Troubleshooting and Lessons Learned Using Protective Relay Event Analysis

GE Digital Energy Multilin

imagination at work

Seminar Presenter

Terrence Smith
Terrence.Smith@GE.com
423-304-0843

imagination at work

Seminar Agenda

- Overhead distribution ground fault inside industrial facility causes a generator stator fault
- Incorrect current transformer wiring causes bus fault during power transformer energization
- Fault on distribution system causes unusual transformer high side currents
- Incorrect current transformer wiring causes motor thermal overload trip
- Generator loss of excitation and reverse power trips
- Overcurrent trip on paralleling switchgear
- Synchronous motor trip on power factor
- Substation heat pumps drops bus voltage by 1kV causes capacitor bank trip

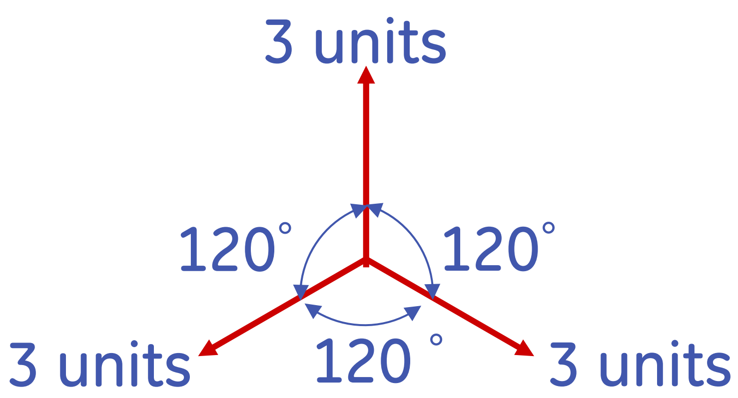
Review Of Symmetrical Components

imagination at work

Symmetrical and Non-Symmetrical Systems:

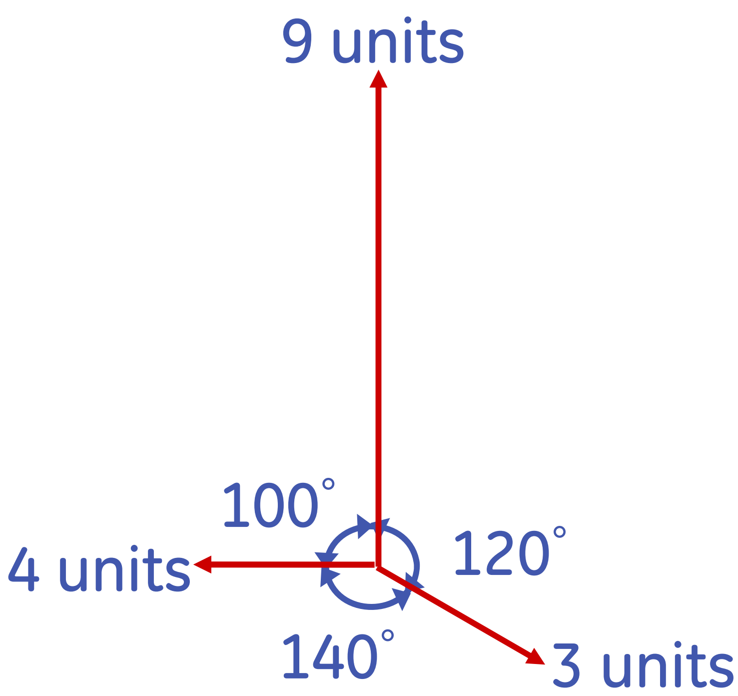
Symmetrical System:

- Counter-clockwise rotation
- All current vectors have equal amplitude
- All voltage phase vectors have equal amplitude
- All current and voltage vectors have 120 degrees phase shifts and a sum of <u>0v</u>.



Non-Symmetrical System:

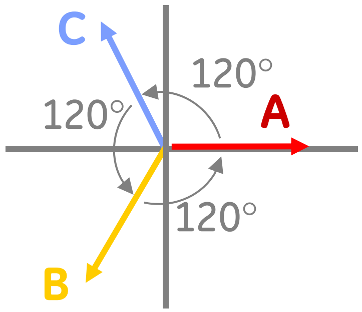
- Fault or Unbalanced condition
- If one or more of the symmetrical system conditions is not met



imagination at work

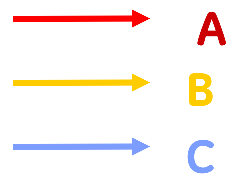
Symmetrical Components:

Positive Sequence
(Always Present)



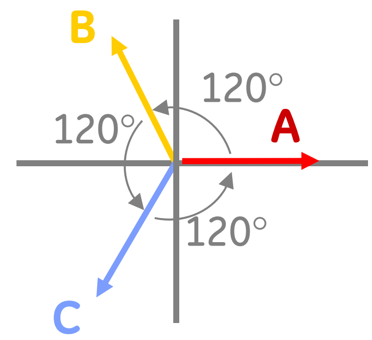
- A-B-C **Counter-clockwise** phase rotation
- All phasors with equal magnitude
- All phasors displaced 120 degrees apart

Zero Sequence



- No Rotation Sequence
- All phasors with equal magnitude
- All phasors are in phase

Negative Sequence



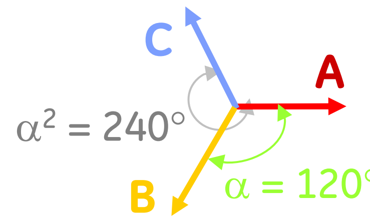
- A-C-B **counter-clockwise** phase rotation
- All phasors with equal magnitude
- All phasors displaced 120 degrees apart

imagination at work

Symmetrical Components:

Positive Sequence Component:

$I_1 = ⅓ (I_a + \alpha I_b + \alpha^2 I_c)$ $V_1 = ⅓ (V_a + \alpha V_b + \alpha^2 V_c)$

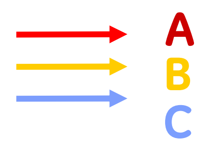


Negative Sequence Component:

$I_2 = ⅓ (I_a + \alpha^2 I_b + \alpha I_c)$ $V_2 = ⅓ (V_a + \alpha^2 V_b + \alpha V_c)$

Zero Sequence Component:

$I_0 = ⅓ (I_a + I_b + I_c)$ $V_0 = ⅓ (V_a + V_b + V_c)$



Unbalanced Line-to-Neutral Phasors:

$I_a = I_1 + I_2 + I_0$ $V_a = V_1 + V_2 + V_0$

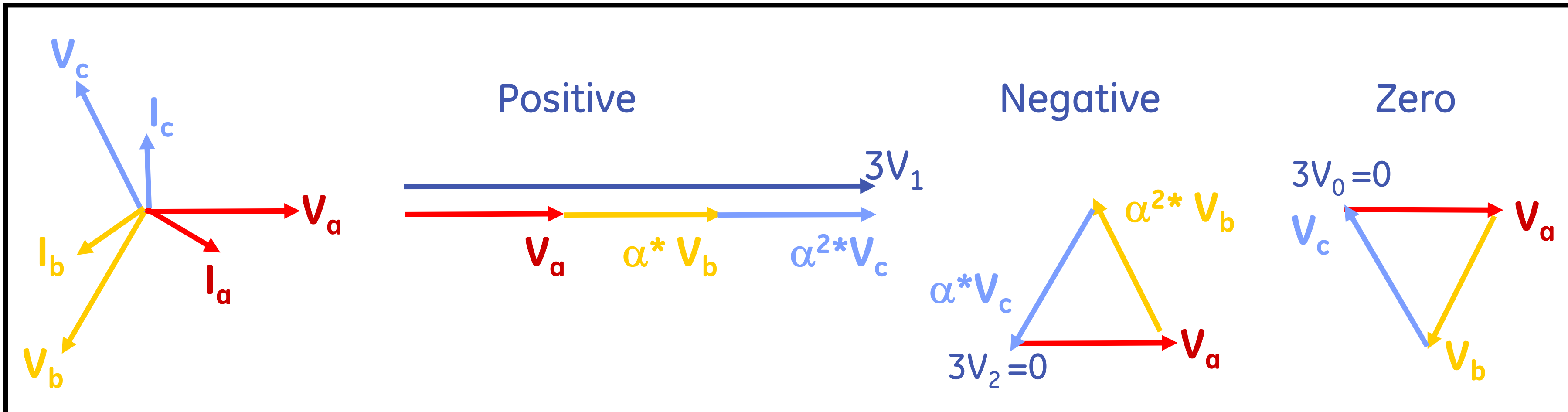
$I_b = \alpha^2 I_1 + \alpha I_2 + I_0$ $V_b = \alpha^2 V_1 + \alpha V_2 + V_0$

$I_c = \alpha I_1 + \alpha^2 I_2 + I_0$ $V_c = \alpha V_1 + \alpha^2 V_2 + \alpha V_0$

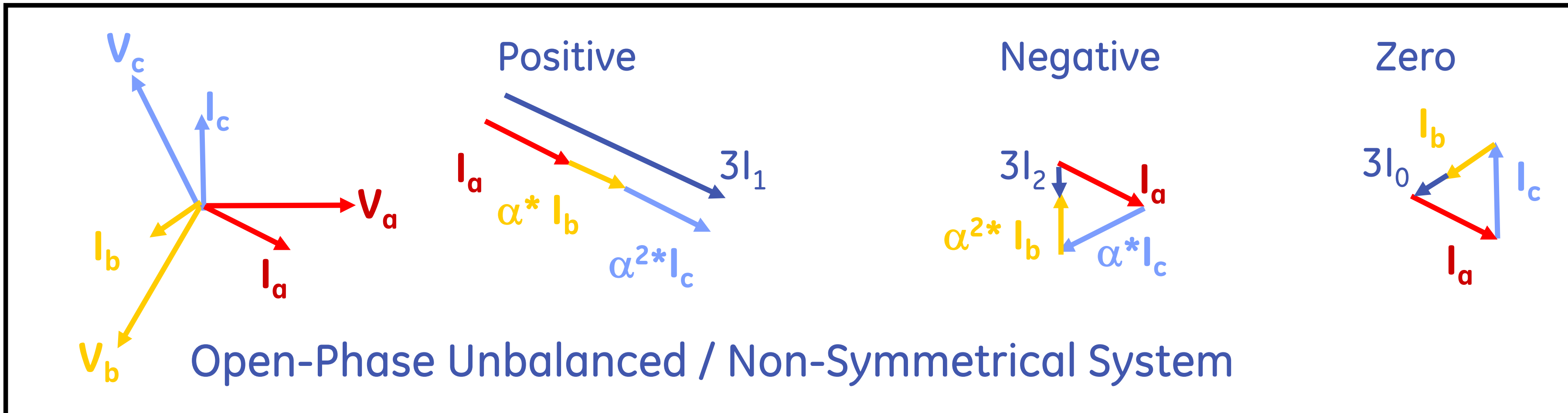
α =Phasor @ +120°

α^2 =Phasor @ 240°

Calculating Symmetrical Components:



Three-Phase Balanced / Symmetrical System



Open-Phase Unbalanced / Non-Symmetrical System

imagination at work

Symmetrical Components

Example: Perfectly Balanced & ABC Rotation

$I_0 = 1/3(I_a + I_b + I_c)$

$I_1 = 1/3(I_a + aI_b + a^2I_c)$

$I_2 = 1/3(I_a + a^2I_b + aI_c)$

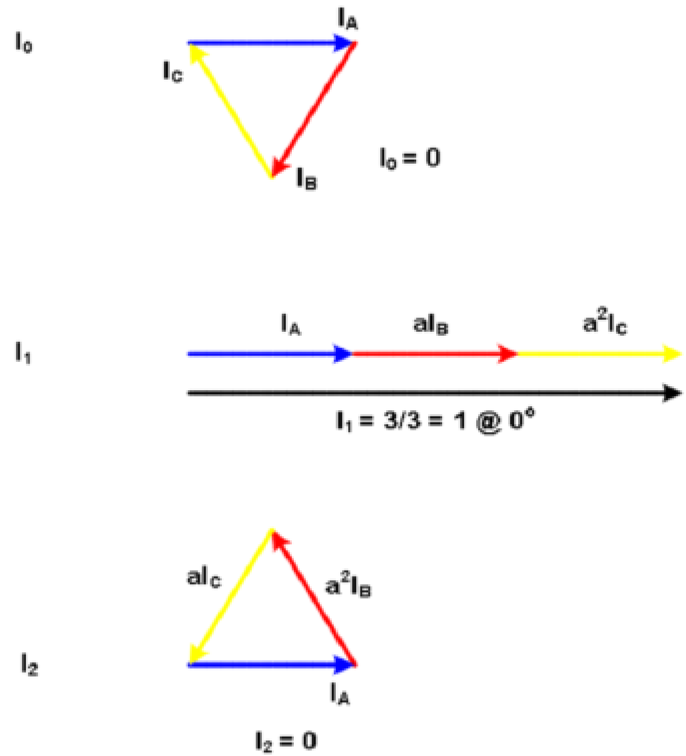
$a = 1 \angle 120^o$

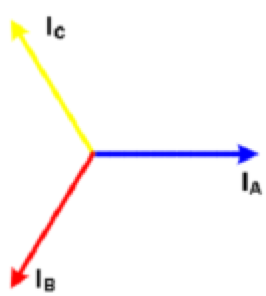
$V_0 = 1/3(V_a + V_b + V_c)$

$V_1 = 1/3(V_a + aV_b + a^2V_c)$

$V_2 = 1/3(V_a + a^2V_b + aV_c)$

$a^2 = 1\angle 240^o$





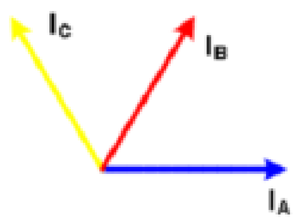
Result: 100% I1 (Positive Sequence Component)

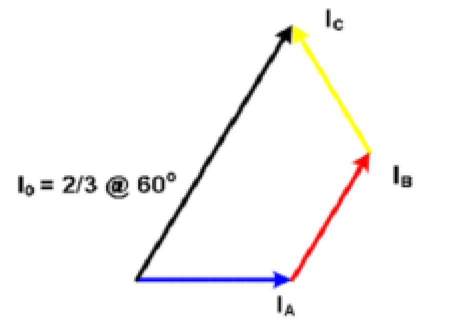
imagination at work

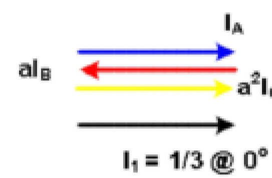
Symmetrical Components

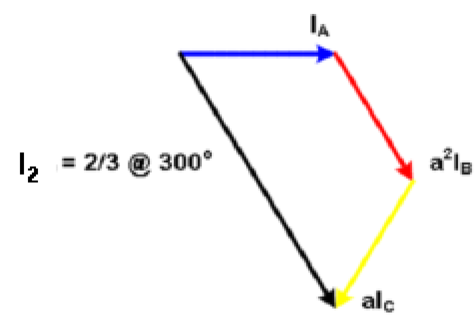
Example: B-Phase Rolled & ABC Rotation

$I_0 = 1/3(I_a + I_b + I_c)$	$V_0 = 1/3(V_a + V_b + V_c)$
$I_1 = 1/3(I_a + aI_b + a^2I_c)$	$V_1 = 1/3(V_a + aV_b + a^2V_c)$
$I_2 = 1/3(I_a + a^2I_b + aI_c)$	$V_2 = 1/3(V_a + a^2V_b + aV_c)$
$a = 1 \angle 120^o$	$a^2 = 1\angle 240^o$









Result: 33% I1, 66% I0 and 66% I2

Symmetrical Components

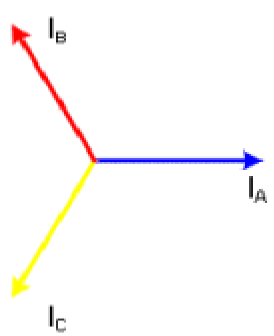
Example: B-Phase & C-Phase Rolled & ABC Rotation

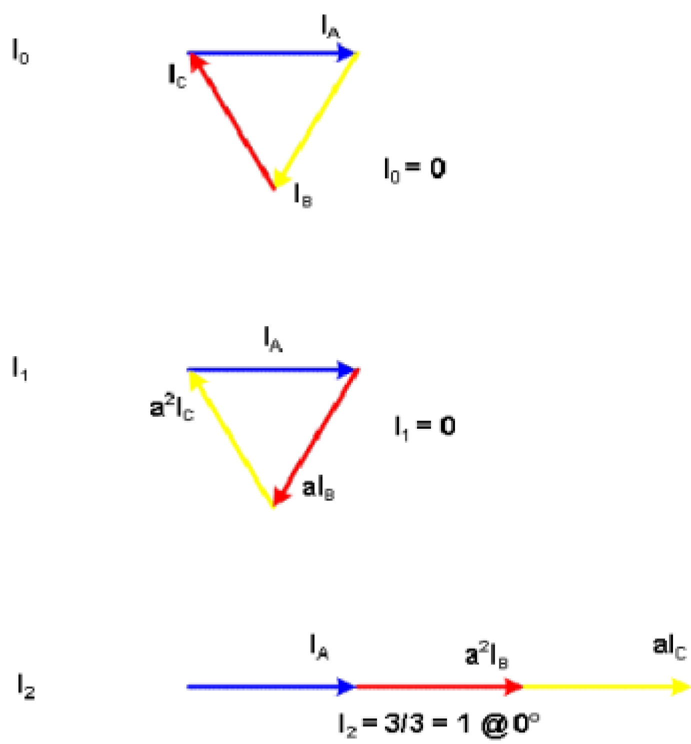
$I_0 = 1/3(I_a + I_b + I_c)$ $\quad$ $V_0 = 1/3(V_a + V_b + V_c)$

$I_1 = 1/3(I_a + aI_b + a^2I_c)$ $\quad$ $V_1 = 1/3(V_a + aV_b + a^2V_c)$

$I_2 = 1/3(I_a + a^2I_b + aI_c)$ $\quad$ $V_2 = 1/3(V_a + a^2V_b + aV_c)$

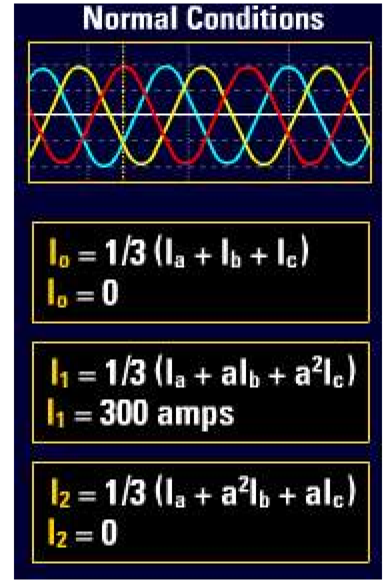
$a = 1 \angle 120^o$ $\quad$ $a^2 = 1 \angle 240^o$





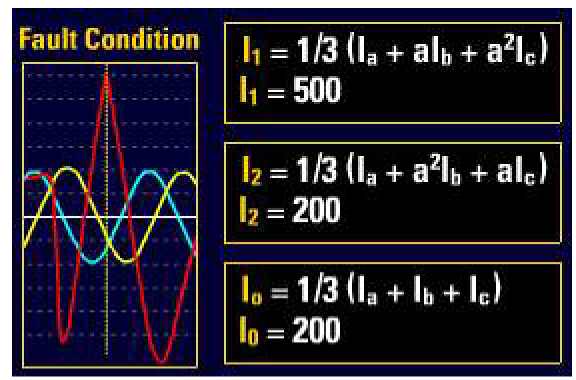
Result: 100% I2 (Negative Sequence Component)

Summary of Symmetrical Components:



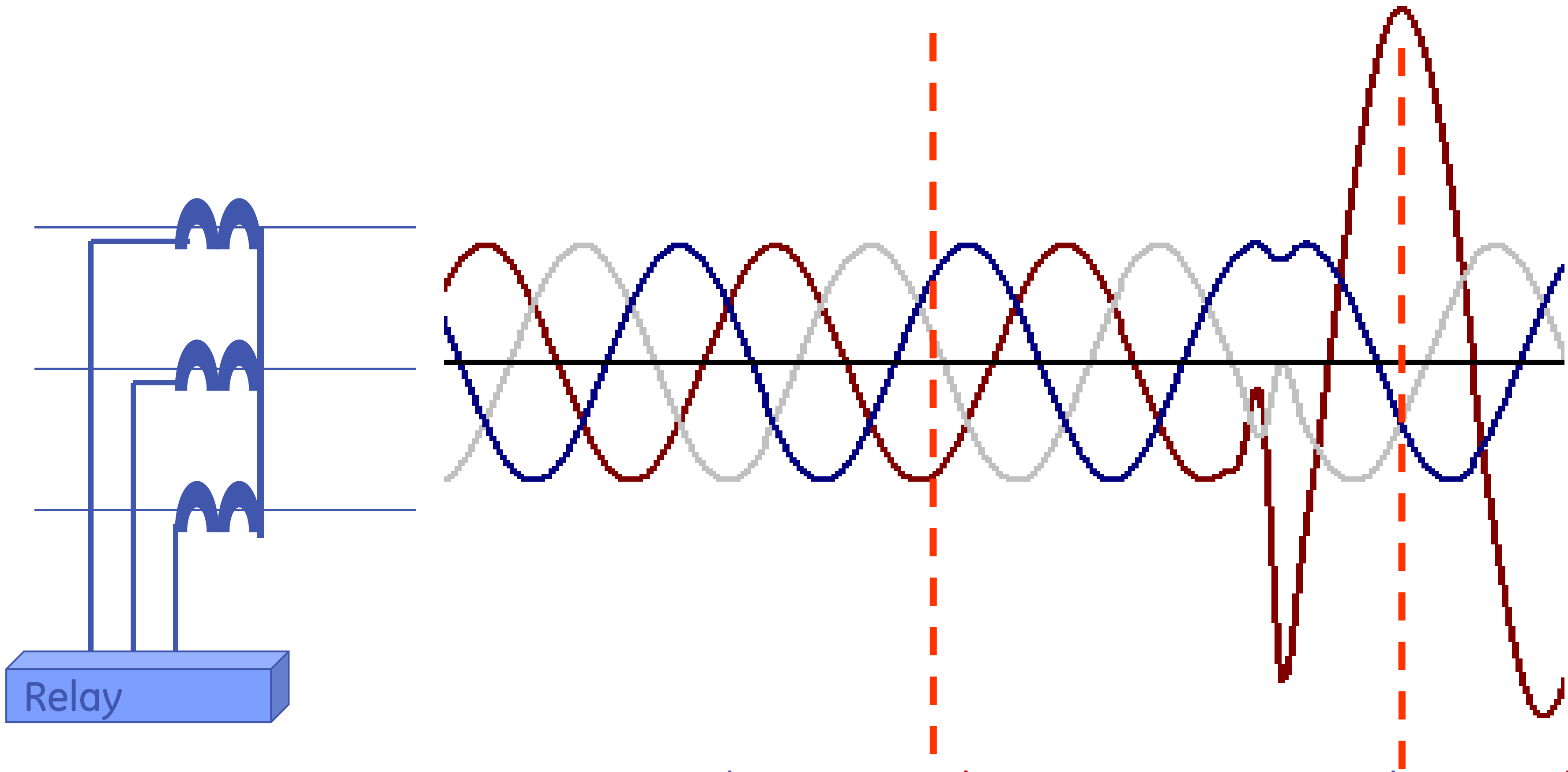
- Under a <u>no-fault</u> condition, the power system is considered to be essentially <u>*symmetrical*</u> therefore, only <u>*positive sequence*</u> currents and voltages exist.

- At the time of a <u>fault</u>, <u>*positive*</u>, <u>*negative*</u> and possibly <u>*zero sequence*</u> currents and voltages exist.
  - All positive, negative and zero sequence currents can be calculated using real world phase voltages and currents along with Fortescue's formulas.
  - In = Ia + Ib + Ic = 3 I0



Power System Faults

Fault Analysis



Data Sample 1 = No Fault

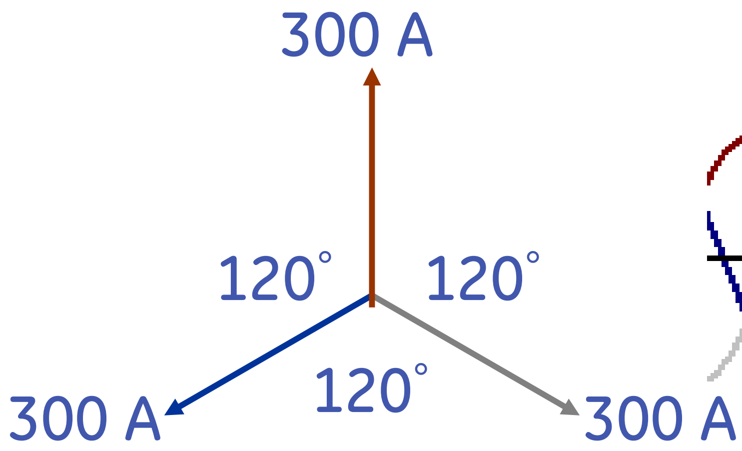
Data Sample 2 = Fault

Power System Faults

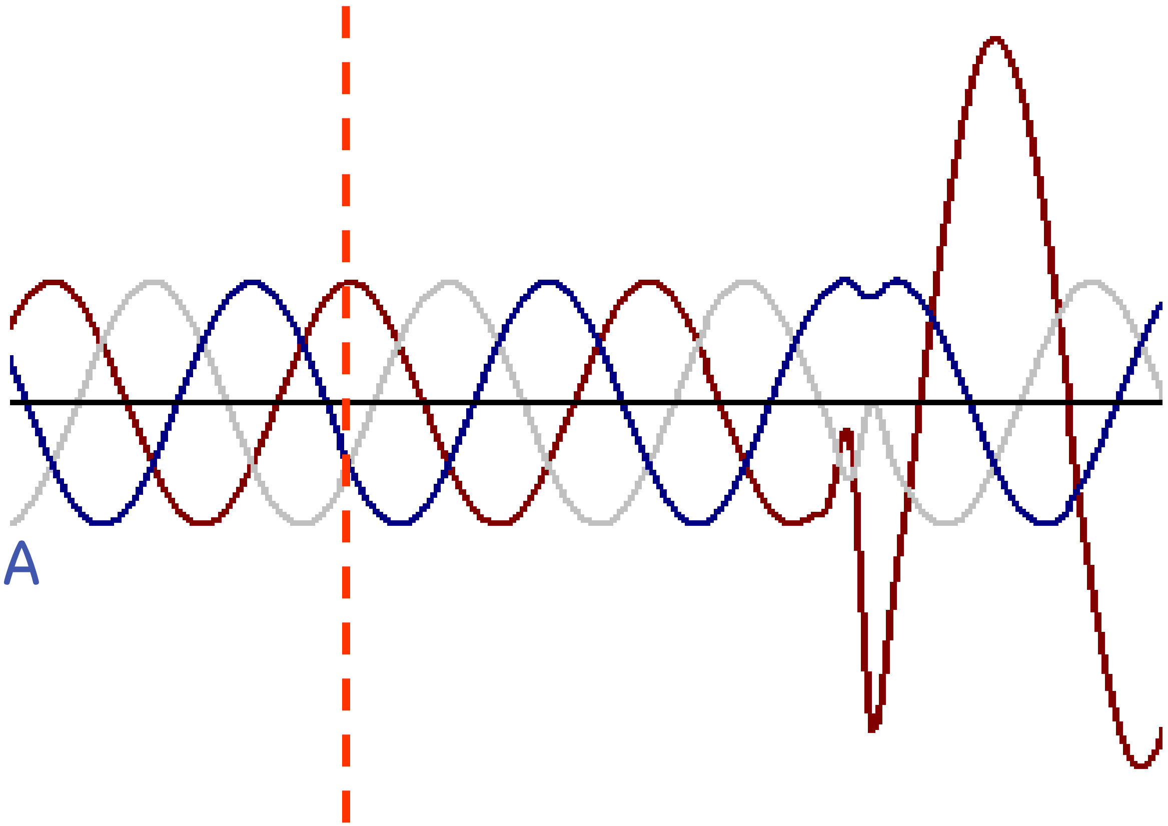
Fault Analysis

For Normal Conditions:

Data Sample 1
Phasor Diagram:



Waveform Capture:



Data Sample 1 = No Fault

Power System Faults

Fault Analysis - Example

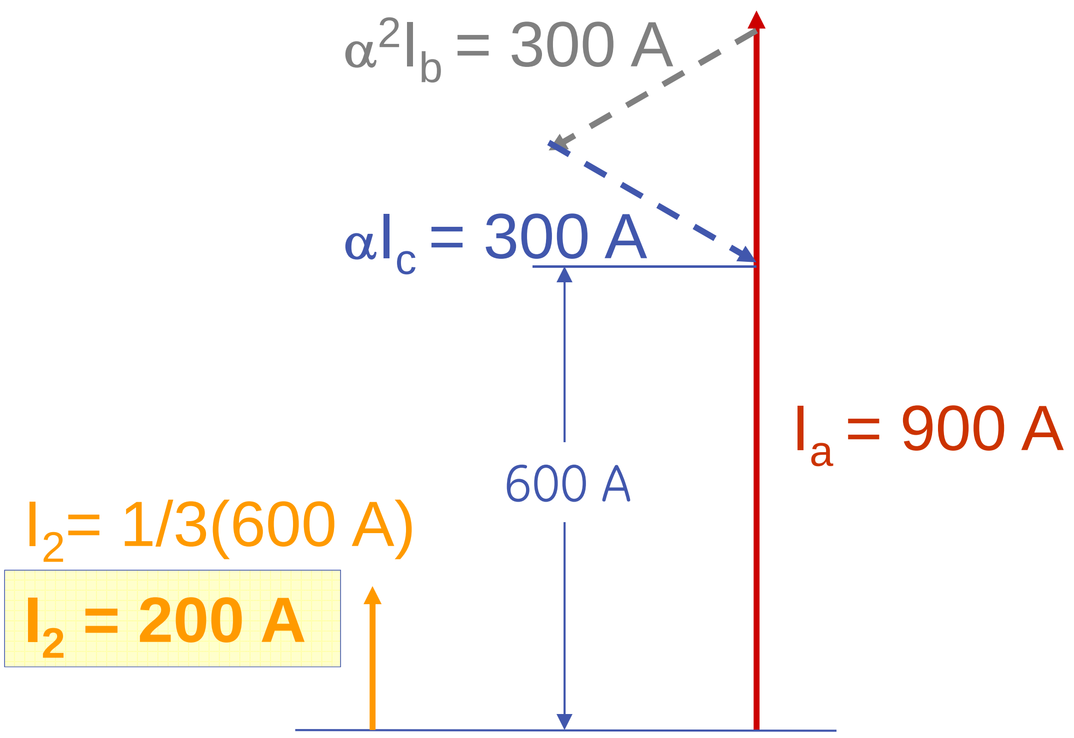
For Fault Condition:

Negative Sequence Component, I_2:

$$\mathbf{I_2 = 1/3(I_a + \alpha^2 I_b + \alpha I_c)}$$

$$= 1/3(600\ A)$$

$$\mathbf{I_2 = 200\ Amps}$$

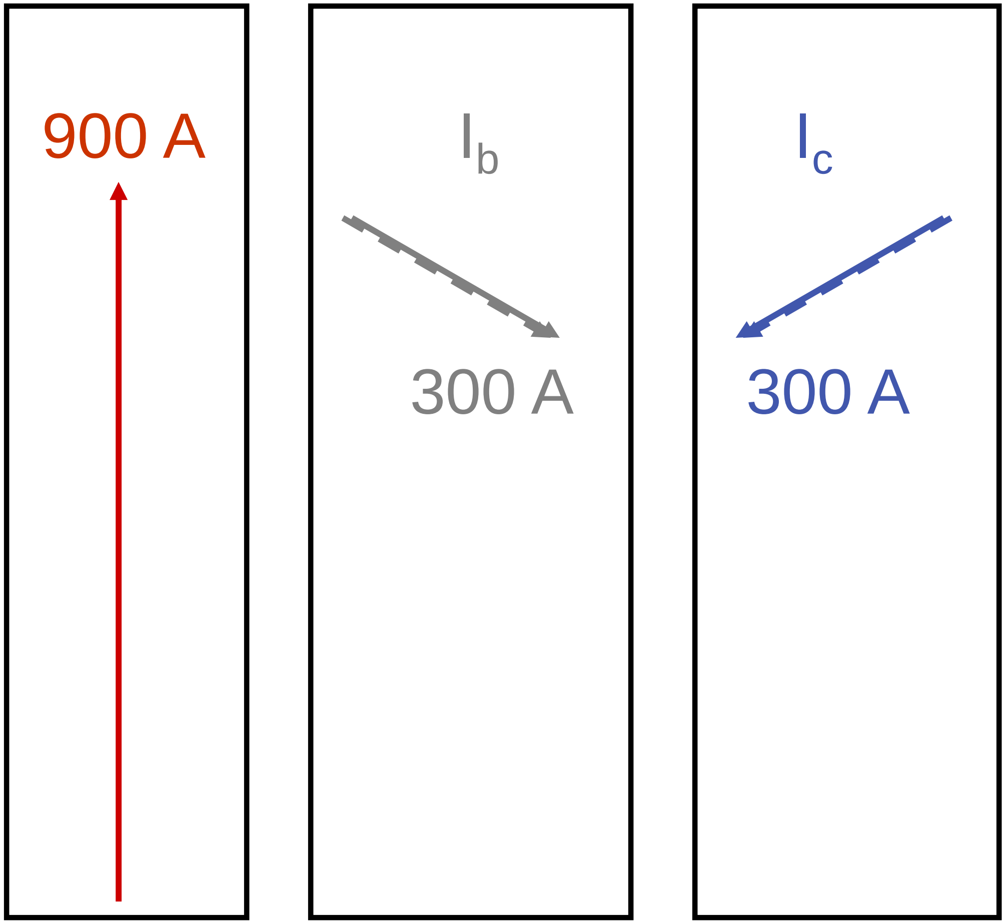


Power System Faults

Fault Analysis - Example

For Fault Condition:

Zero Sequence Component, I_0: $I_0 = 1/3(I_a+I_b+I_c)$



imagination at work

Power System Faults

Fault Analysis - Example

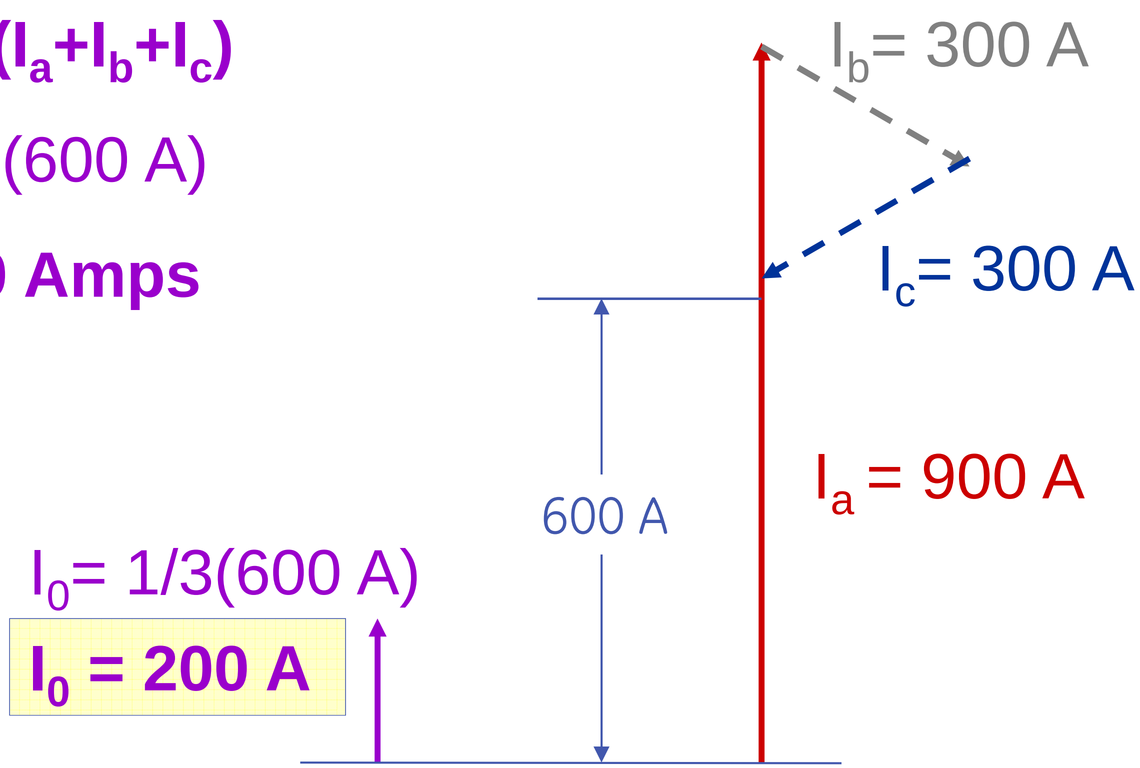
For Fault Condition:

Zero Sequence Component, I_0:

$$I_0 = 1/3(I_a + I_b + I_c)$$

$$= 1/3(600\ A)$$

$$I_0 = 200\ Amps$$



Power System Faults

Fault Analysis - Example

For Fault Condition:

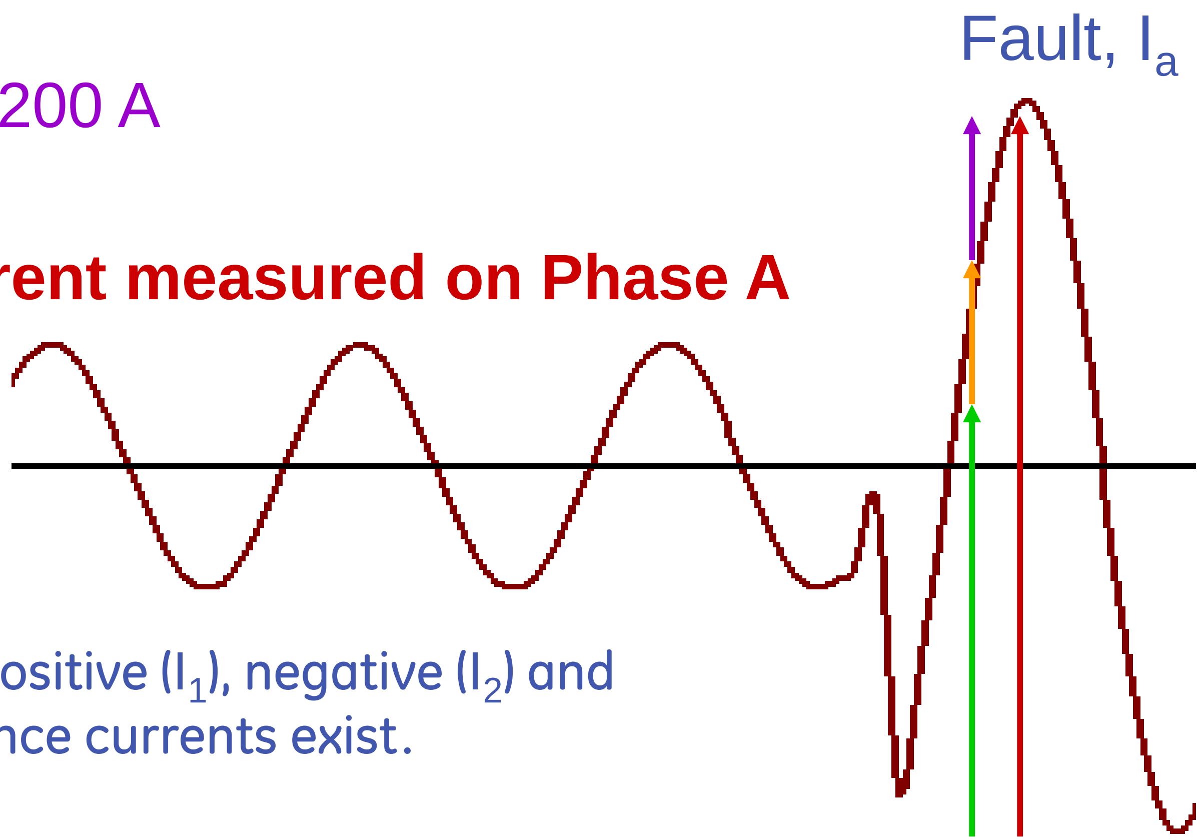
Verifying Fault Current on Phase A:

$I_a = I_1 + I_2 + I_0$

$= 500\ A + 200\ A + 200\ A$

I_a = 900 Amps

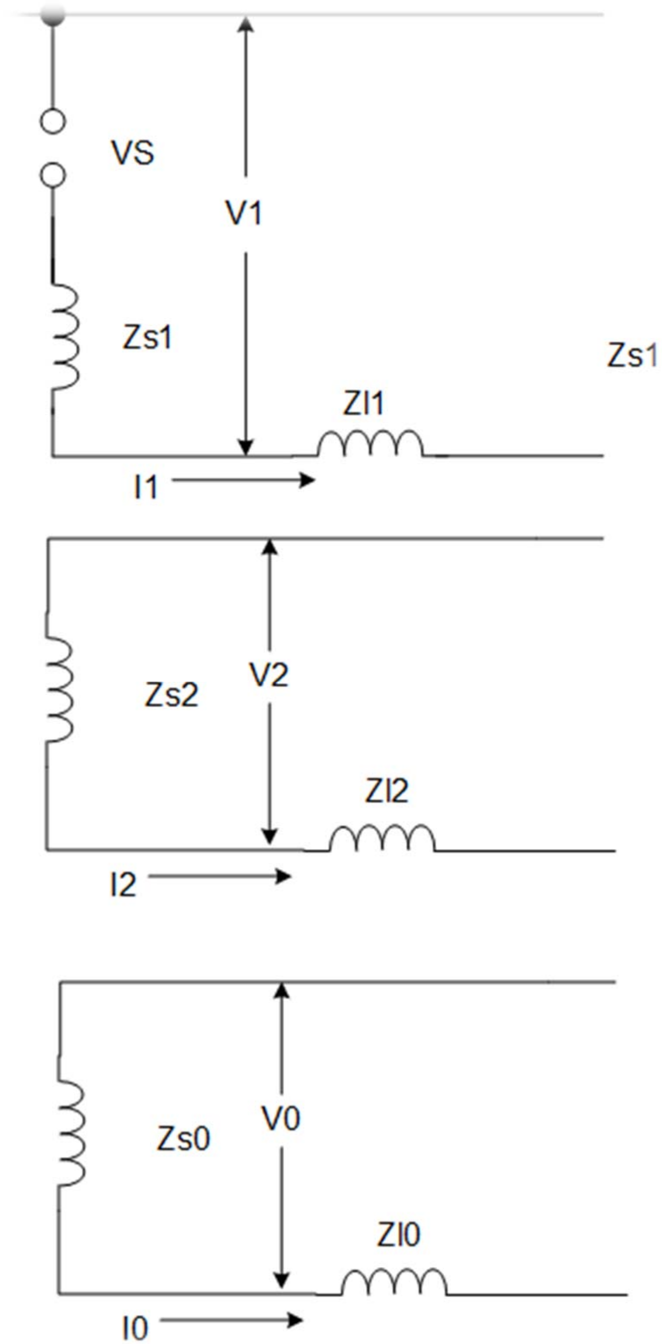
= actual fault current measured on Phase A



At the time of a fault, positive (I_1), negative (I_2) and possibly zero (I_0) sequence currents exist.

