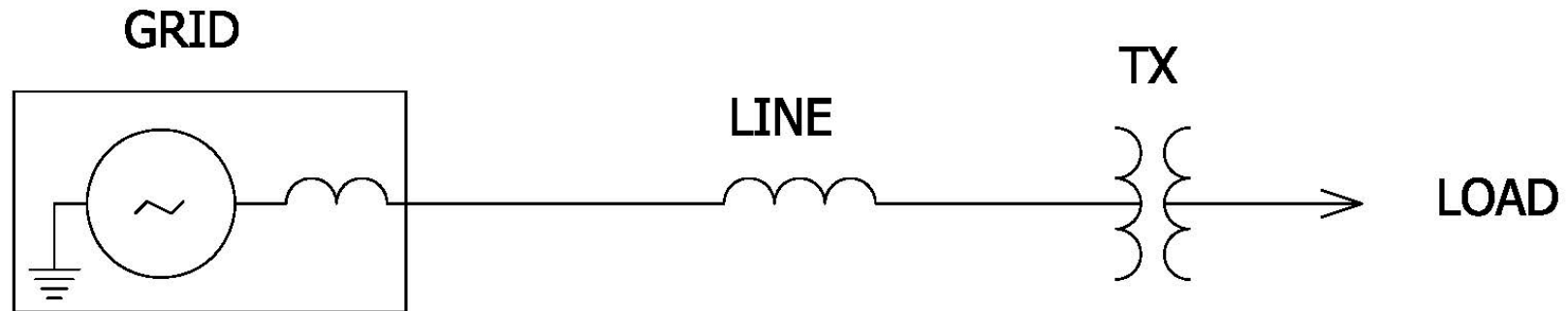
- Voltage re-generated simply by voltage build-up across the coil by the other two coils on the low side.
- High side is then energized back from the low side coil.
- No magnetic flux involved in voltage re-generation- Energy not being transferred- No current in the coils with lost phase.

Open Phase in Transformers- Yg-D

- Low side line currents and voltages fairly balanced in lower loadings.
- Only two coils carry current and power-
High side currents considerably increase.
- More imbalance at higher loads due to flux leakage and voltage drops.

Open Phase in Transformers- Yg-D

-Sample power system to be studied.

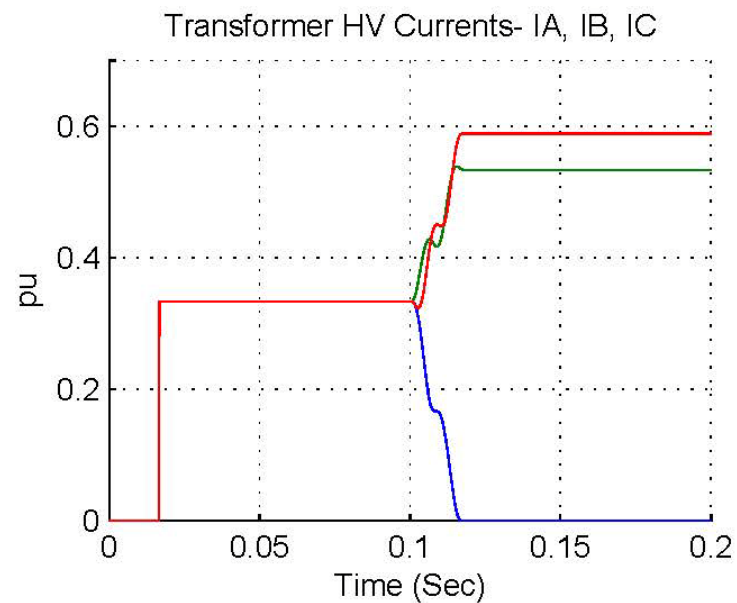
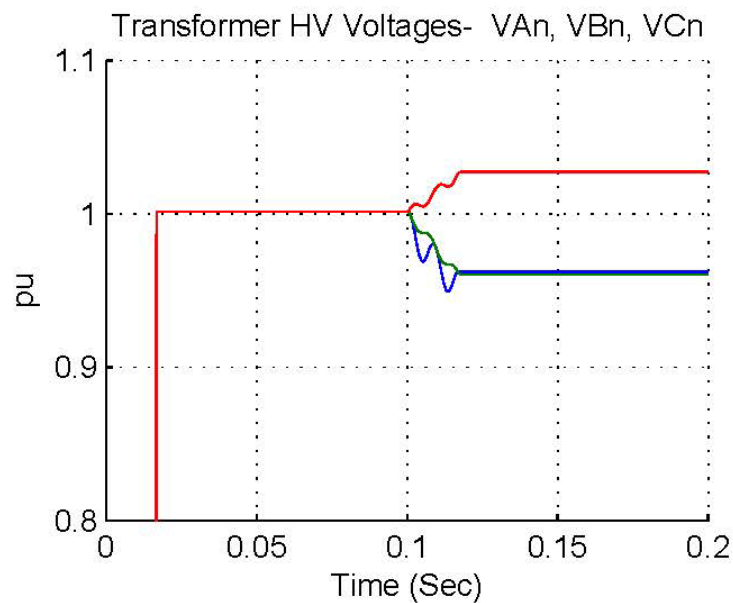
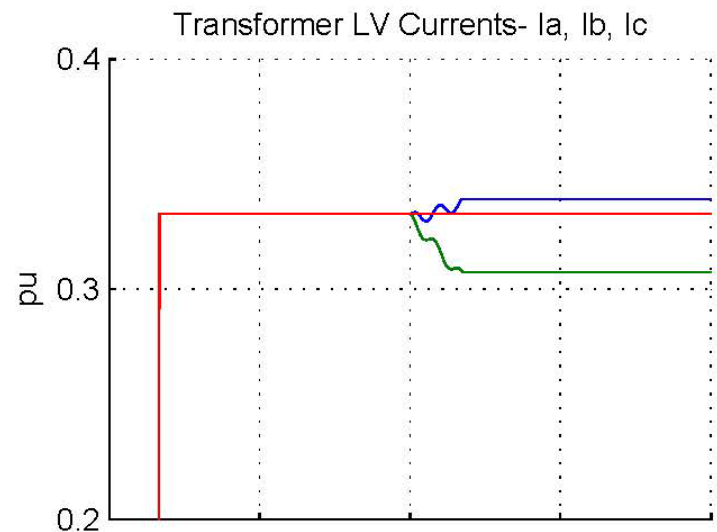
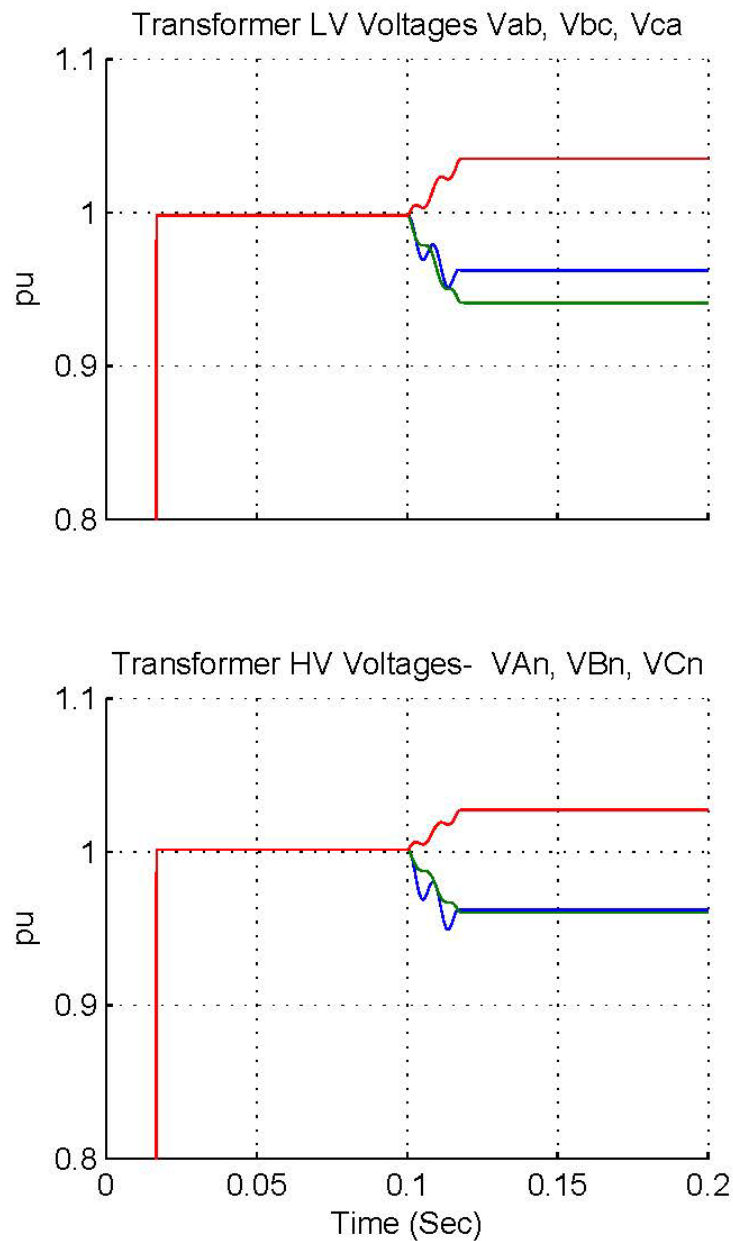


GRID:
12.55KV
SCC: 80MVA

TRANSMISSION LINE:
20KM
 $L1=0.8$ mH/Km, $L0=1.2$ mH/Km
 $R1=0.05$ Ohms/Km
 $R0=0.05$ Ohms/Km

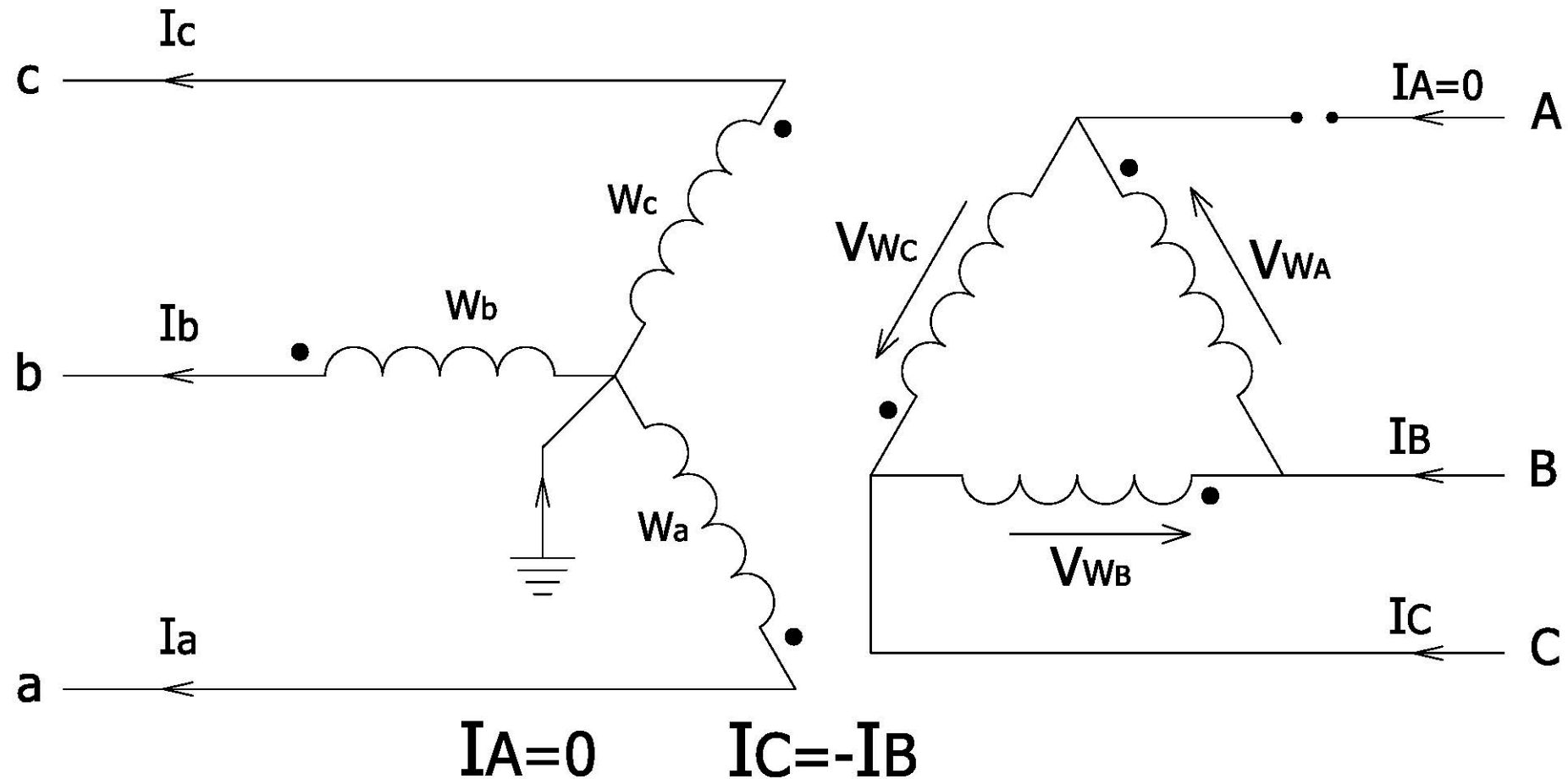
TRANSFORMER:
12.47/0.46 KV, 1800KVA
 $R=0.005$ pu
 $X1=0.05$ pu
NO LOAD LOSS: 1200 W
NO LOAD EXCITATION
CURRENT: 0.1% of I_{nom} .