Sequence Networks

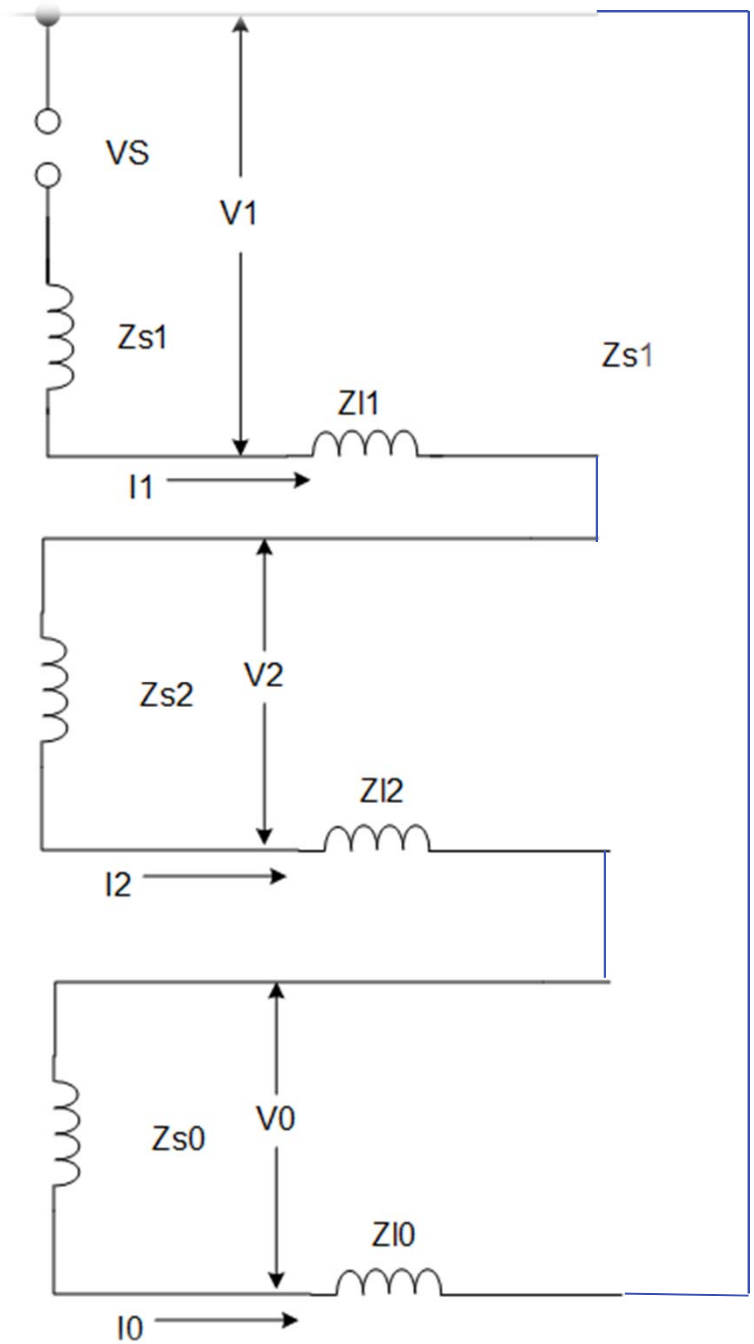
- Where is sequence voltage highest?
- What generates negative and zero sequence currents?



imagination at work

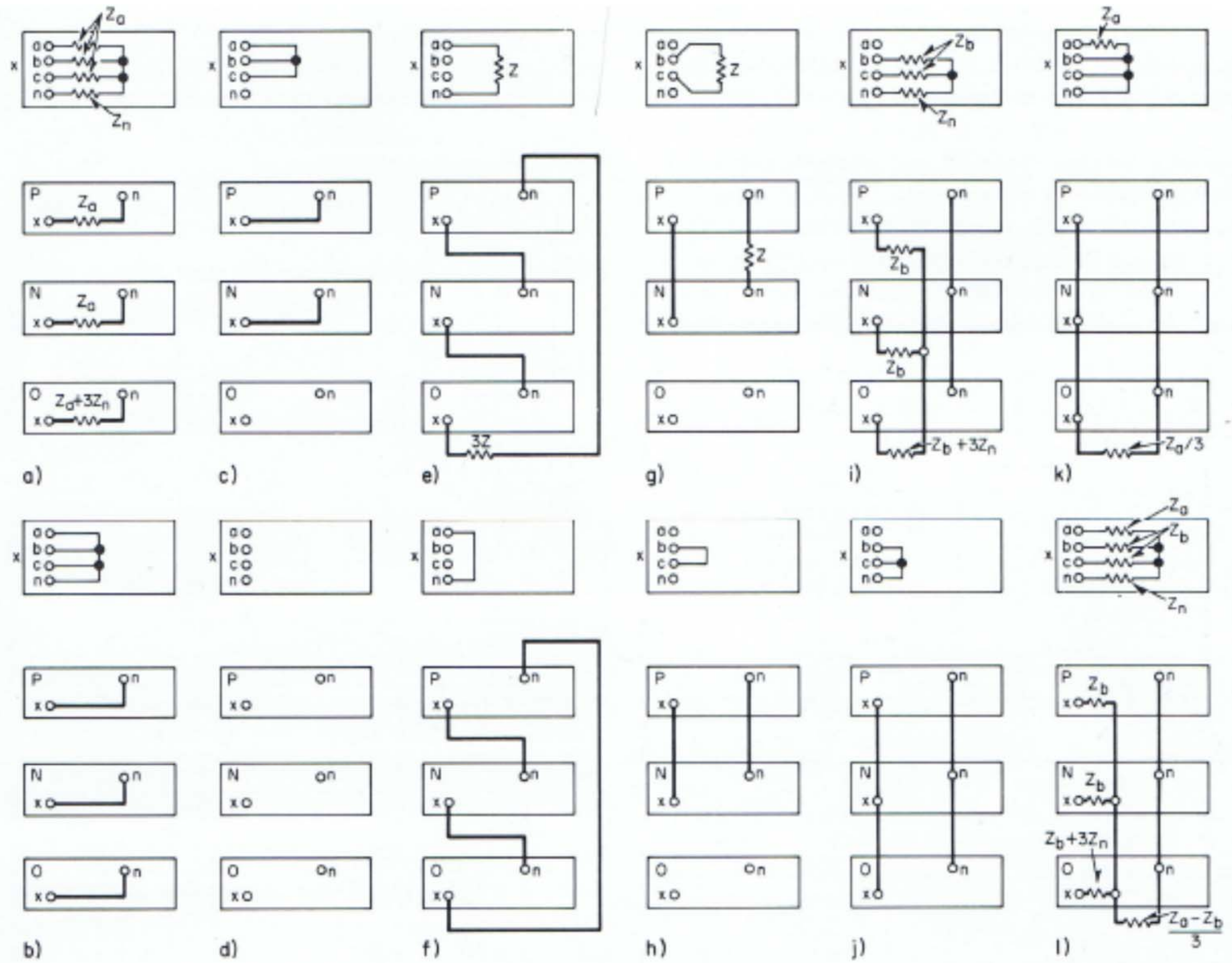
How do we connect so that I1=I2=I0?

- The sequence networks have to be in series for a phase to ground fault on a solidly grounded system.



imagination at work

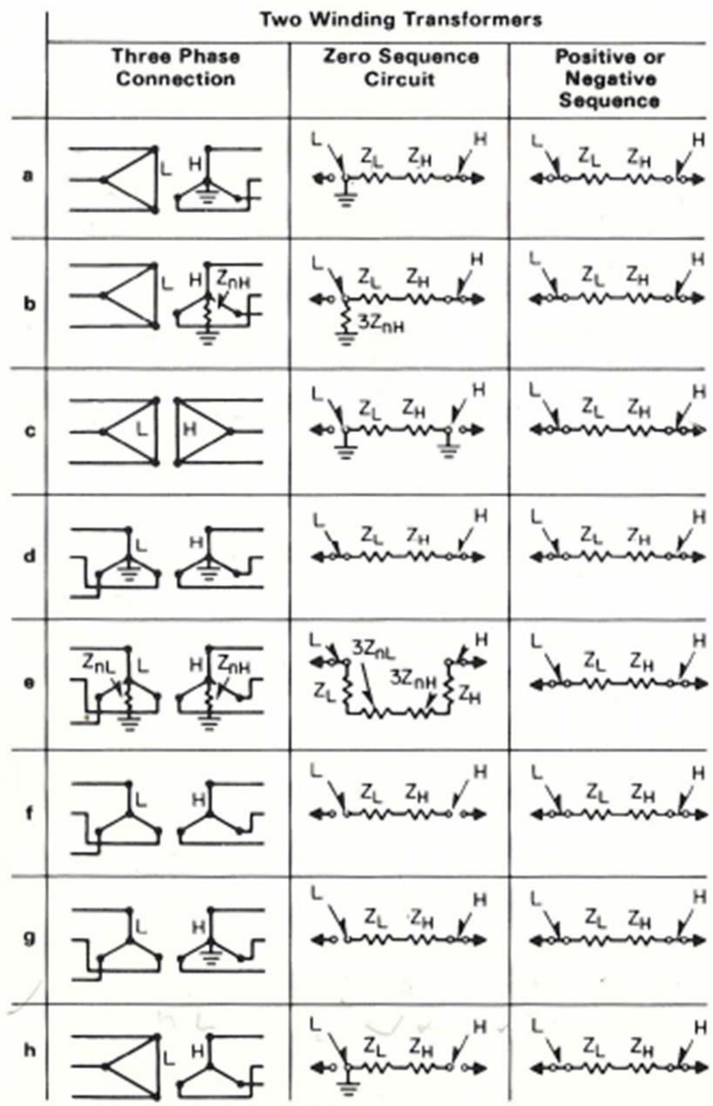
Common Fault Types:



Note:

a) Balanced load or three-line-to-ground fault with impedances.
b) A three-line-to-ground fault.
c) A three-phase fault.
d) A shunt circuit open.
e) A line-to-ground fault through an impedance.
f) A line-to-ground fault.
g) A line-to-line fault through impedance.
h) A line-to-line fault.
i) A two-line-to-ground fault with impedance.
j) A two-line-to-ground fault.
k) A three-line-to-ground fault with impedance in phase a.
l) Unbalanced load or three-line-to-ground fault with impedance.

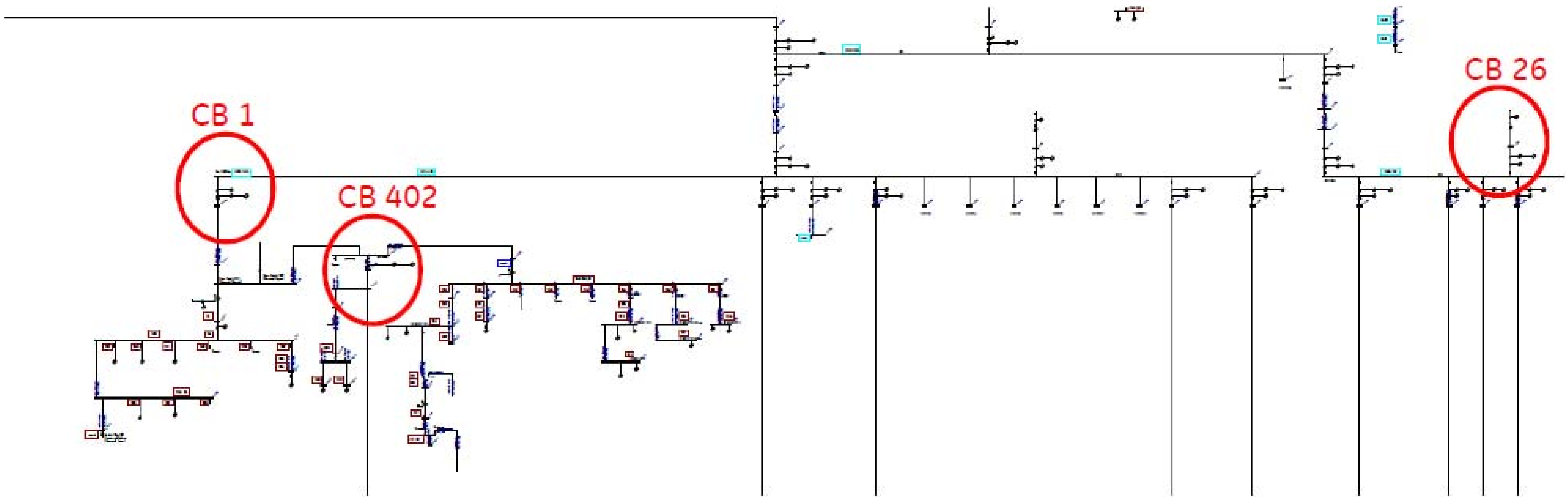
Transformer Interconnections:



Analysis of Interesting Events Using Waveforms

imagination at work

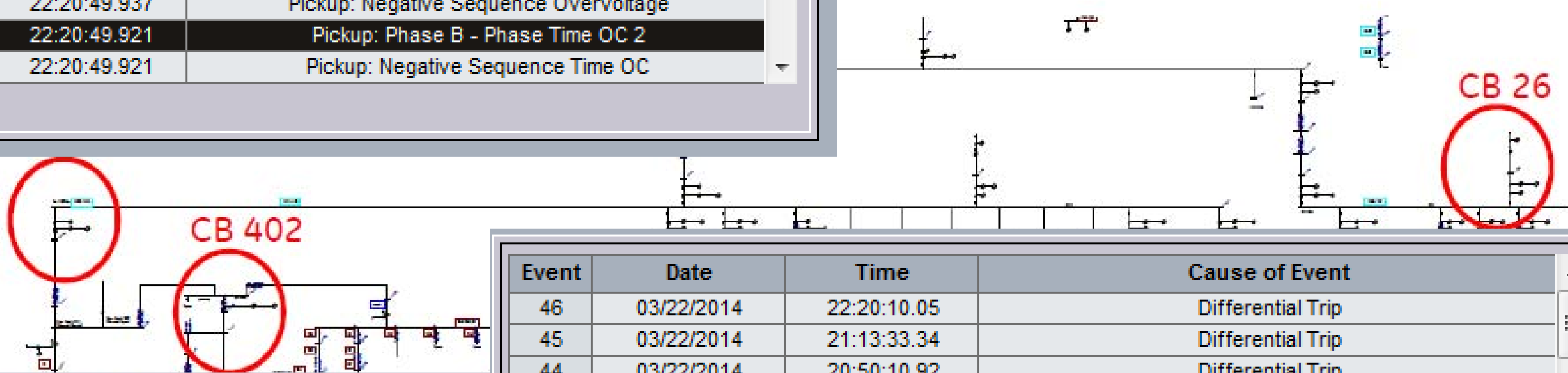
Snake Causes a Distribution Fault



imagination at work

tion Fault

Event	Date	Time	Cause of Event
48	03/20/2014	22:20:49.968	Dropout: Phase Instantaneous OC 1
47	03/20/2014	22:20:49.954	Alarm: Phase B - Arcing Current
46	03/20/2014	22:20:49.953	Dropout: Neutral Time OC 1
45	03/20/2014	22:20:49.953	Dropout: Ground Time OC
44	03/20/2014	22:20:49.945	Input(C) ON-Block Neutral Time OC 1
43	03/20/2014	22:20:49.945	Input(C) ON-Block Ground Time OC
42	03/20/2014	22:20:49.945	Input(C) ON-User Input D / ABB 50D Blk
41	03/20/2014	22:20:49.937	Pickup: Negative Sequence Overvoltage
40	03/20/2014	22:20:49.921	Pickup: Phase B - Phase Time OC 2
39	03/20/2014	22:20:49.921	Pickup: Negative Sequence Time OC

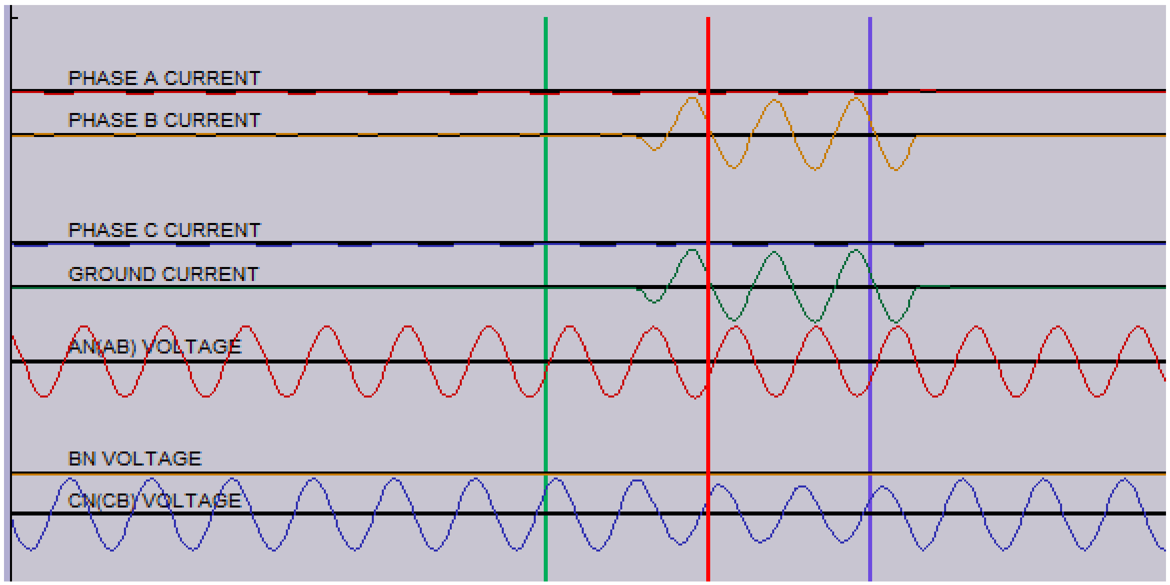


Event	Date	Time	Cause of Ev
374	03/20/2014	22:00:48.232	Pickup: Ground Insta
373	03/20/2014	22:00:48.232	Pickup: Ground
372	03/20/2014	22:00:48.232	Trip: Phase C - Phase Ins
371	03/20/2014	22:00:48.232	Pickup: Phase C - Phase Ir
370	03/20/2014	22:00:48.232	Trigger Trace M
369	03/20/2014	22:00:48.232	Trip: Phase C - Phase Ins
368	03/20/2014	22:00:48.232	Pickup: Phase C - Phase Ir
367	03/20/2014	22:00:48.231	Trigger Data Logger
366	03/20/2014	22:00:48.231	Pickup: Phase C - Phase Time OC 1
365	02/11/2014	07:37:38.182	Trigger Data Logger

Event	Date	Time	Cause of Event
46	03/22/2014	22:20:10.05	Differential Trip
45	03/22/2014	21:13:33.34	Differential Trip
44	03/22/2014	20:50:10.92	Differential Trip
43	03/21/2014	11:33:29.68	Differential Trip
42	03/21/2014	09:14:34.50	Differential Trip
41	03/21/2014	08:47:18.56	Differential Trip
40	03/20/2014	23:20:33.15	Differential Trip
39	02/11/2014	08:38:36.53	Cont. Power Applied
38	02/11/2014	08:38:35.74	Control Power Lost
37	02/11/2014	08:31:11.56	Cont. Power Applied

Relays at all three locations tripped. All three had different times. Are these events related???