Open Phase in Transformers- Yg-D



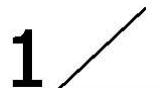








Open Phase in Transformers- Ungrounded Primary

-Similar characteristics with Delta or Y primary regardless of secondary winding



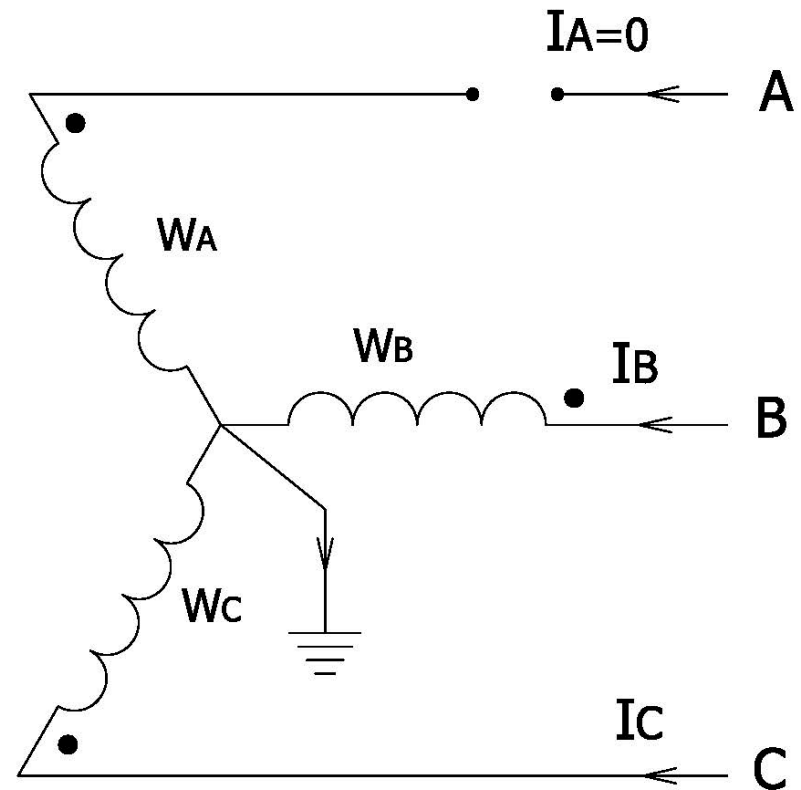
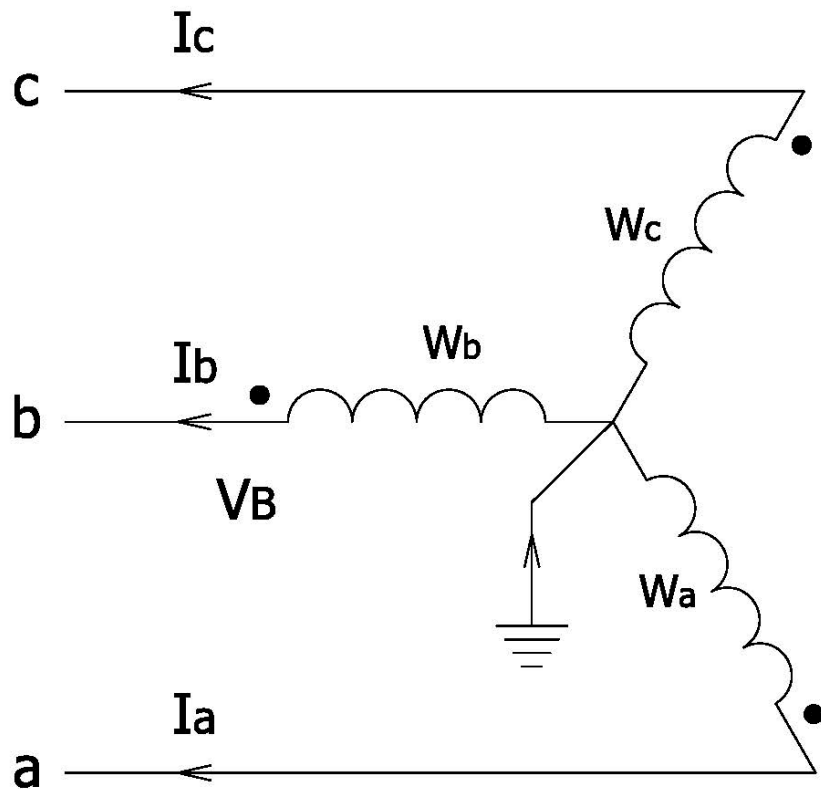
Open Phase in Transformers- Ungrounded Primary

$-\frac{I_2}{I_1}$ values on the low side for an open phase on the high side. Applicable to DG as well.

Case	Pri. and Sec. in phase	Pri. lags Sec. by 30°	Pri. leads Sec. by 30°
A Open	1  180°	1  120°	1  -120°
B Open	1  -60°	1  -120°	1  0°
C Open	1  60°	1  0°	1  120°

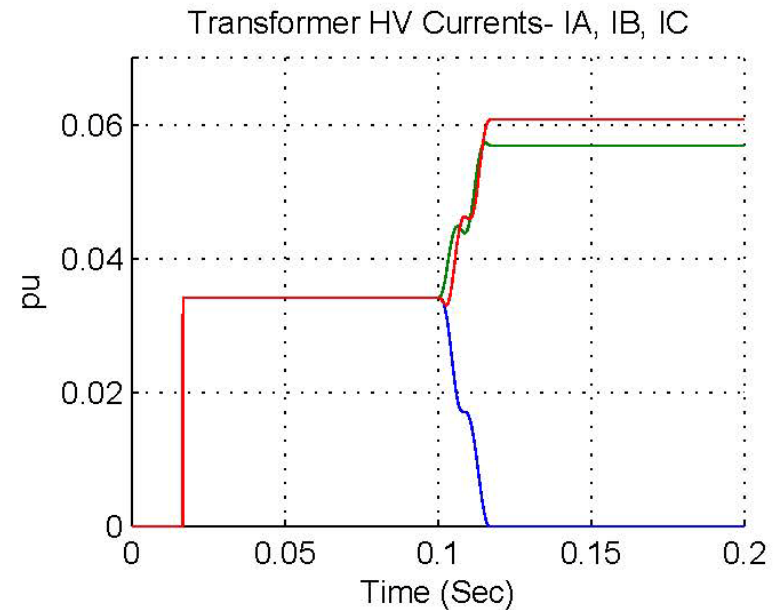
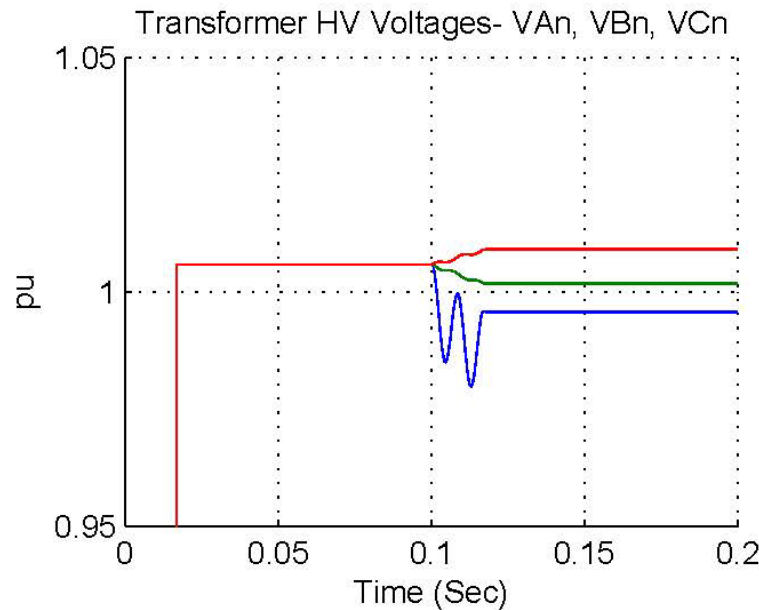
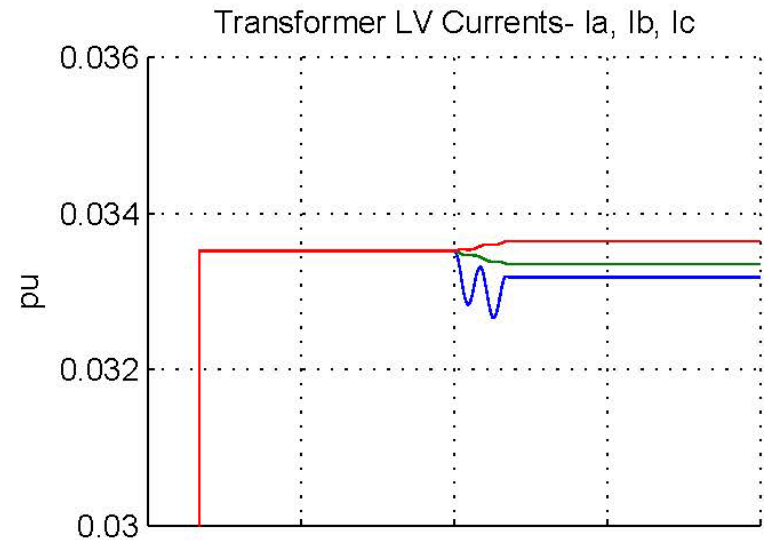
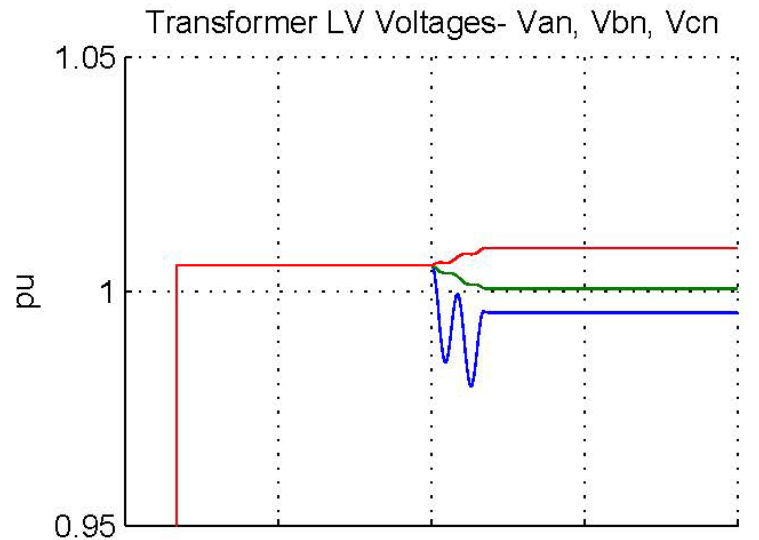
Open Phase in Transformers- Yg-Yg Transformers

- Voltage re-generation in primary side only in three-leg cores due to the flux going through the third leg. Not the case in other core types



Open Phase in Transformers- Yg-Yg Transformers

(three



Open Phase in Transformers- Yg-Yg Transformers (three-leg)

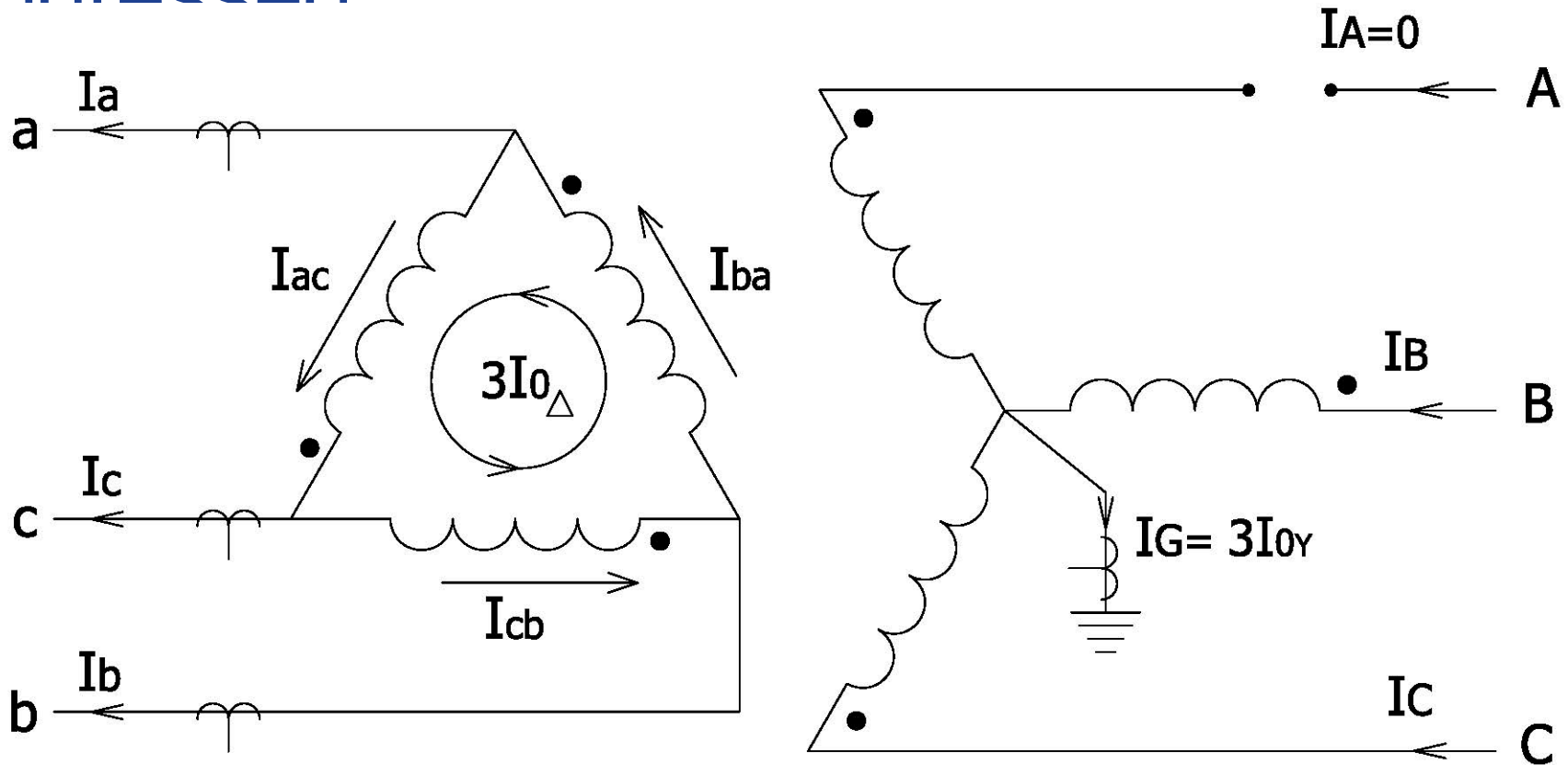
- Energy being transferred by magnetic flux to the low side coil with lost phase- Different from Yg-Delta transformers.

- The coil with lost phase on the low side gets energy magnetically from the core, not electrically from the high side feeder!