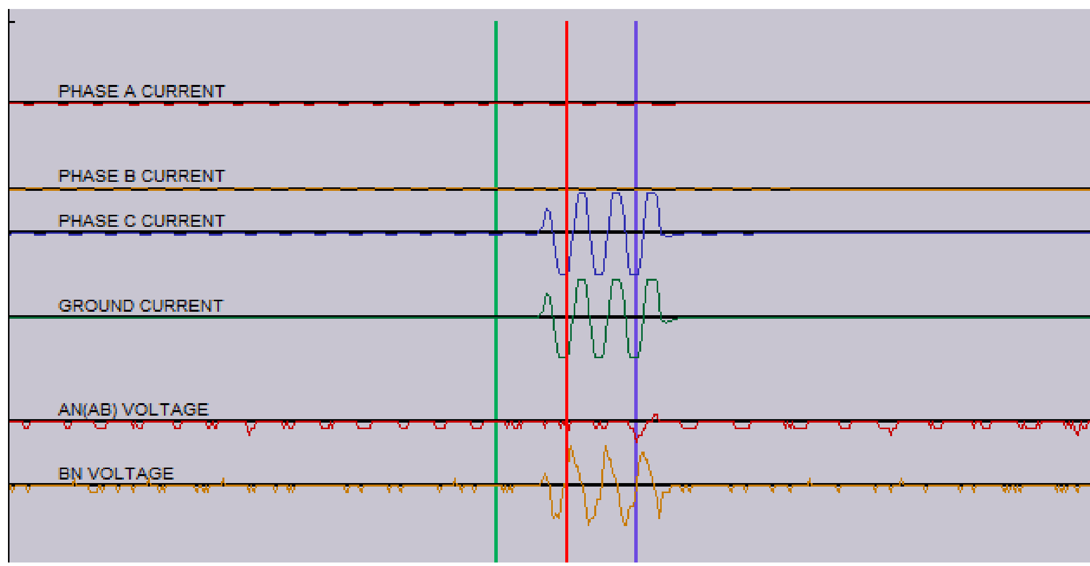
Relays at all three locations tripped. All three had different times. Are these events related???



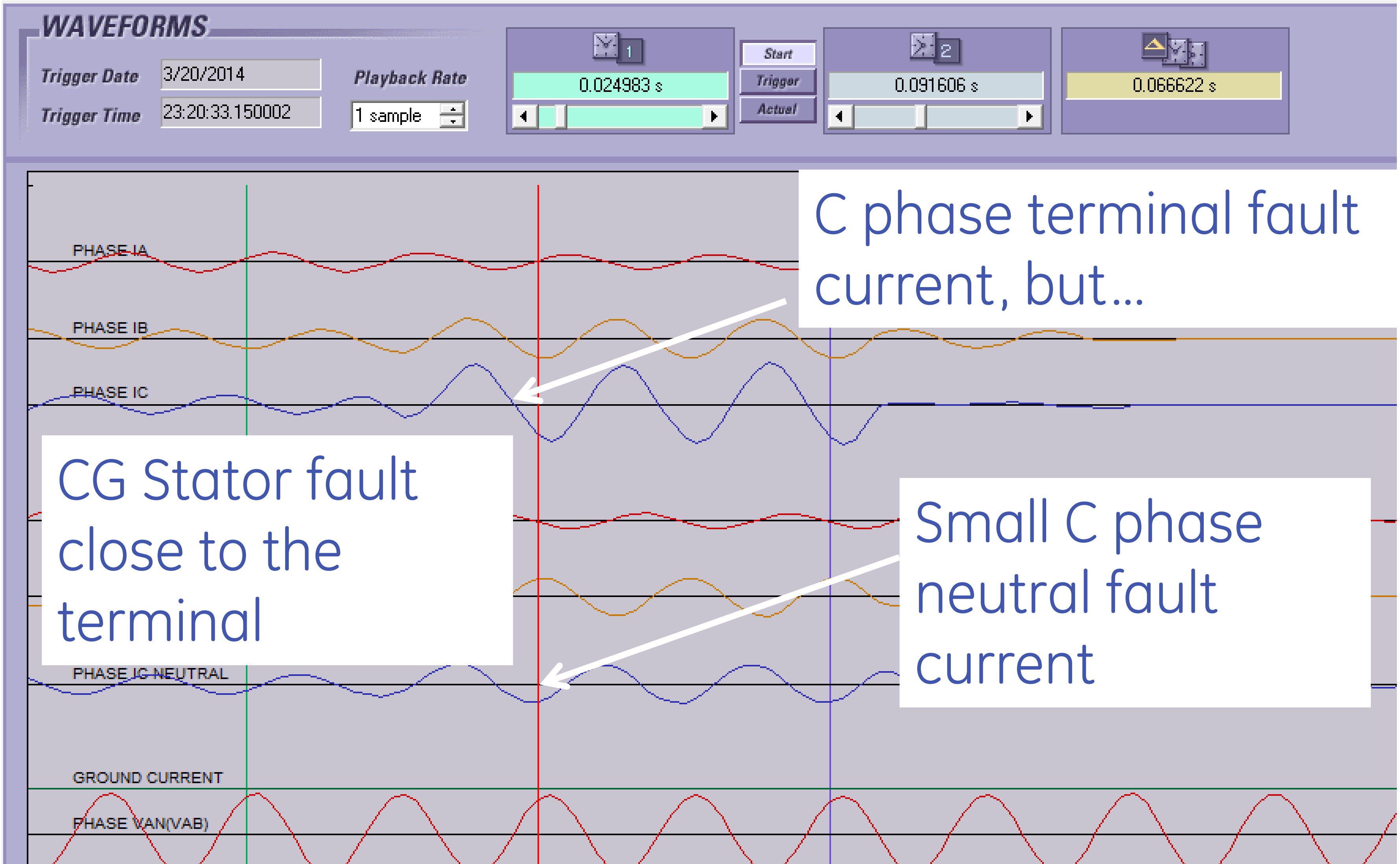
CB01

Why B phase on one and C on the other?

CB402



What about the Generator???

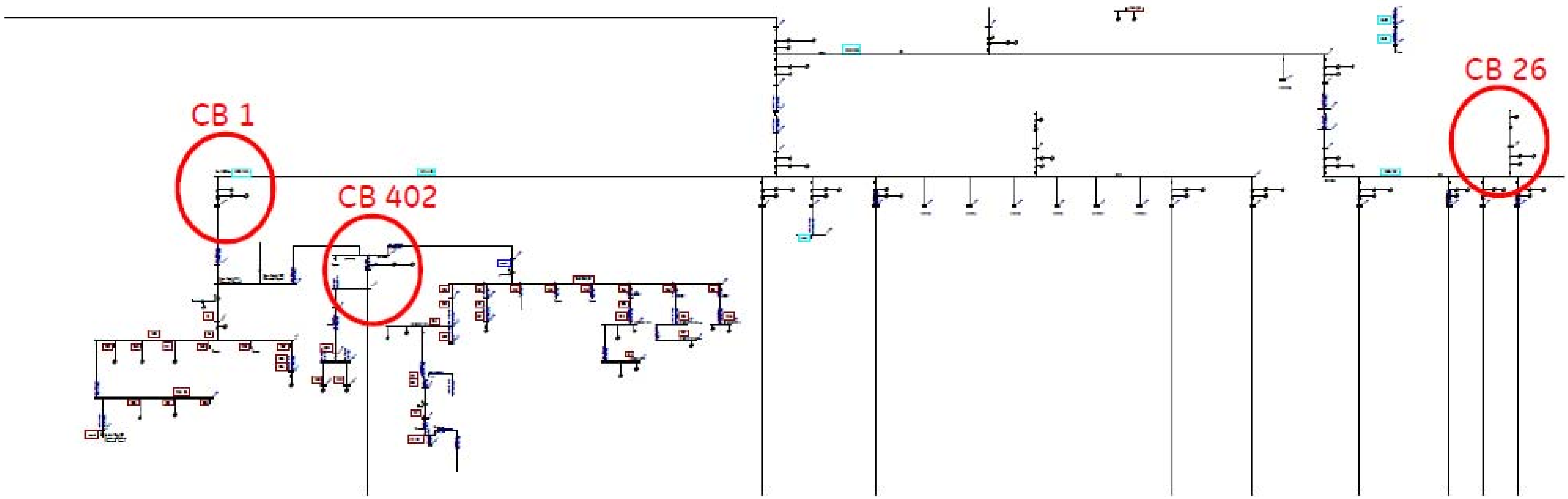


What happened here??

- C phase to ground fault because of the snake
- Zone interlocking scheme failed because of a settings error
- Generator failed due to the extra stress caused by the fault.
- Biggest Challenge was synchronizing the time differences in the relays.

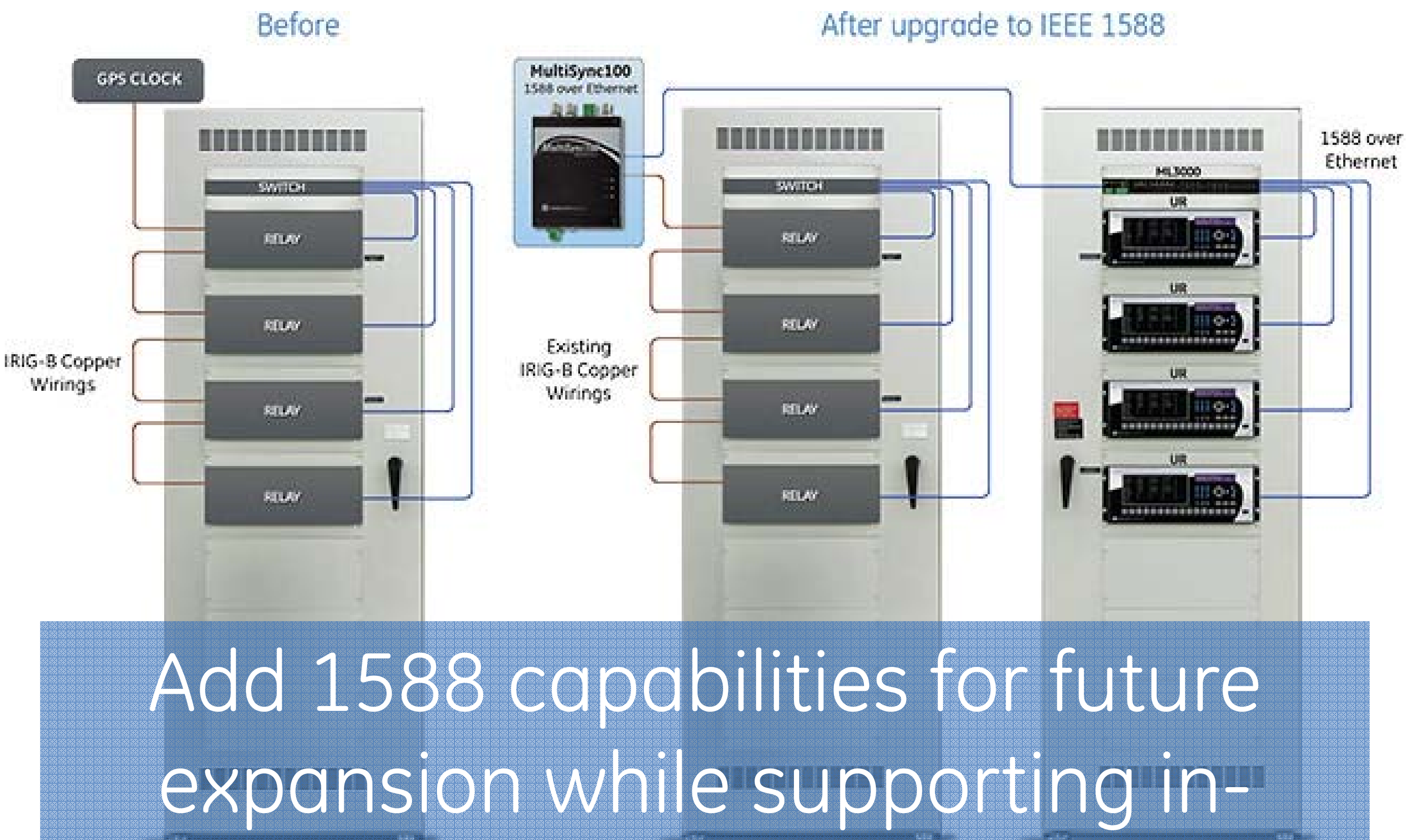
imagination at work

Challenges to Time Synch



imagination at work

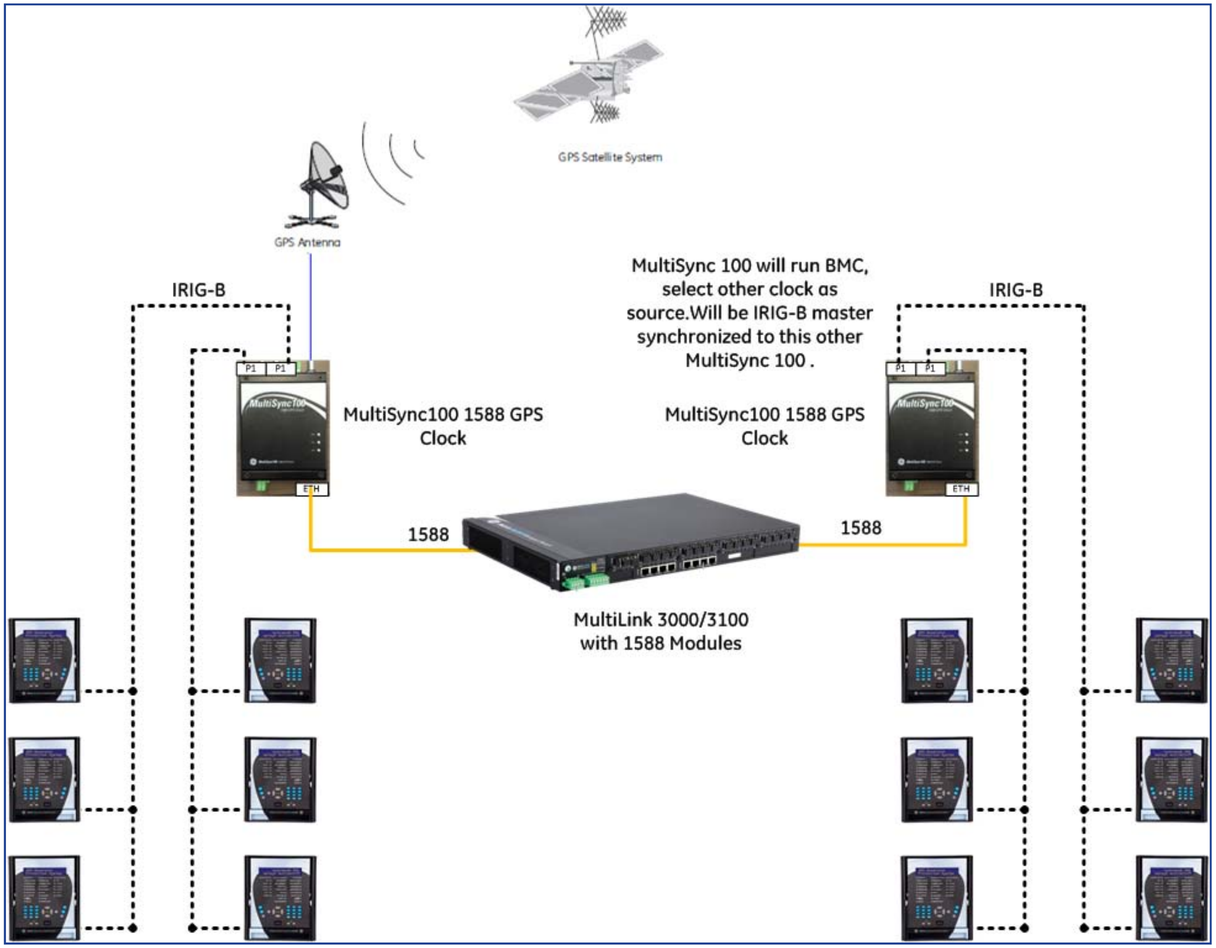
Modern Time Synchronization



Add 1588 capabilities for future expansion while supporting in-service IRIG-B devices

imagination at work

1588 Protocol over a wide area with legacy devices



imagination at work

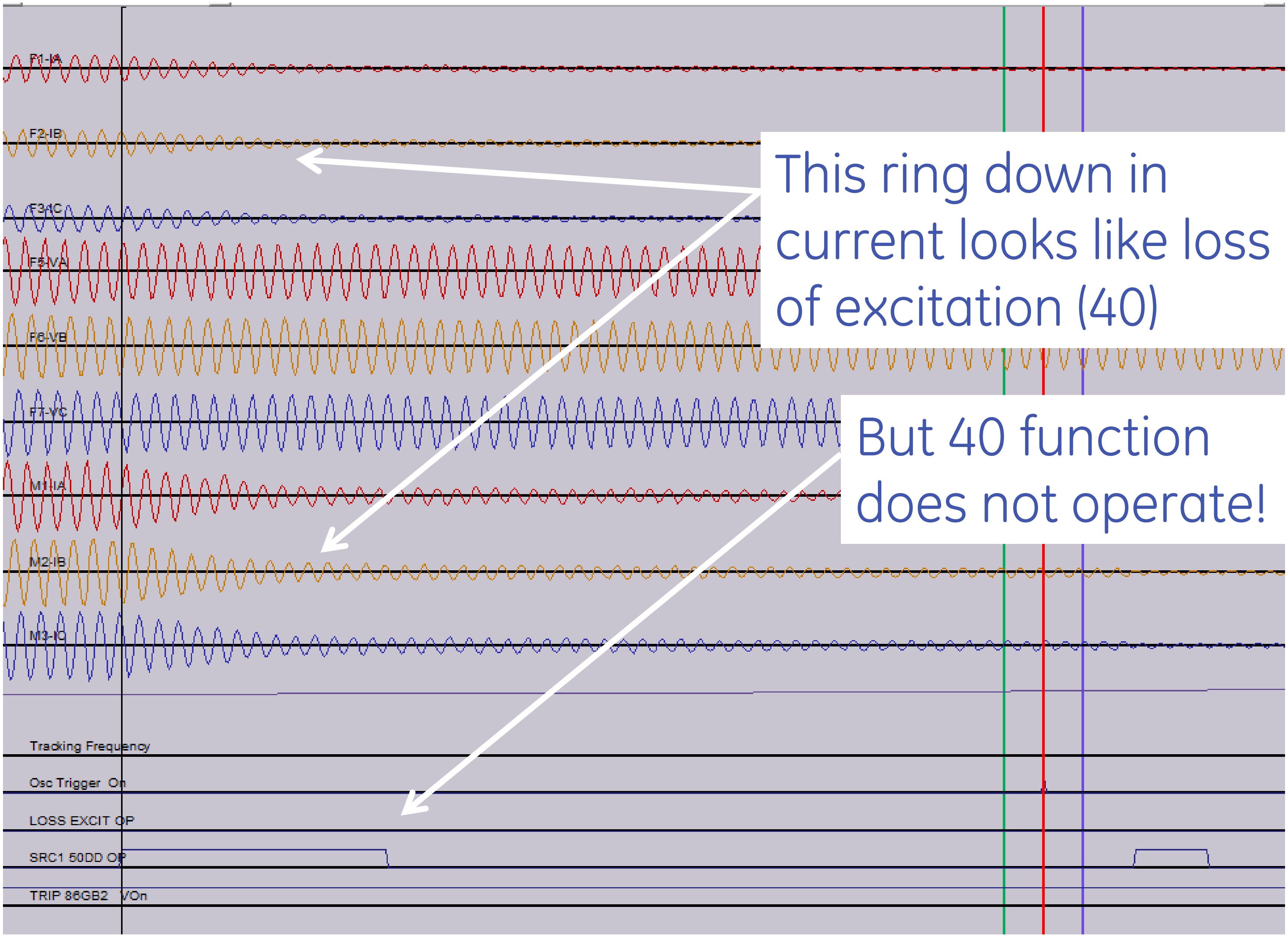
Generator Relay Failure to Trip on Loss of Excitation