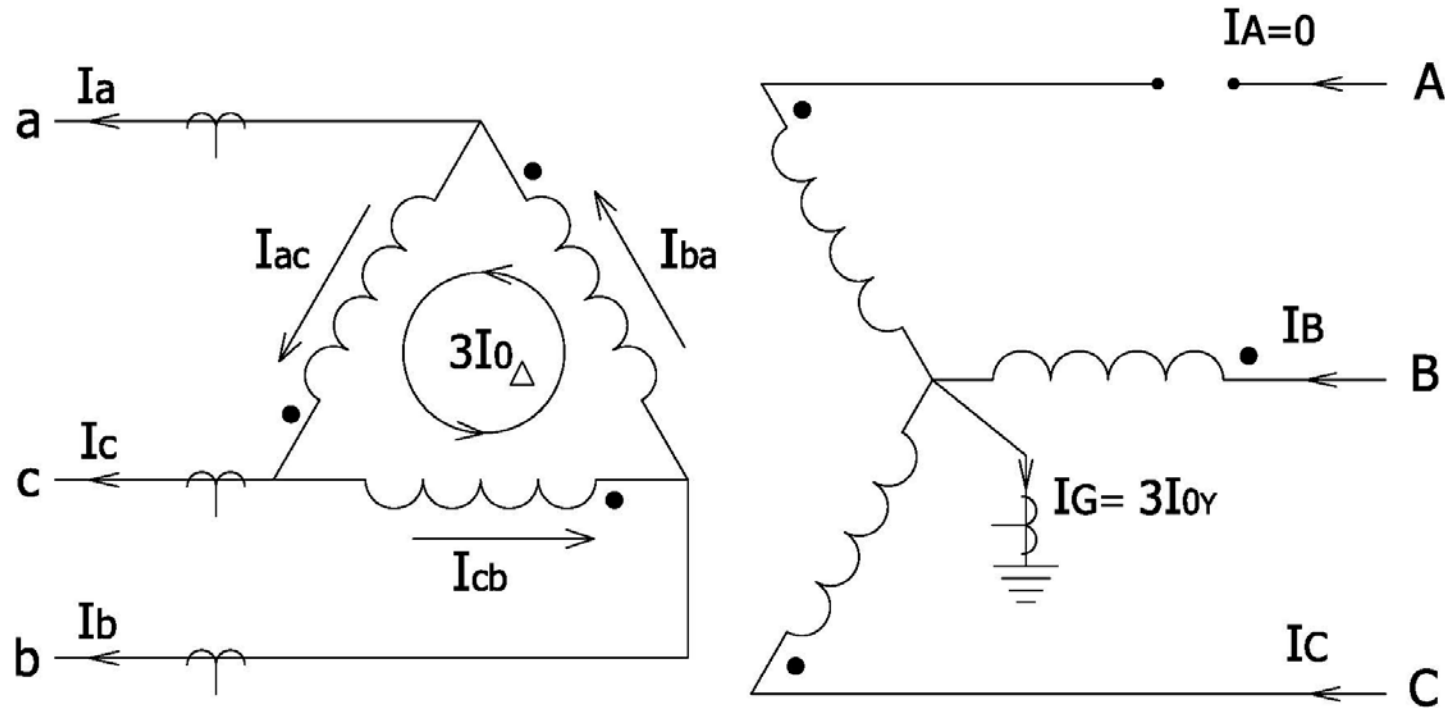
- Greater imbalance than Yg-Delta due to impact of the leakage flux on voltage re-generation.

Protection Algorithm- Yg-D Transformers

- The key is to be able to calculate high side currents from the low side CTs.
- Zero sequence current must be addressed