imagination at work

The Story

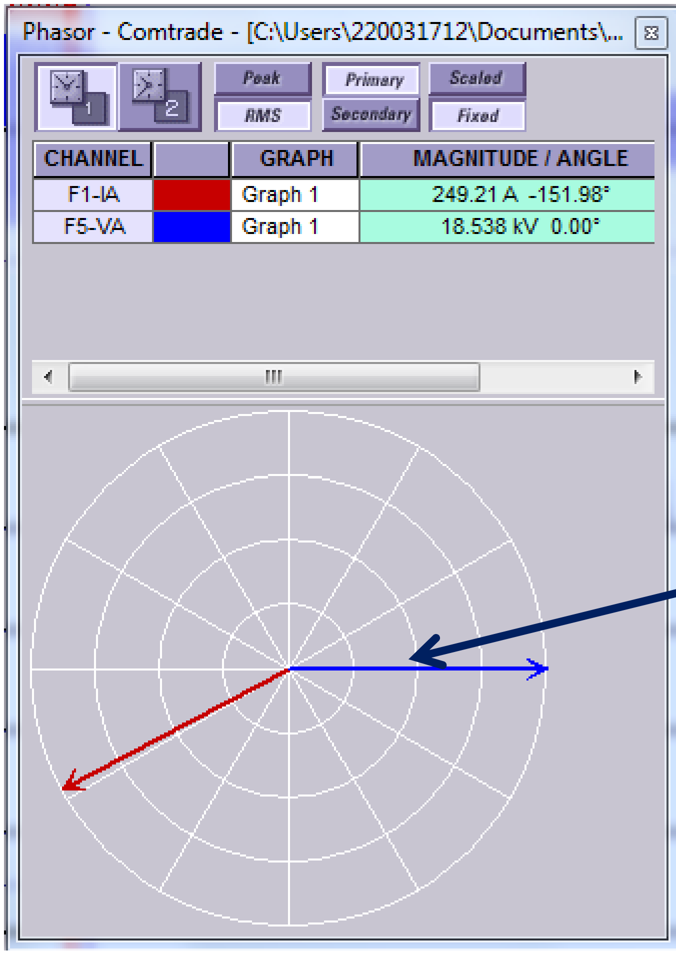
- We lost the exciter
- The relay failed to trip on loss of excitaton

imagination at work



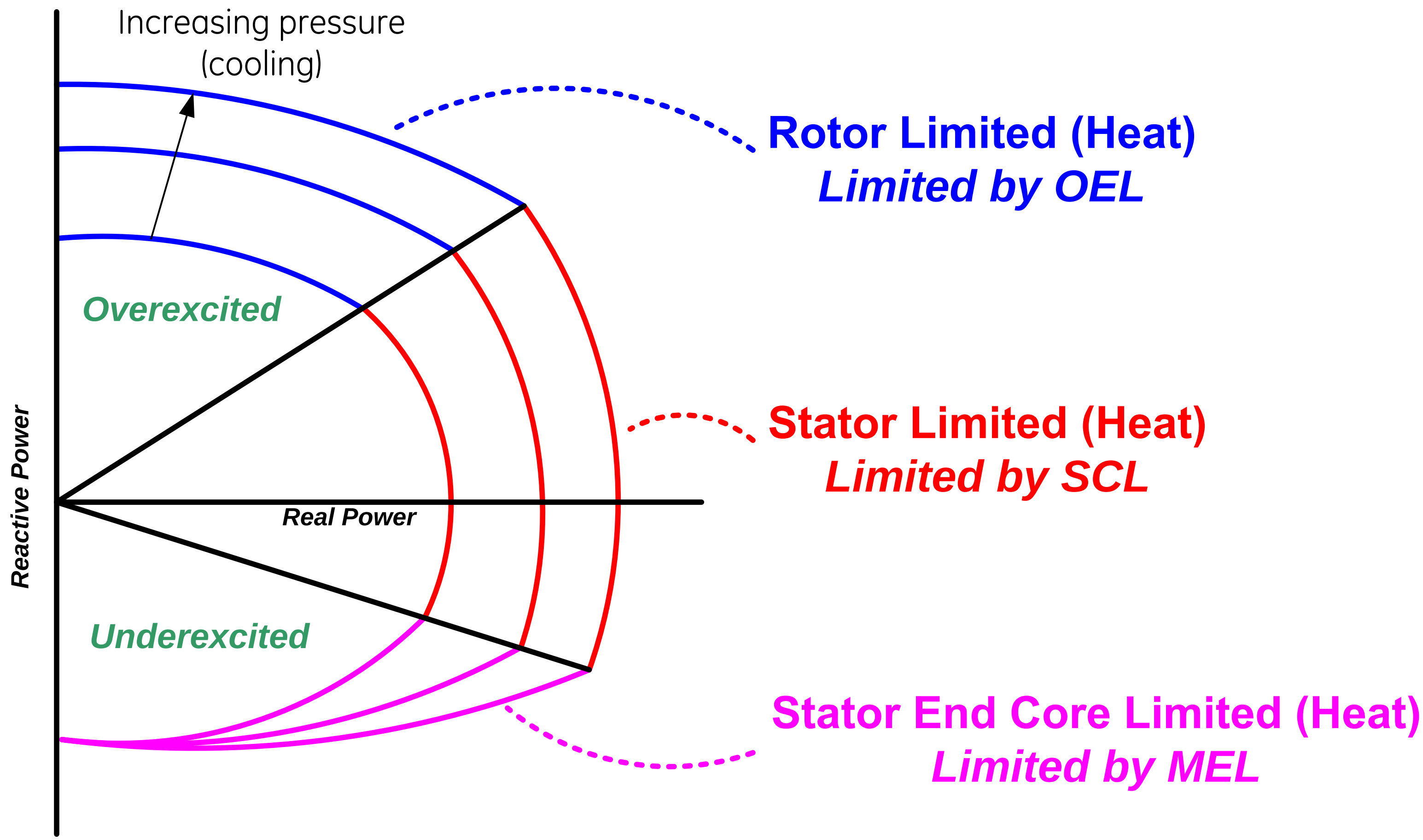
imagination at work

Let's look at the phasors



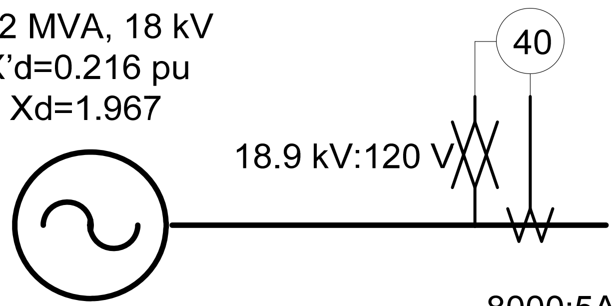
Why is current in opposite direction from voltage?

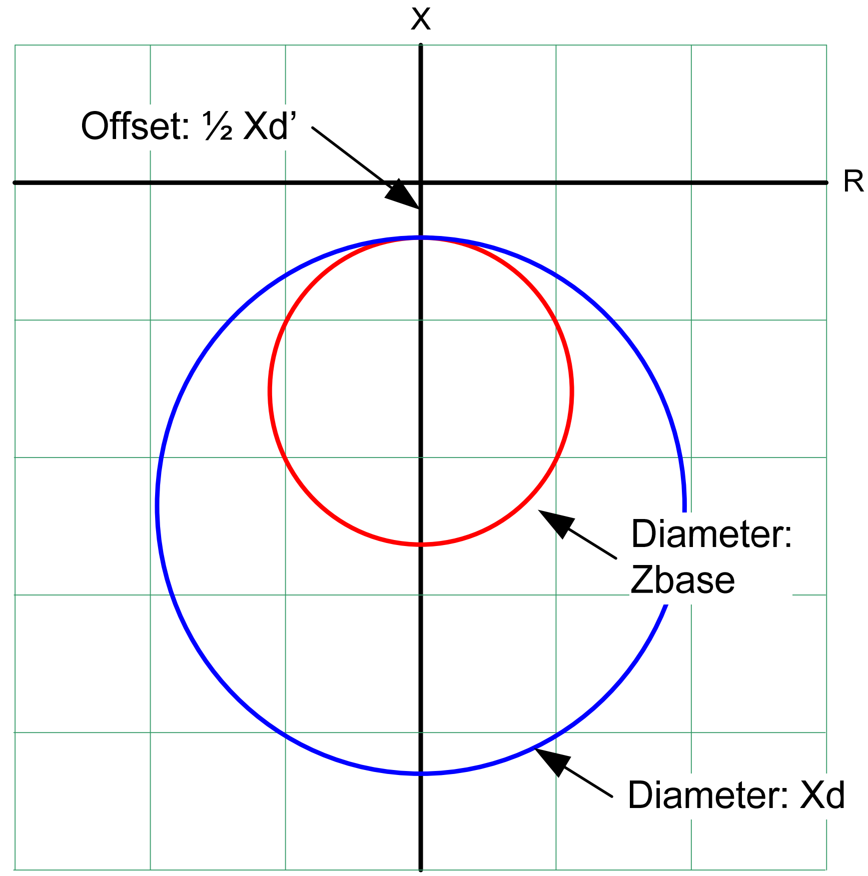
Machine limits



imagination at work

Loss of field





$$VT = \frac{18900}{120} = 157.5$$

$$CT = \frac{8000}{5} = 1600$$

$$Zbase(\text{sec}) = \frac{base\ kV^2}{base\ MVA} \cdot \frac{CTR}{VTR} = \frac{(18kV)^2}{211MVA} \cdot \frac{1600}{157.5} = 15.54\Omega$$

$$X'_d(\text{sec}) = X'_d \cdot Zbase(\text{sec}) = 0.216 \cdot 15.54 = 3.36\Omega$$

$$X_d(\text{sec}) = X_d \cdot Zbase(\text{sec}) = 1.967 \cdot 15.54 = 30.57\Omega$$

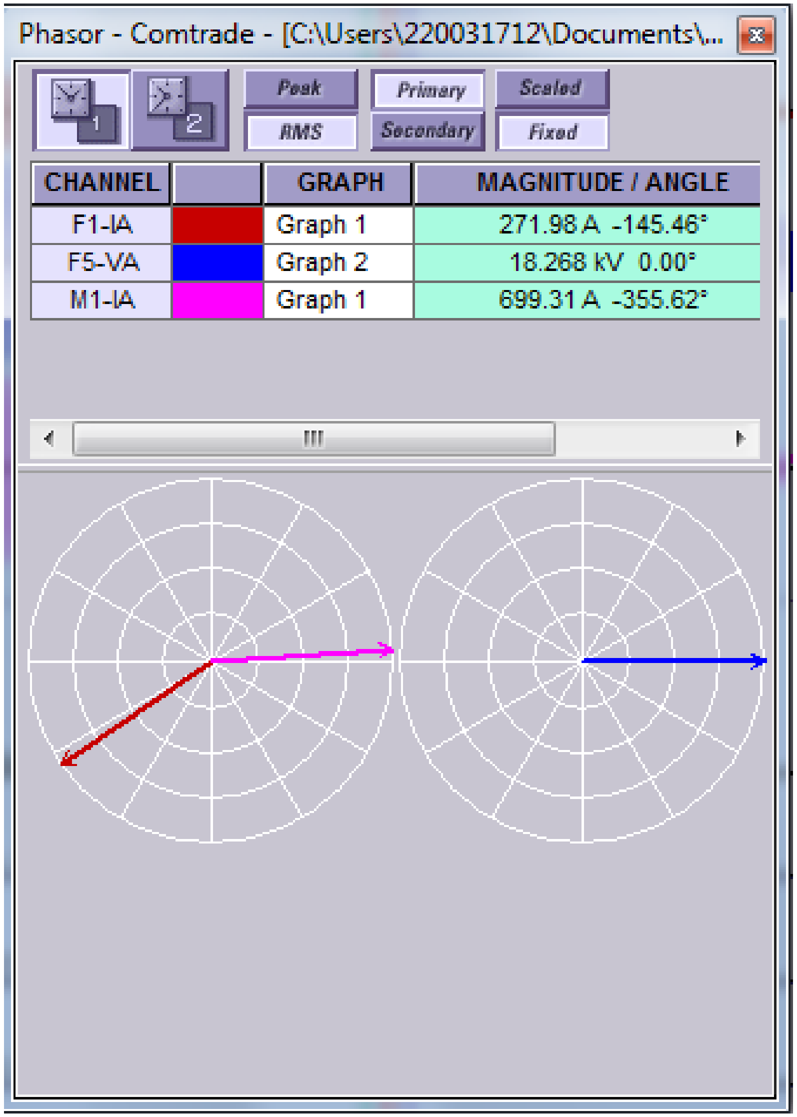
imagination at work

Something with your current is not right !

Ok, then why don't I trip on Differential?

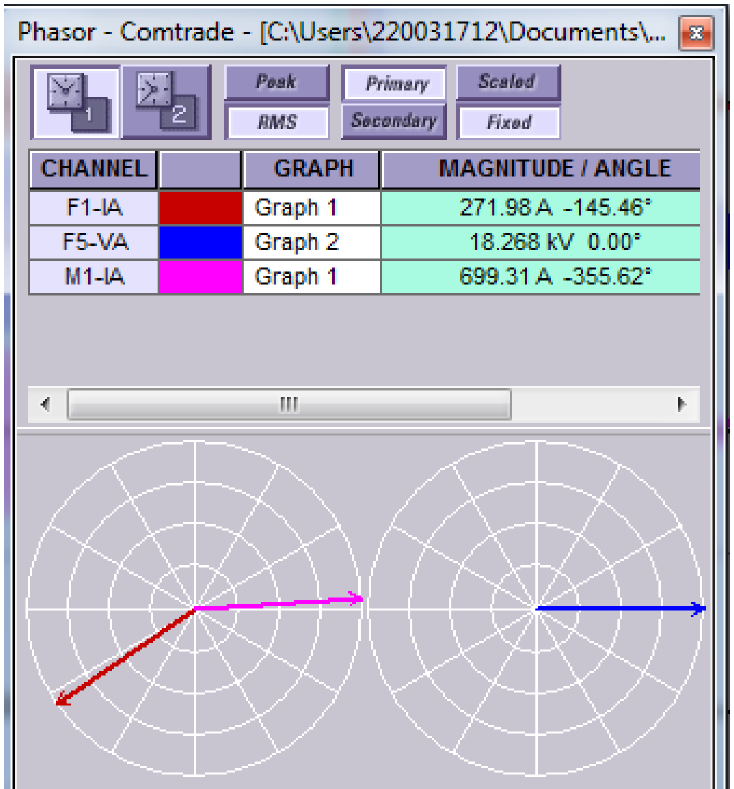
imagination at work

Once I account for transformer, currents sum to zero

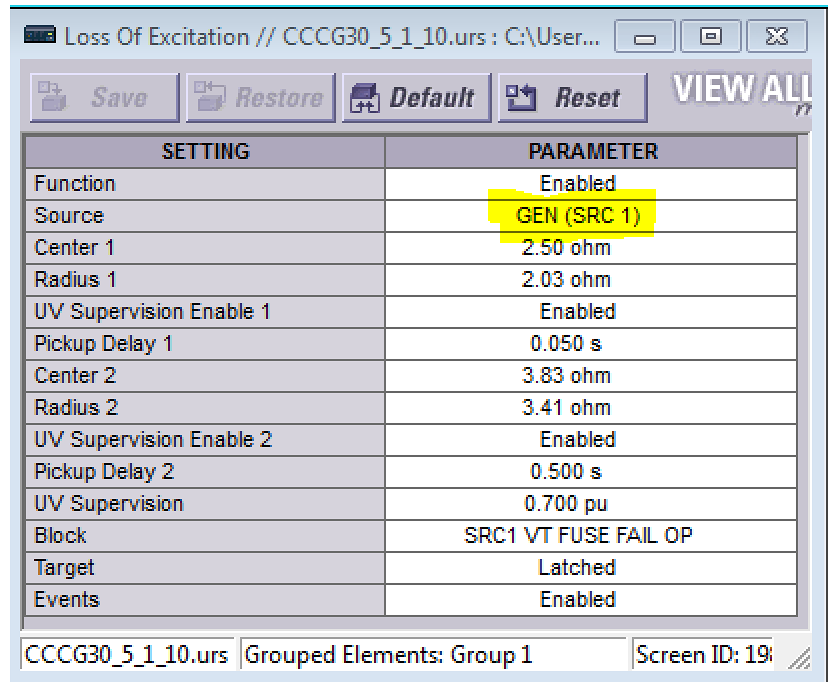


imagination at work

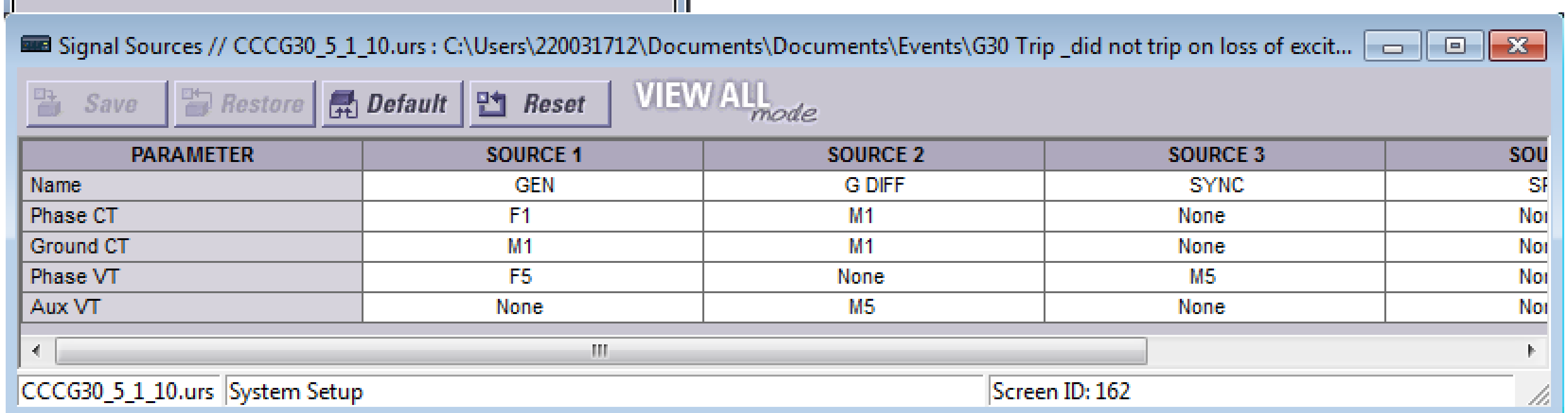
So what's wrong with 40 function?