Protection Algorithm- Yg-D Transformers



$$I_a = I_{ba} - I_{ac}$$

$$I_b = I_{cb} - I_{ba}$$

$$I_c = I_{ac} - I_{cb}$$

$$I_{ac} + I_{ba} + I_{cb} = 3I_{0\Delta}$$

$$I_{0\Delta} = \frac{nI_G}{3\sqrt{3}}$$

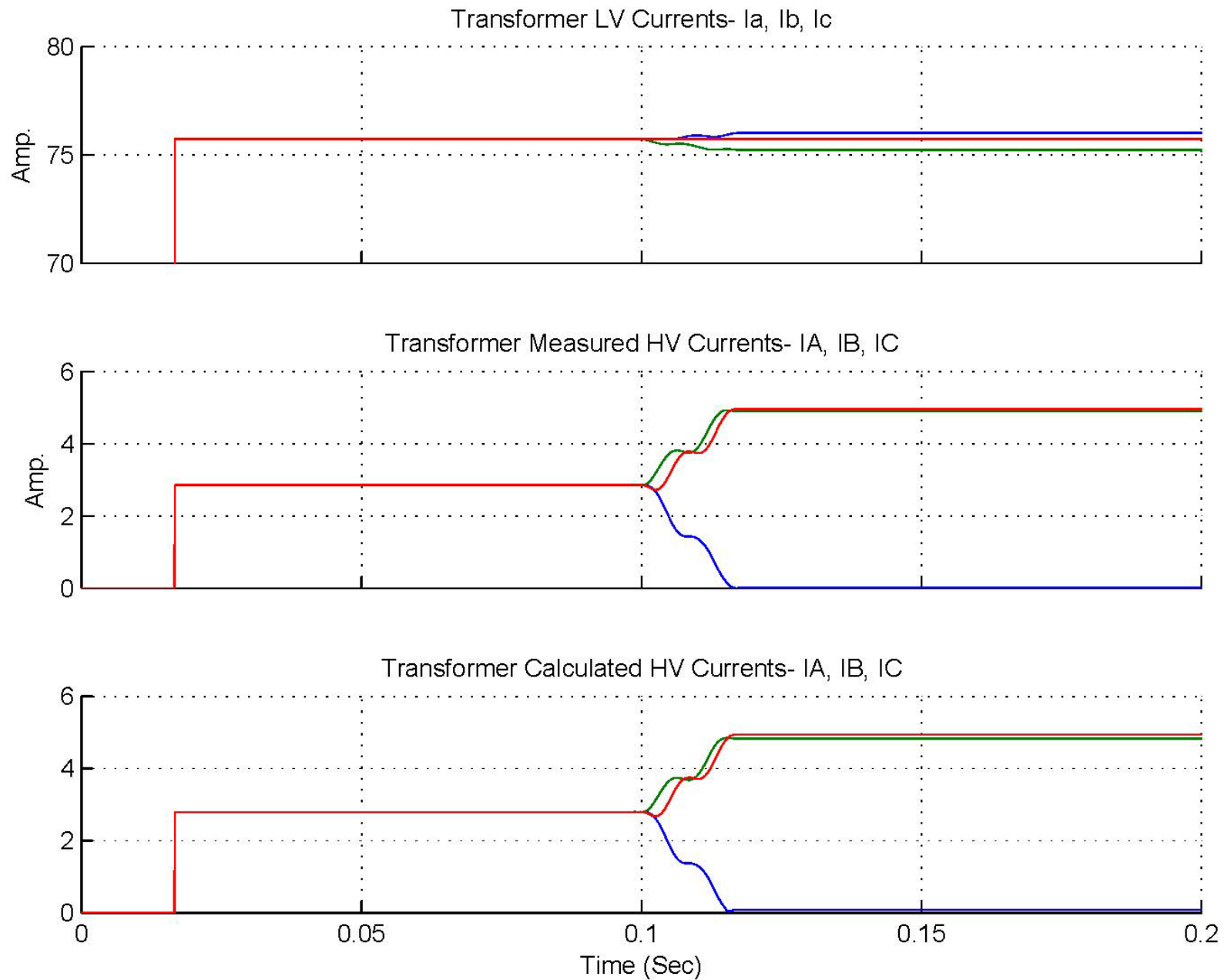


$$I_{ba} = \frac{1}{3}(I_a - I_b) + I_{0\Delta}$$

$$I_{cb} = \frac{1}{3}(I_b - I_c) + I_{0\Delta}$$

$$I_{ac} = \frac{1}{3}(I_c - I_a) + I_{0\Delta}$$

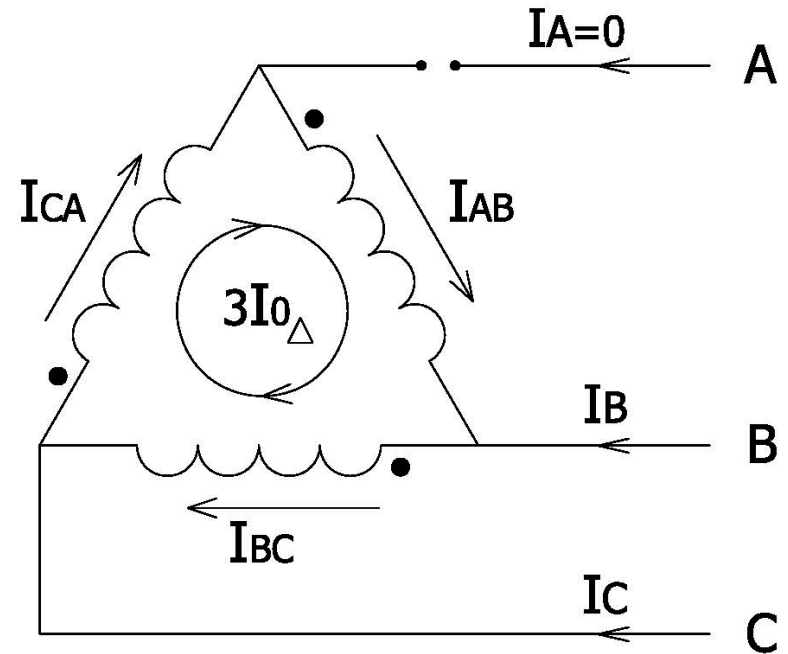
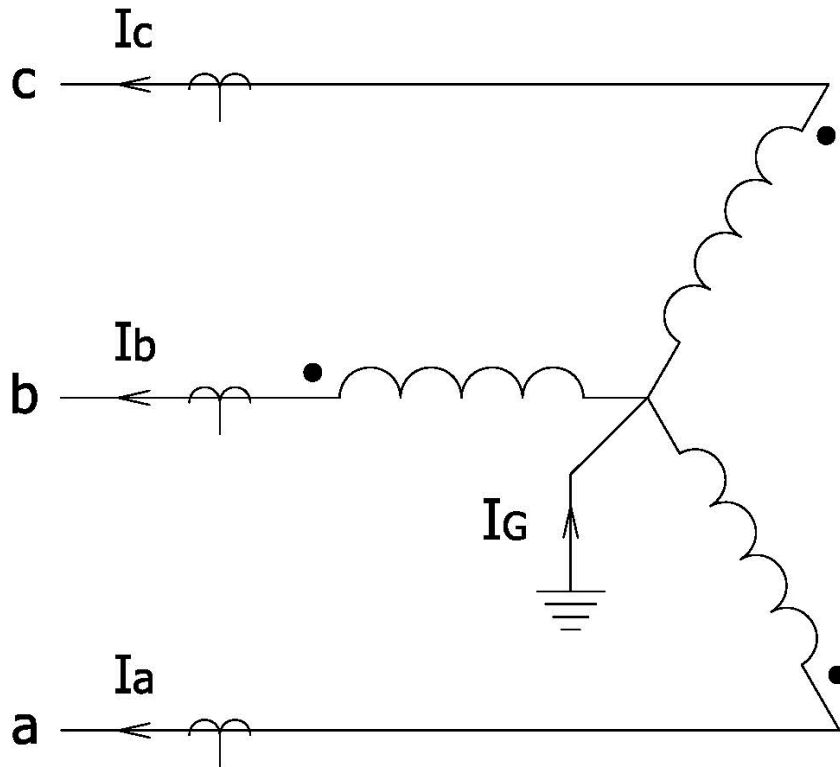
Protection Algorithm- Yg-D Transformers



Protection Algorithm- Ungrounded Primary

- Standard current or voltage protection elements will pick up a fault, but do not identify an open phase as the cause of the fault.
- One method is to use $\frac{I_2}{I_1}$ values to identify the open phase on the high side.
- Other method is to calculate high side currents from low side CTs. Unlike Yg-D, no I_0 is involved.

Protection Algorithm- Ungrounded Primary- D-Yg Transformers



$$I_{CA} = \frac{I_c}{n\sqrt{3}} \quad I_{BC} = \frac{I_b}{n\sqrt{3}}$$

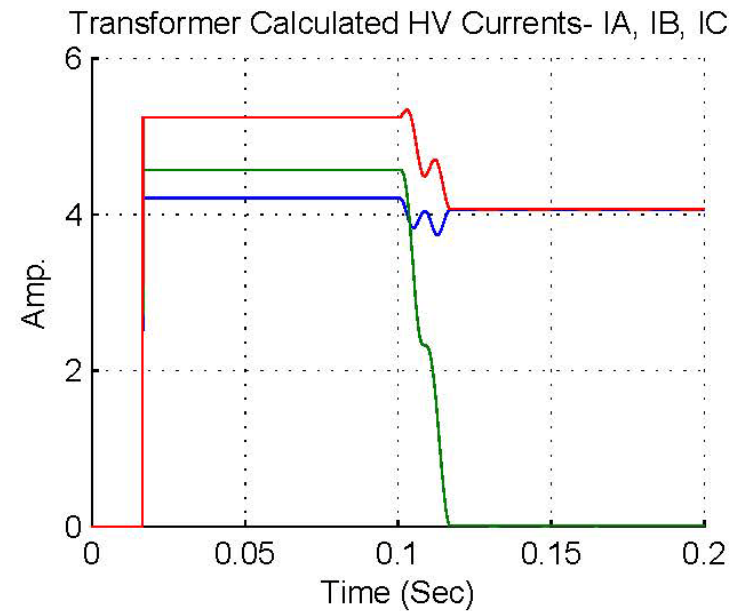
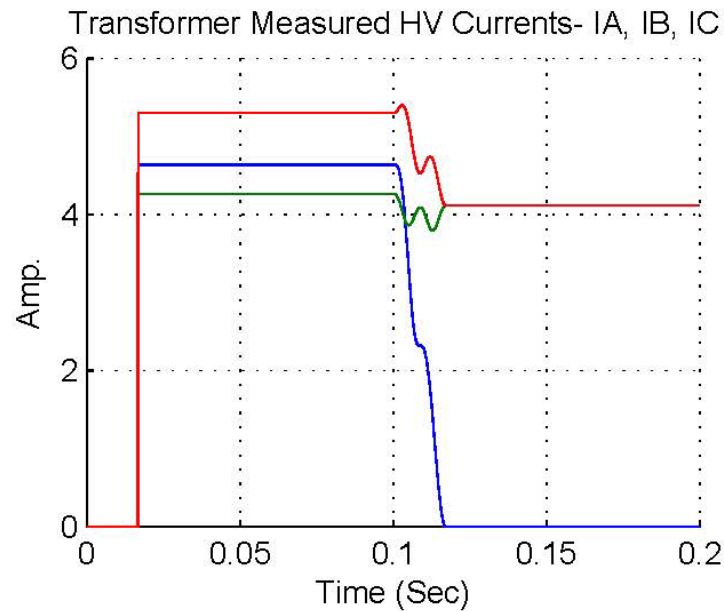
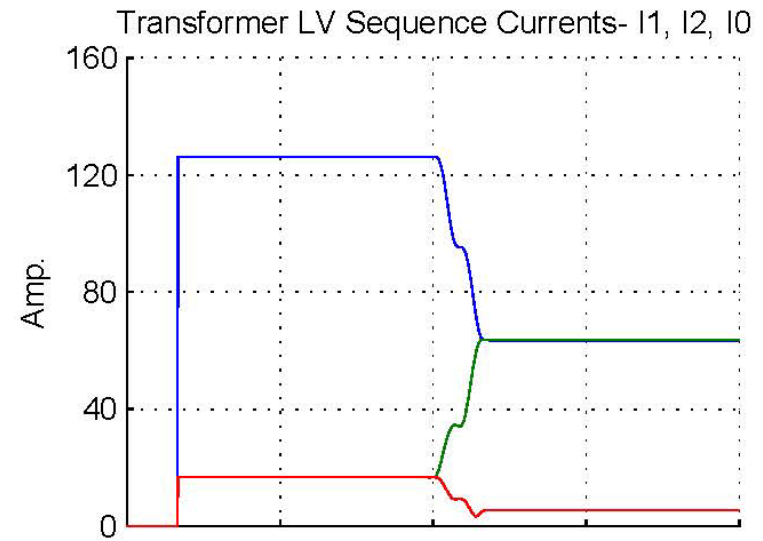
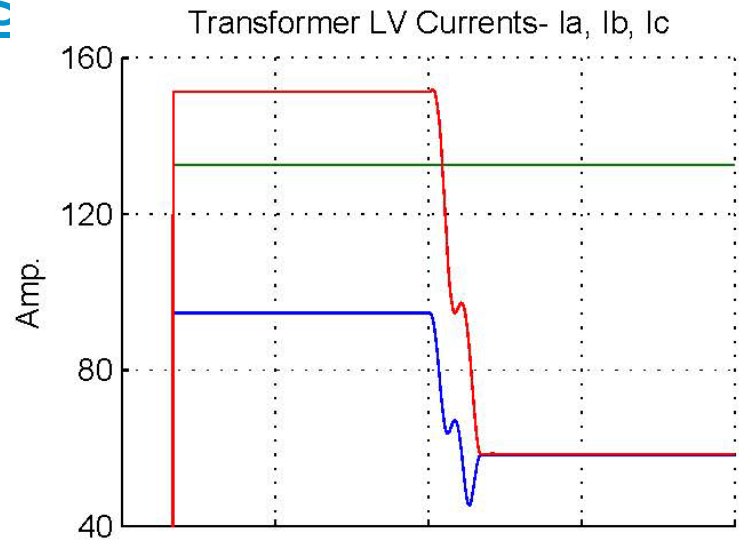
$$I_{AB} = \frac{I_a}{n\sqrt{3}}$$

$$I_A = I_{AB} - I_{CA}$$

$$I_B = I_{BC} - I_{AB}$$

$$I_C = I_{CA} - I_{BC}$$

Protection Algorithm- Ungrounded Primary- D-Yg Trans'

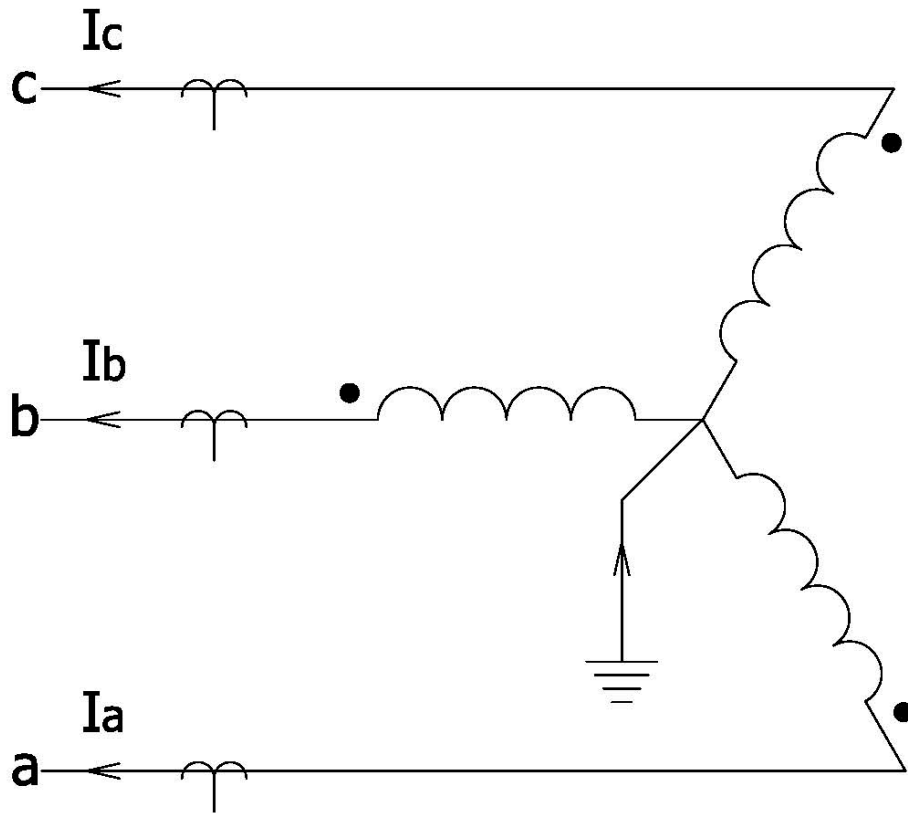


Protection Algorithm- Yg-Yg Transformers

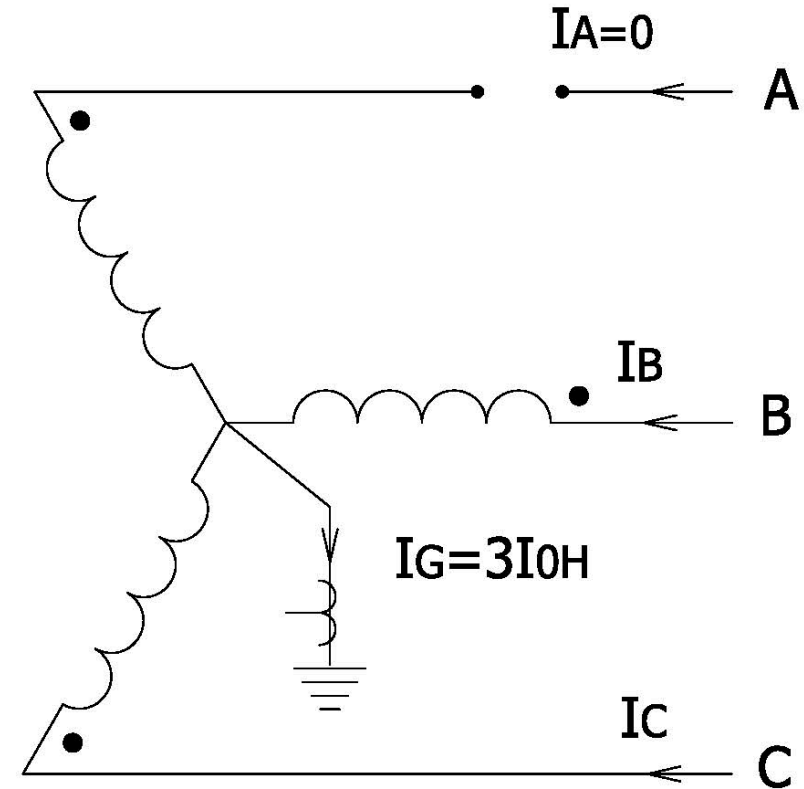
- In three-leg cores open phase is re-generated while in other types voltage collapses.
- The method of high side current calculation is used to identify an open phase.
- I_0 needs particular attention. Three-leg cores have very high zero sequence magnetization current. Primary and secondary I_0 not per transformer ratio.