CHANNEL		GRAPH	MAGNITUDE / ANGLE
F1-IA		Graph 1	271.98 A -145.46°
F5-VA		Graph 2	18.268 kV 0.00°
M1-IA		Graph 1	699.31 A -355.62°



SETTING	PARAMETER
Function	Enabled
Source	GEN (SRC 1)
Center 1	2.50 ohm
Radius 1	2.03 ohm
UV Supervision Enable 1	Enabled
Pickup Delay 1	0.050 s
Center 2	3.83 ohm
Radius 2	3.41 ohm
UV Supervision Enable 2	Enabled
Pickup Delay 2	0.500 s
UV Supervision	0.700 pu
Block	SRC1 VT FUSE FAIL OP
Target	Latched
Events	Enabled



PARAMETER	SOURCE 1	SOURCE 2	SOURCE 3	SOU
Name	GEN	G DIFF	SYNC	SI
Phase CT	F1	M1	None	No
Ground CT	M1	M1	None	No
Phase VT	F5	None	M5	No
Aux VT	None	M5	None	No

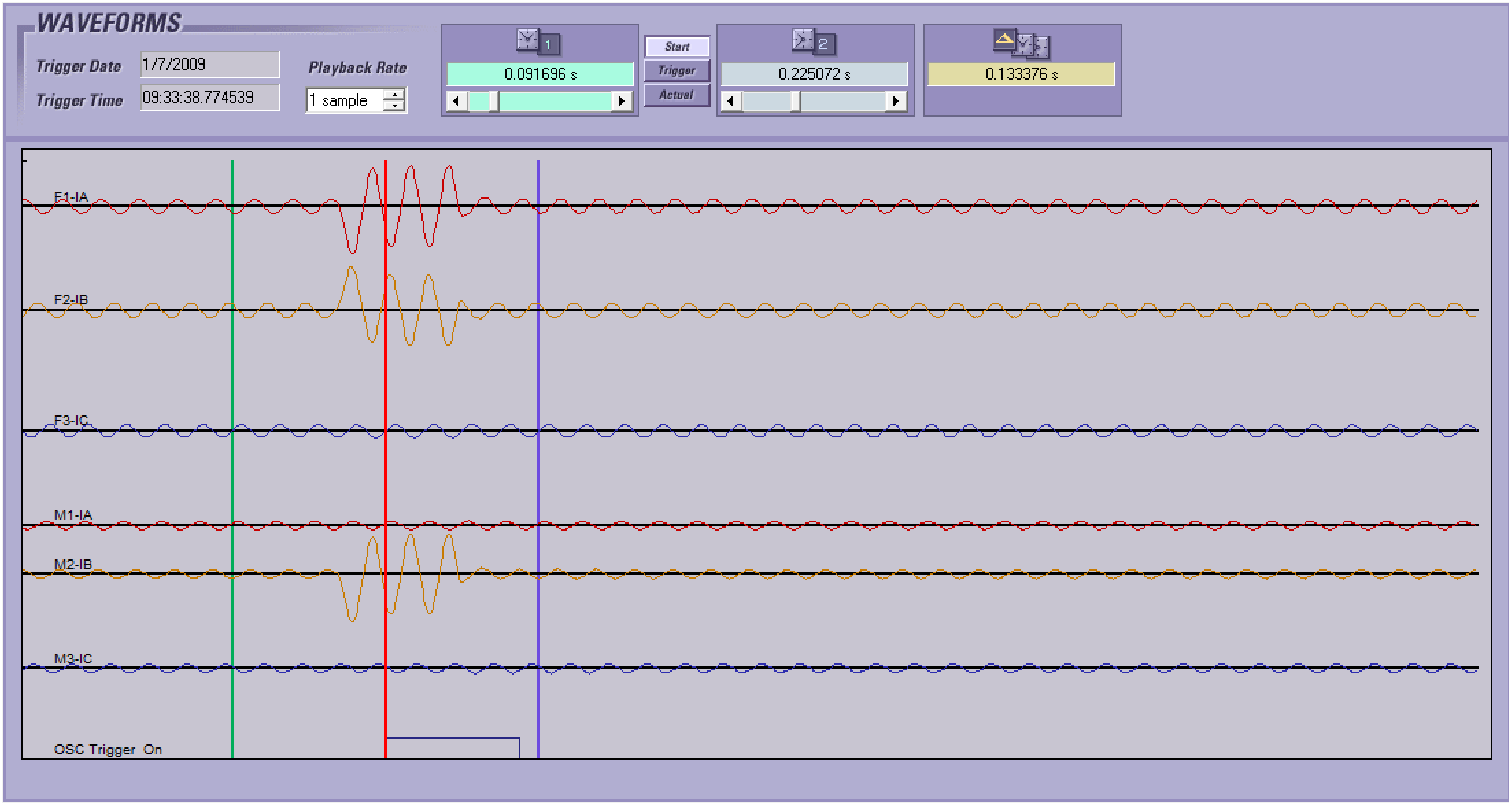
Fault on Distribution System Causes Unusual Transformer High Side Currents

imagination at work

The Story

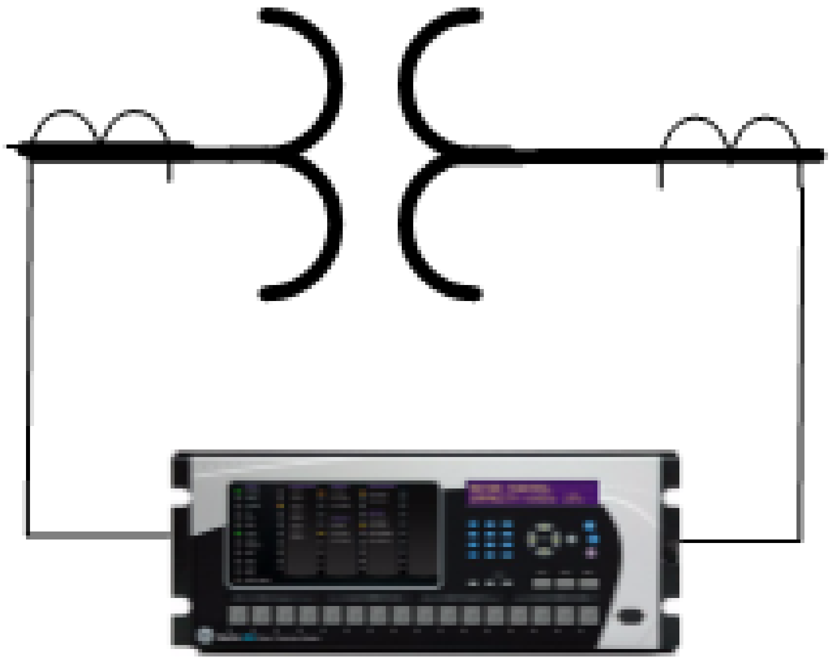
- Distribution transformer feeding medium voltage overhead distribution.
- In oscillography, we see two phases of fault current on the high side of the transformer for a single phase to ground fault on the low side

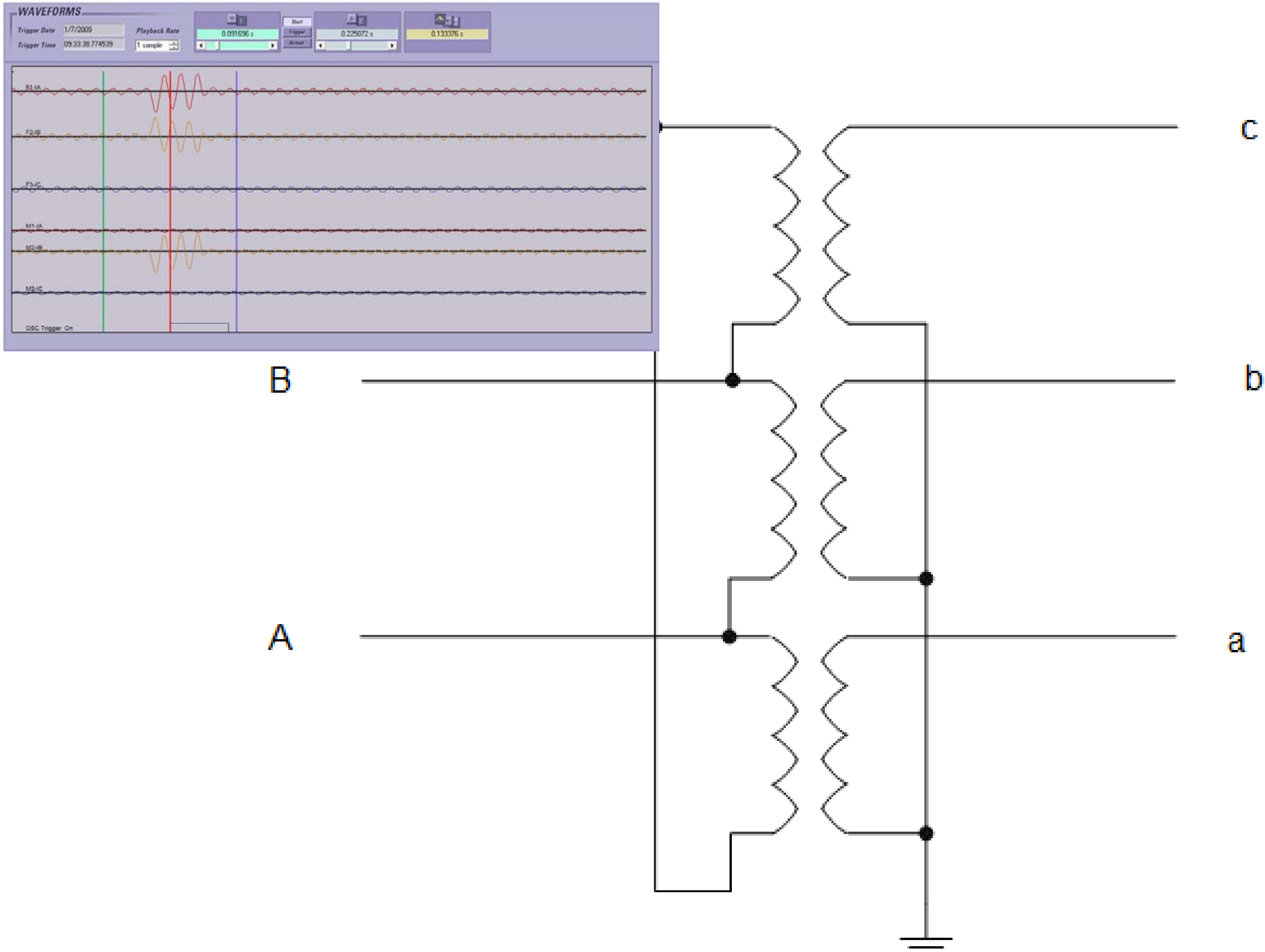
imagination at work



imagination at work

Delta-Wye

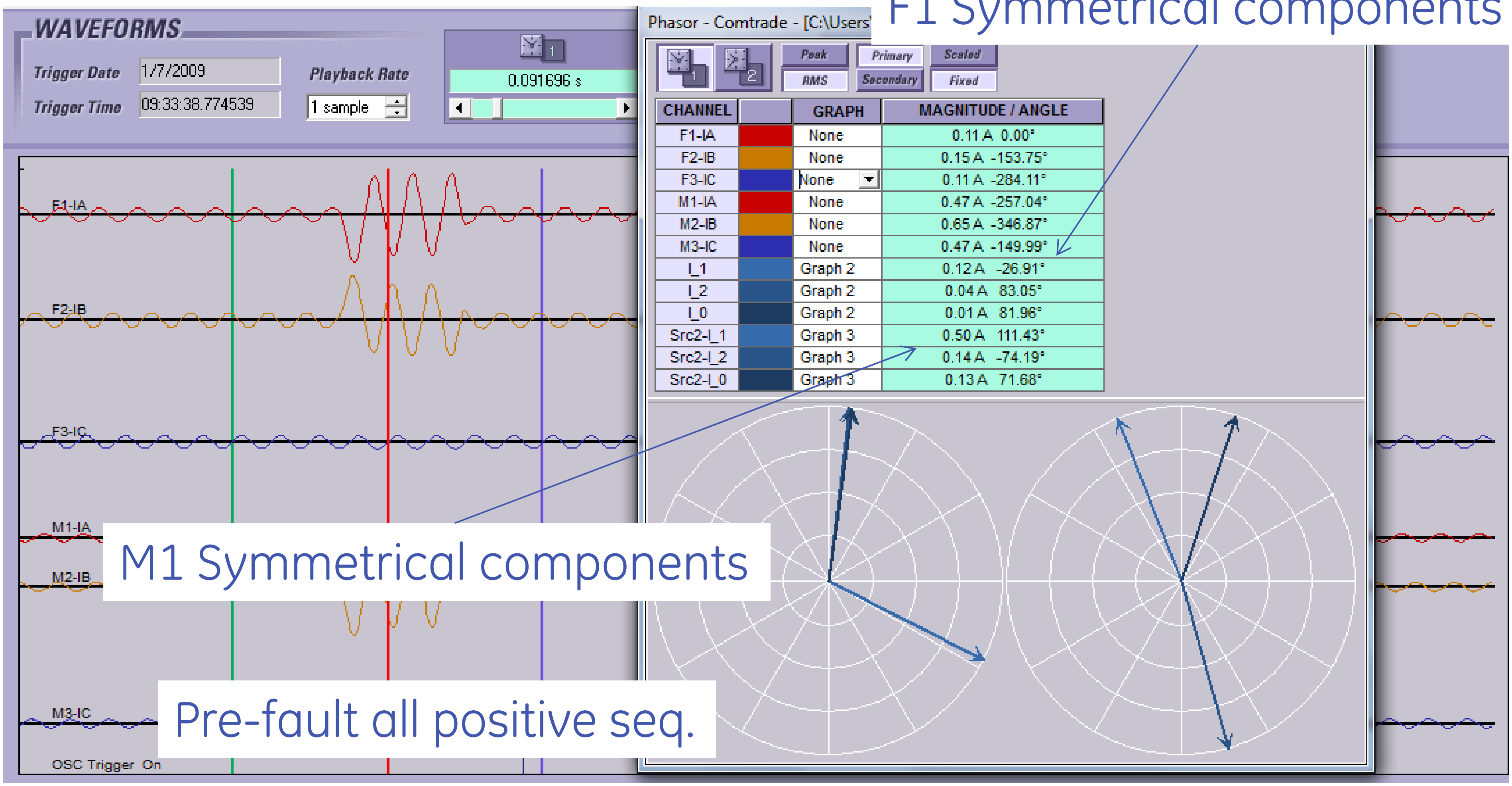




WAVEFORMS
Trigger Date
1/7/2009
Trigger Time
09:33:38.774539
Playback Rate
1 sample
0.091696 s
Start
Trigger
Actual
0.225072 s
0.133376 s
c
B
b
A
a

Pre-Fault Values

F1 Symmetrical components



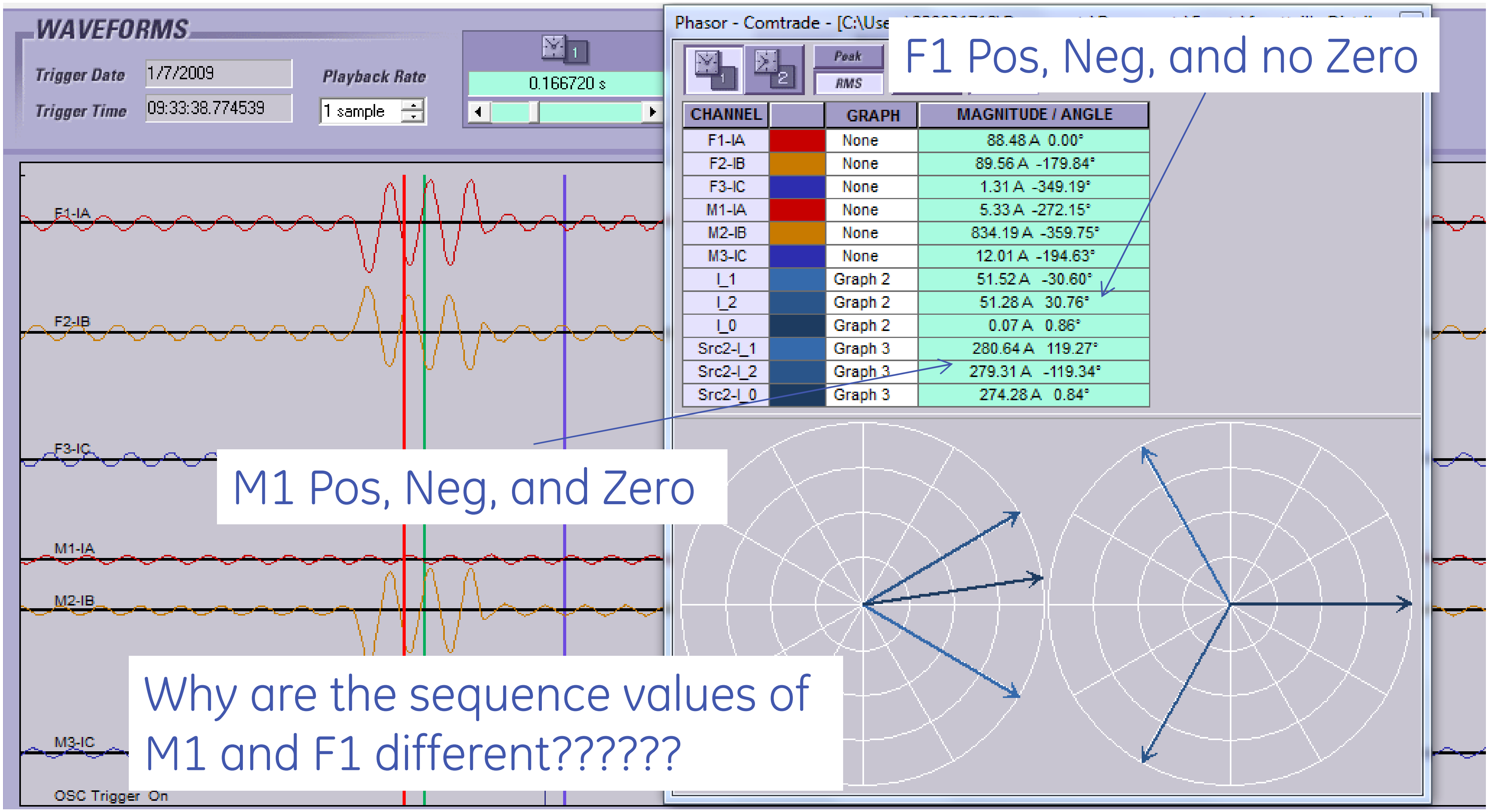
CHANNEL		GRAPH	MAGNITUDE / ANGLE
F1-IA		None	0.11 A 0.00°
F2-IB		None	0.15 A -153.75°
F3-IC		None	0.11 A -284.11°
M1-IA		None	0.47 A -257.04°
M2-IB		None	0.65 A -346.87°
M3-IC		None	0.47 A -149.99°
I_1		Graph 2	0.12 A -26.91°
I_2		Graph 2	0.04 A 83.05°
I_0		Graph 2	0.01 A 81.96°
Src2-I_1		Graph 3	0.50 A 111.43°
Src2-I_2		Graph 3	0.14 A -74.19°
Src2-I_0		Graph 3	0.13 A 71.68°