Protection Algorithm- Yg-Yg Transformers

- No phase shift in currents.

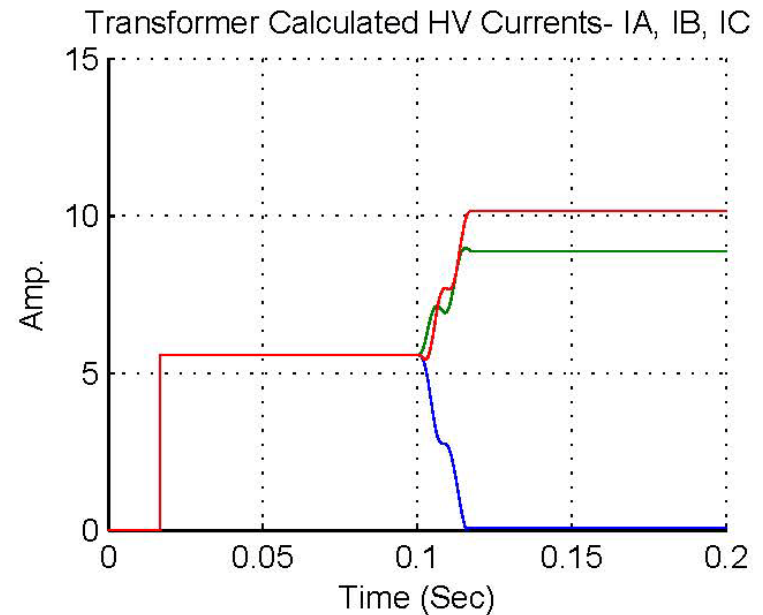
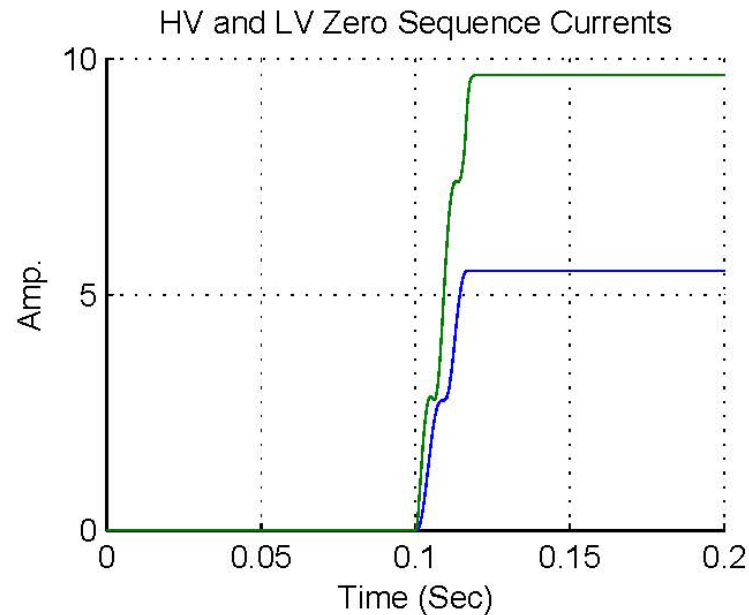
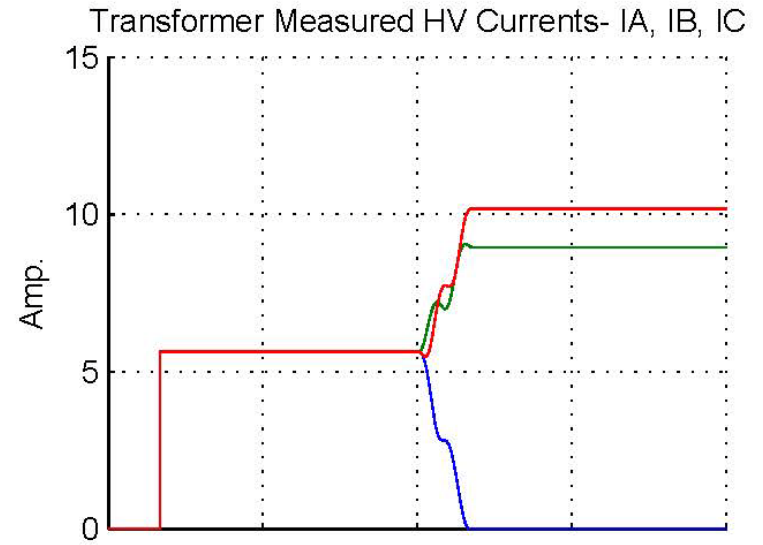
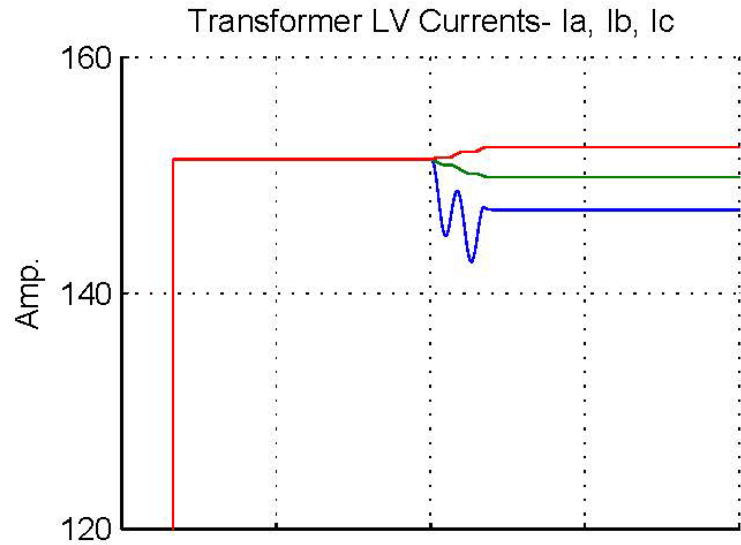


$$\frac{I_{1\text{Sec.}}}{I_{1\text{Pri.}}} = \frac{I_{2\text{Sec.}}}{I_{2\text{Pri.}}} = n$$



$$I_{0\text{Pri.}} = \frac{1}{3} I_G$$

Protection Algorithm- Yg-Yg Transformers



Conclusion

- Three categories are identified in terms of response to open phase on the high side:
Voltage regeneration always in Yg-D;
Never with ungrounded primary;
Sometimes in Yg-Yg.
- Protection algorithms are developed for identification and protection for each category of transformers, regardless of the core type.
- The algorithms are universally applicable to DG cases.

Questions
?