M1 Symmetrical components

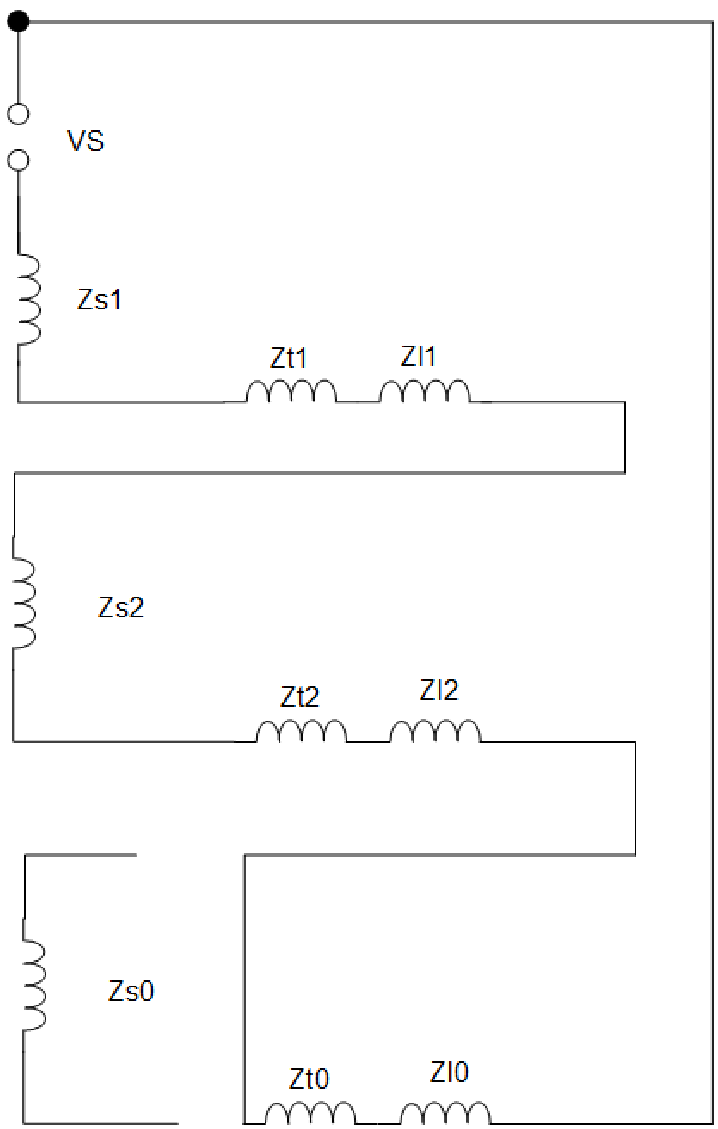
Pre-fault all positive seq.

imagination at work

Fault Values

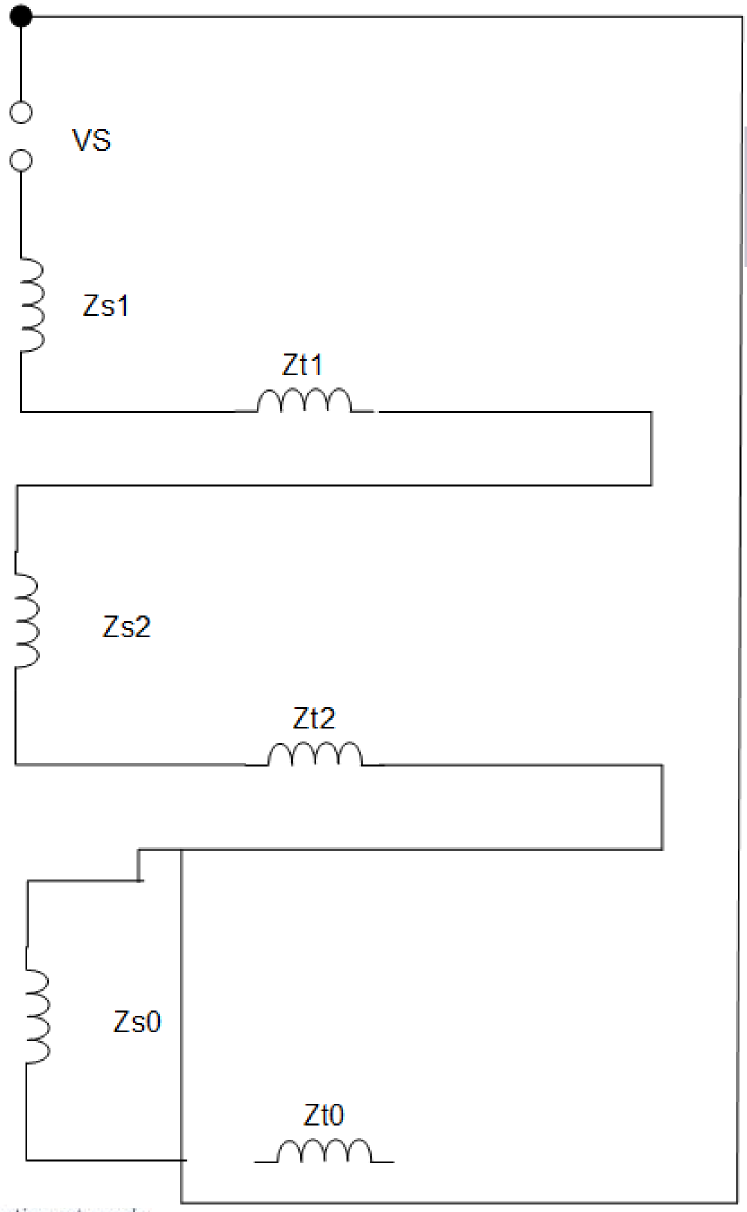


The Fault Network as Seen From F1



Src2-I_1		Graph 3	280.64 A 119.27°
Src2-I_2		Graph 3	279.31 A -119.34°
Src2-I_0		Graph 3	274.28 A 0.84°

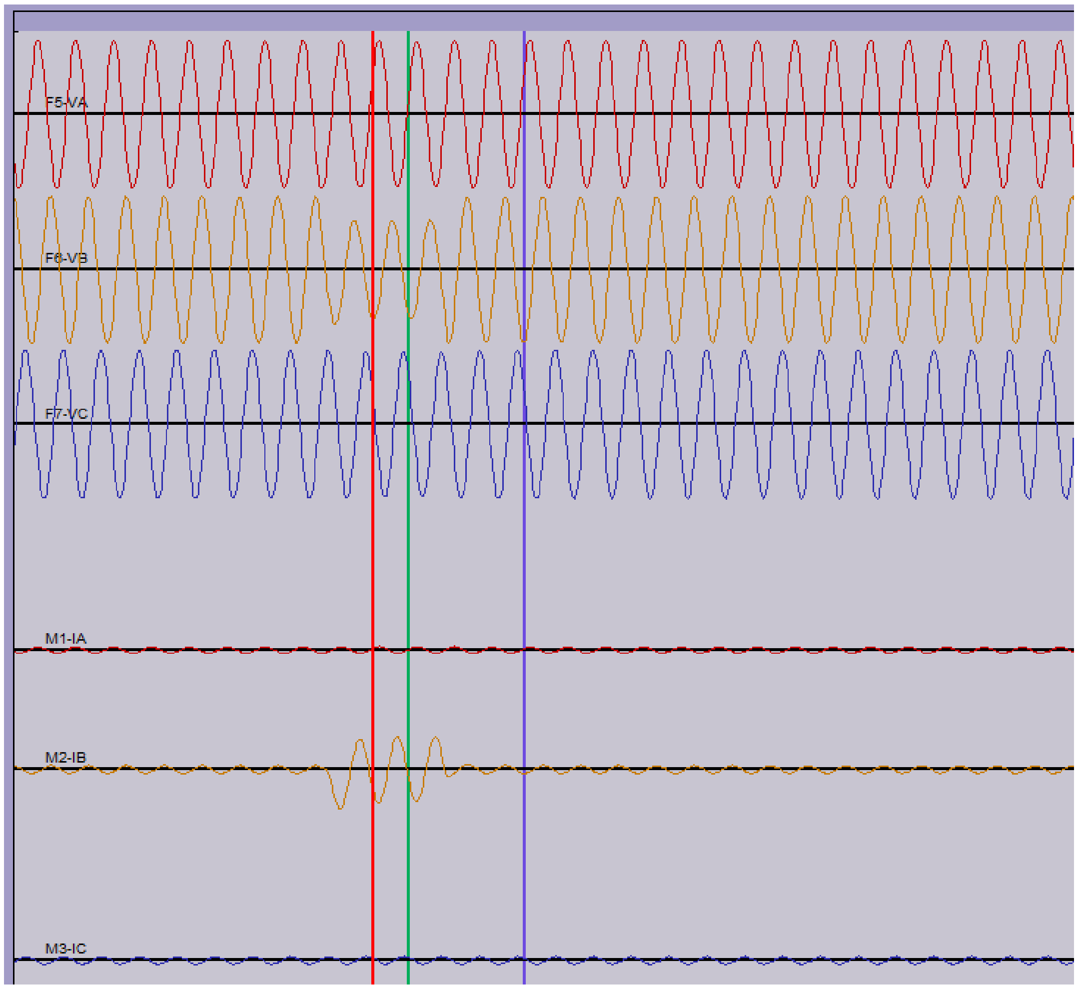
The Fault Network as Seen From M1



I_1		Graph 2	51.52 A -30.60°
I_2		Graph 2	51.28 A 30.76°
I_0		Graph 2	0.07 A 0.86°

imagination at work

What Effect Does this Fault Have on Voltage?



imagination at work

What Effect Does this Fault Have on Voltage?

Incorrect current transformer wiring causes bus fault during power transformer energization

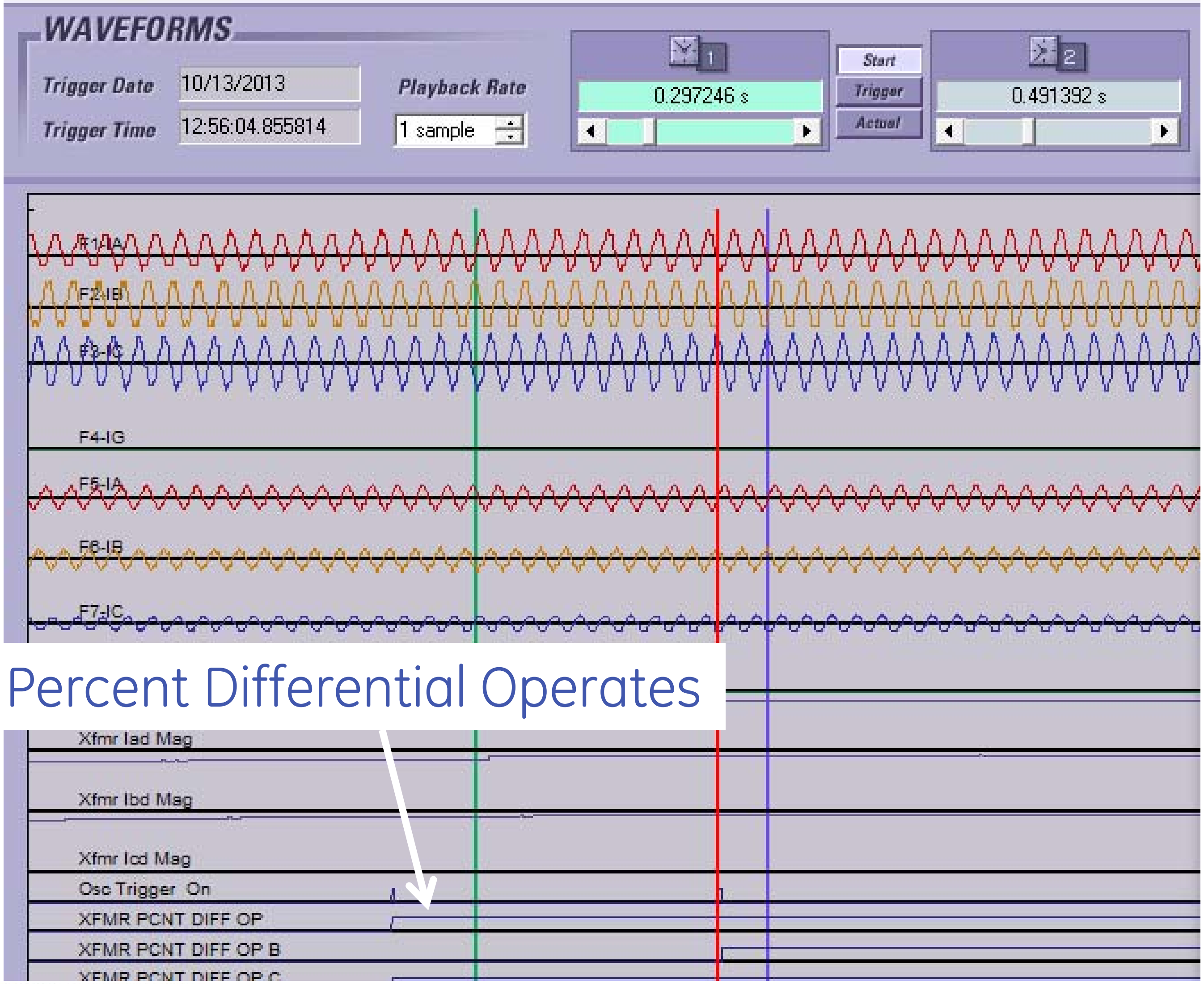
imagination at work

The Story

- I have energized the transformer
- As soon as I pickup load, I get a transformer differential.

imagination at work

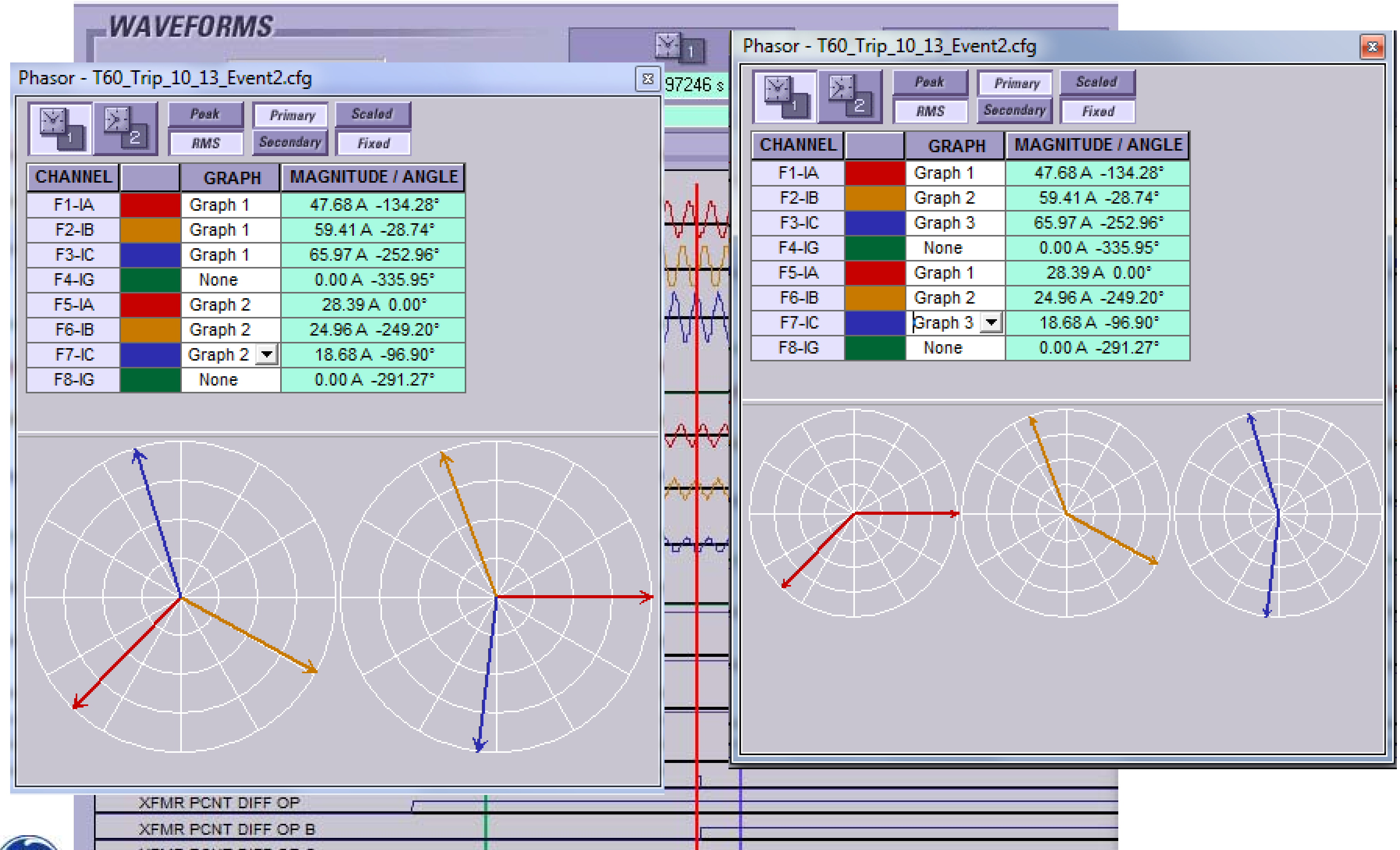
Oscillography



Percent Differential Operates

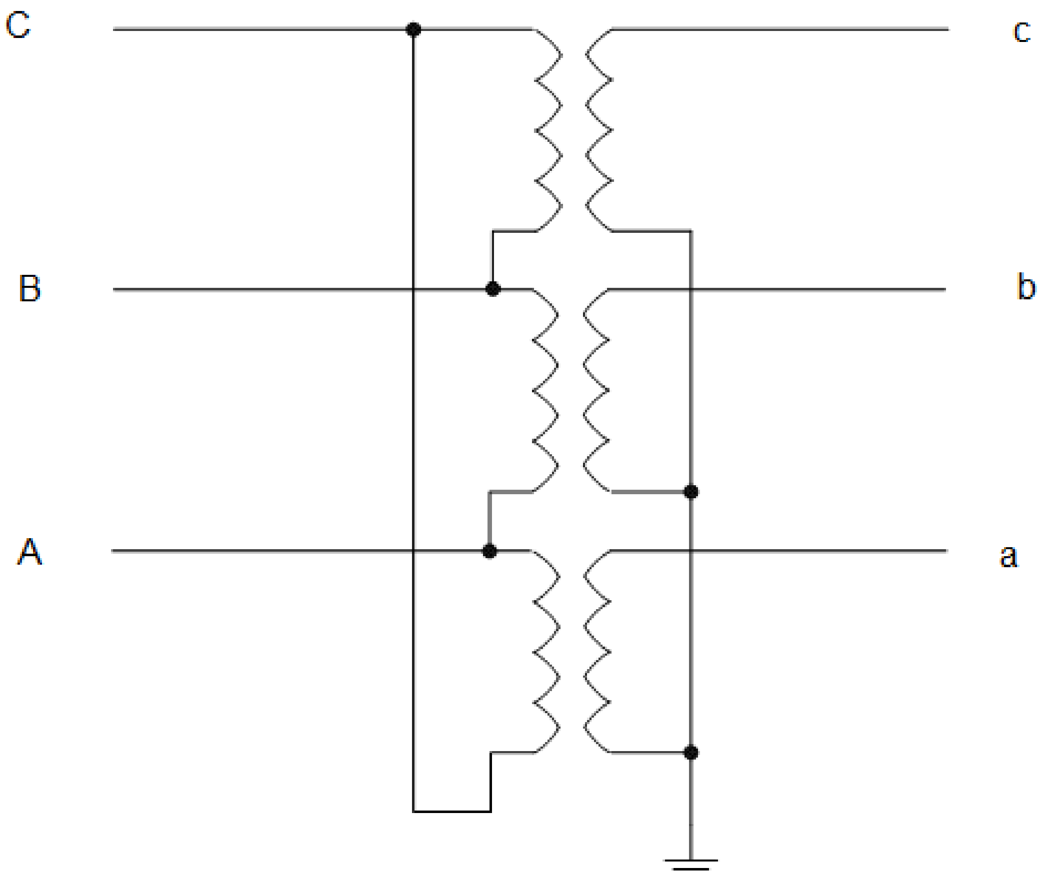
imagination at work

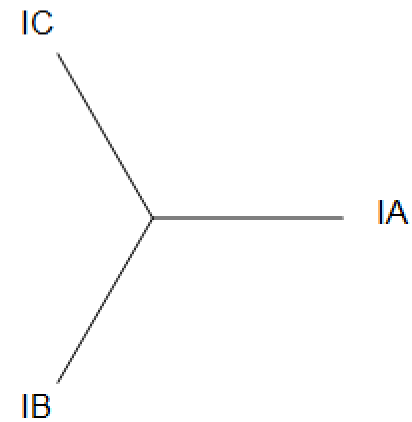
Oscillography

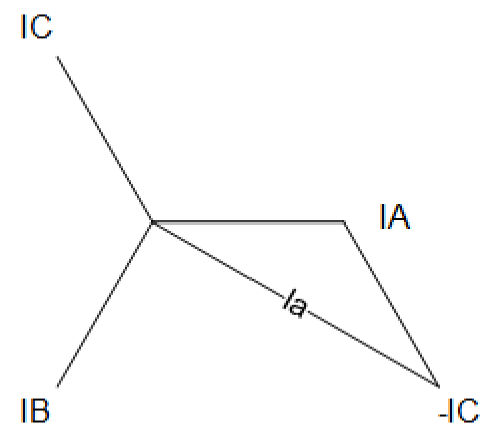


imagination at work

What I expect to see for ABC rotation:

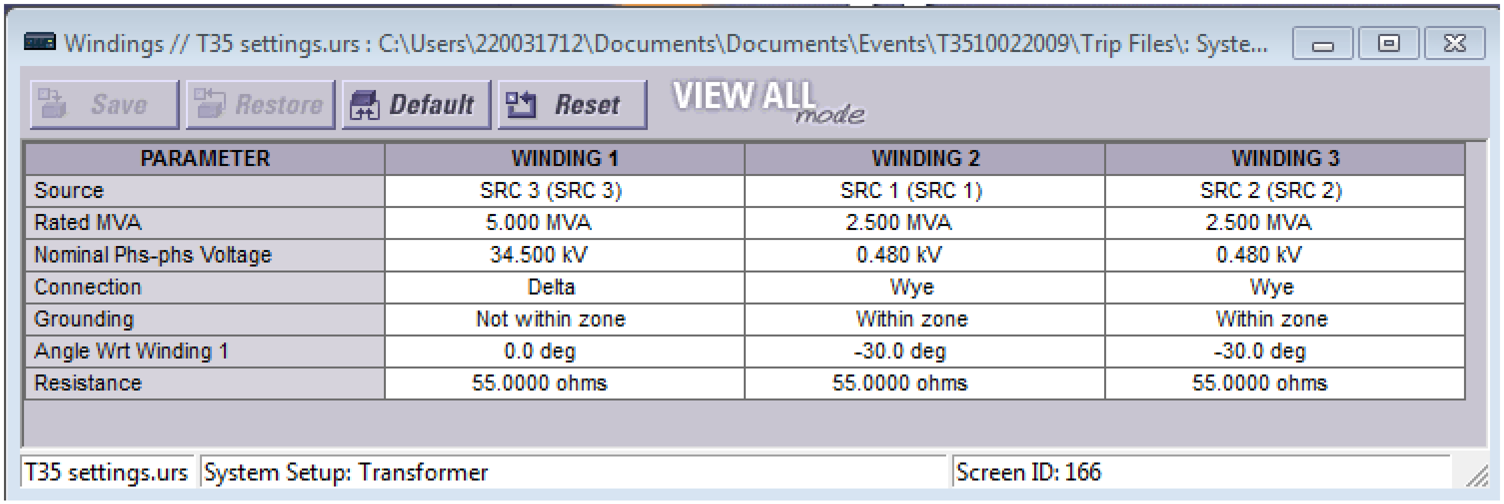






Typically H Winding leads X winding by 30 degrees

What I expect to see for ABC rotation:



Windings // T35 settings.urs : C:\Users\220031712\Documents\Documents\Events\T3510022009\Trip Files\: Syste...

Save | Restore | Default | Reset | VIEW ALL mode

PARAMETER	WINDING 1	WINDING 2	WINDING 3
Source	SRC 3 (SRC 3)	SRC 1 (SRC 1)	SRC 2 (SRC 2)
Rated MVA	5.000 MVA	2.500 MVA	2.500 MVA
Nominal Phs-phs Voltage	34.500 kV	0.480 kV	0.480 kV
Connection	Delta	Wye	Wye
Grounding	Not within zone	Within zone	Within zone
Angle Wrt Winding 1	0.0 deg	-30.0 deg	-30.0 deg
Resistance	55.0000 ohms	55.0000 ohms	55.0000 ohms

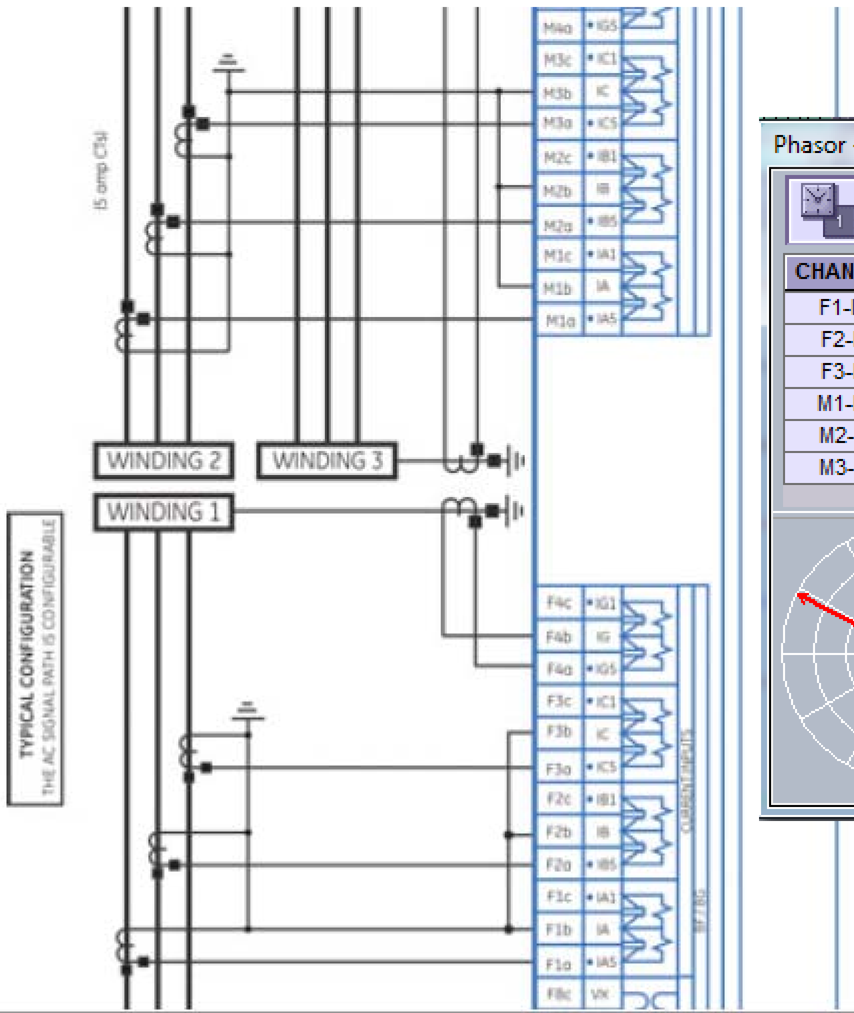
T35 settings.urs | System Setup: Transformer | Screen ID: 166

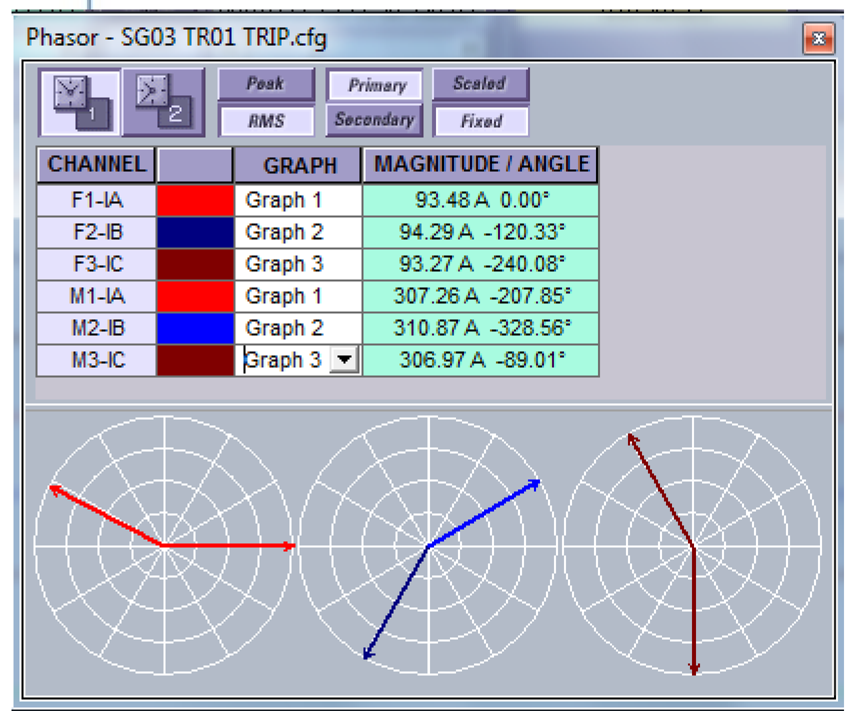
We compensate the measured currents with settings

Typically H Winding leads X winding by 30 degrees

imagination at work

What I expect to see for ABC rotation:





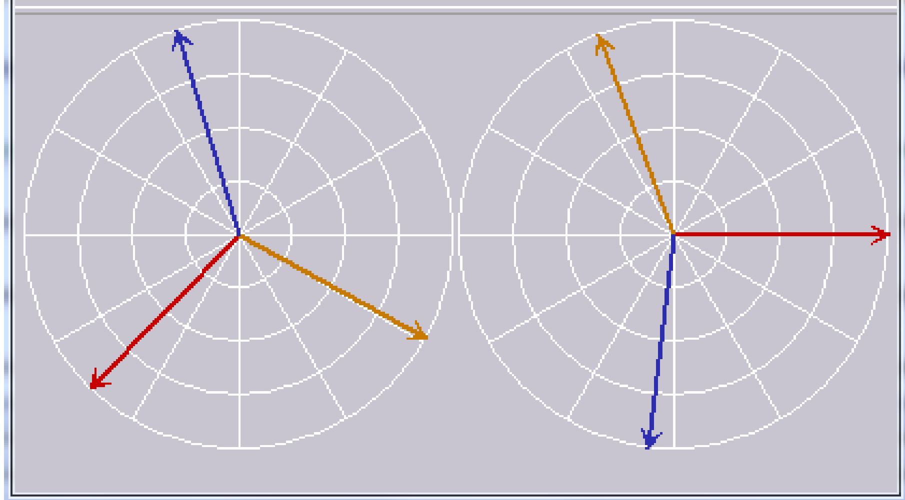
imagination at work

But this isn't ABC rotation:

Phasor - T60_Trip_10_13_Event2.cfg

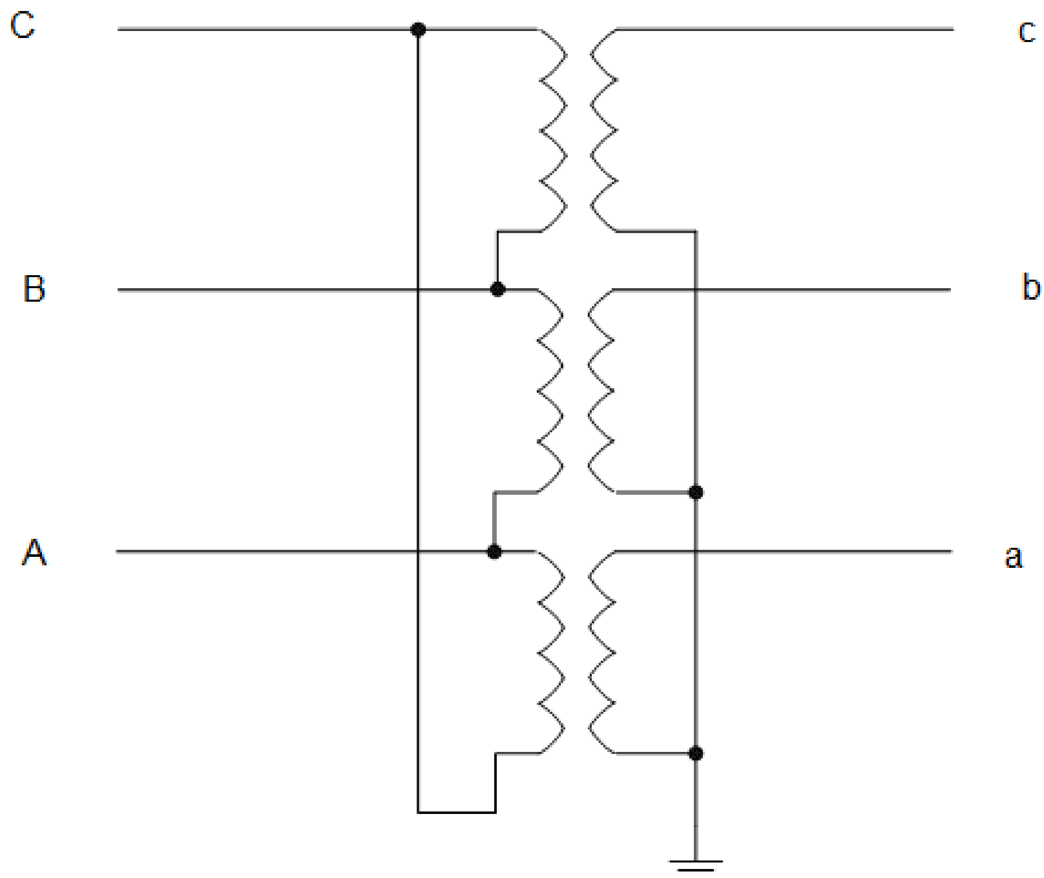
Peak | RMS | Primary | Secondary | Scaled | Fixed

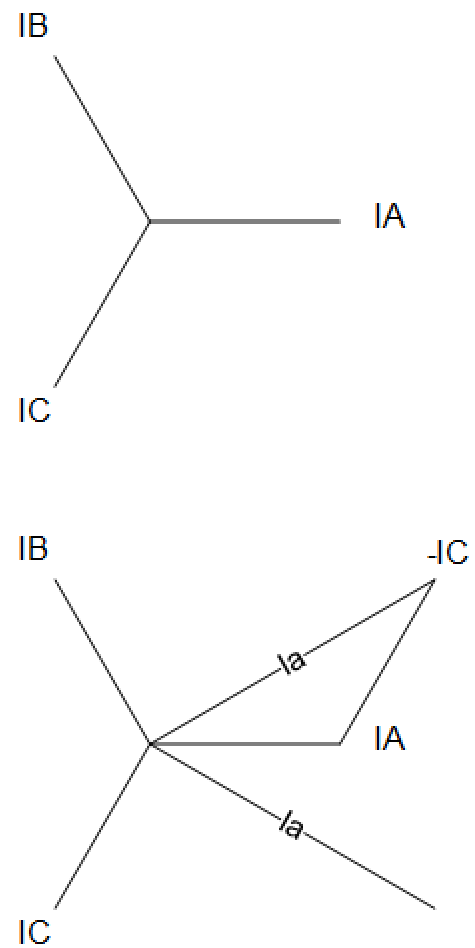
CHANNEL		GRAPH	MAGNITUDE / ANGLE
F1-IA		Graph 1	47.68 A -134.28°
F2-IB		Graph 1	59.41 A -28.74°
F3-IC		Graph 1	65.97 A -252.96°
F4-IG		None	0.00 A -335.95°
F5-IA		Graph 2	28.39 A 0.00°
F6-IB		Graph 2	24.96 A -249.20°
F7-IC		Graph 2	18.68 A -96.90°
F8-IG		None	0.00 A -291.27°



imagination at work

But this isn't ABC rotation:





Typically H Winding lags X winding by 30 degrees on ACB rotation

Trip occurred because of setting

Windings // T35 settings.urs : C:\Users\220031712\Documents\Documents\Events\T351002

Save | Restore | Default | Reset | VIEW ALL mode

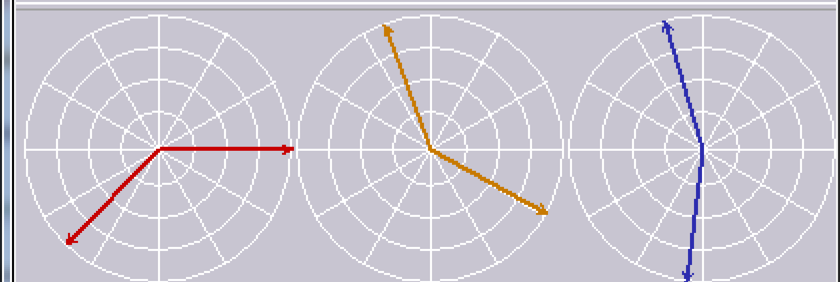
PARAMETER	WINDING 1	WINDING 2
Source	SRC 3 (SRC 3)	SRC 1 (SRC 1)
Rated MVA	5.000 MVA	2.500 MVA
Nominal Phs-phs Voltage	34.500 kV	0.480 kV
Connection	Delta	Wye
Grounding	Not within zone	Within zone
Angle Wrt Winding 1	0.0 deg	-30.0 deg
Resistance	55.0000 ohms	55.0000 ohms

T35 settings.urs | System Setup: Transformer | Scree

Phasor - T60_Trip_10_13_Event2.cfg

Peak | Primary | Scaled | RMS | Secondary | Fixed

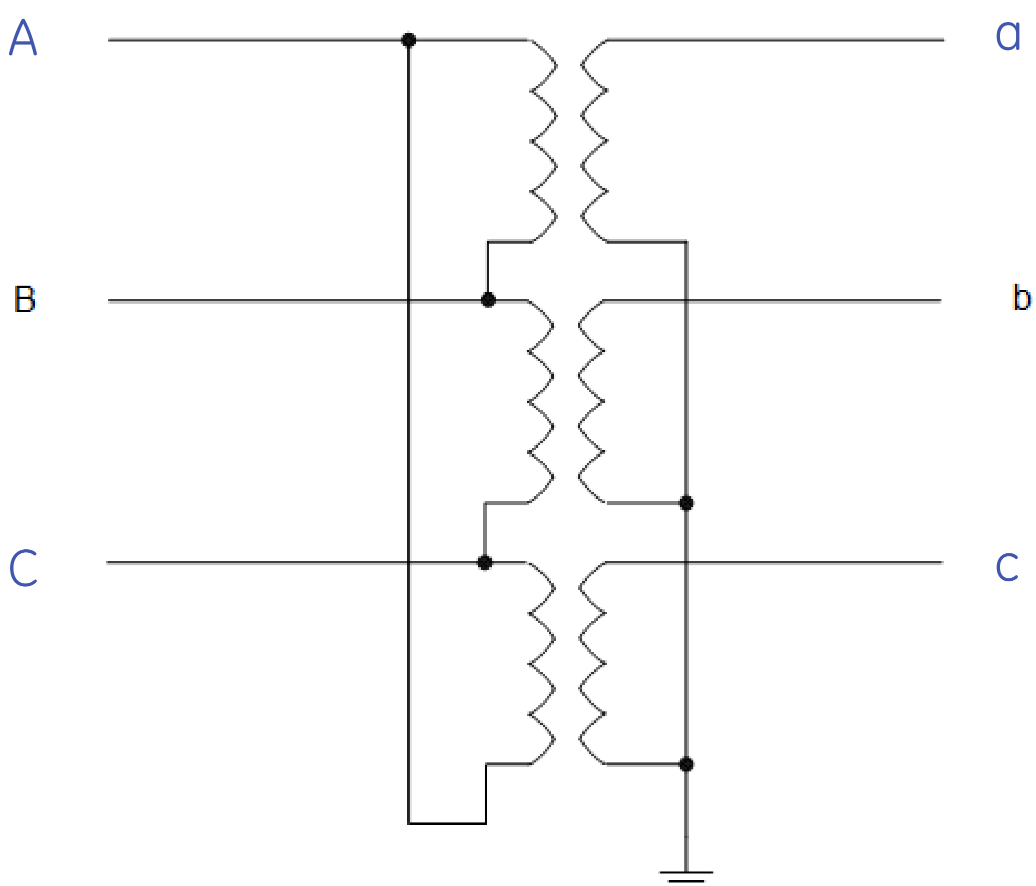
CHANNEL		GRAPH	MAGNITUDE / ANGLE
F1-IA		Graph 1	47.68 A -134.28°
F2-IB		Graph 2	59.41 A -28.74°
F3-IC		Graph 3	65.97 A -252.96°
F4-IG		None	0.00 A -335.95°
F5-IA		Graph 1	28.39 A 0.00°
F6-IB		Graph 2	24.96 A -249.20°
F7-IC		Graph 3	18.68 A -96.90°
F8-IG		None	0.00 A -291.27°

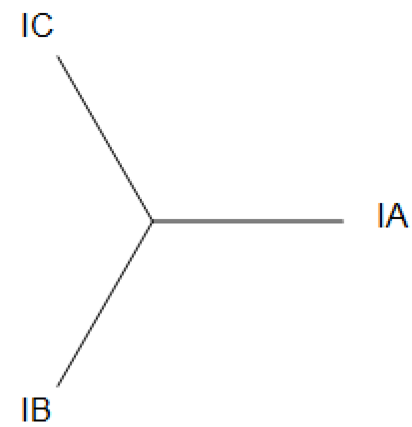


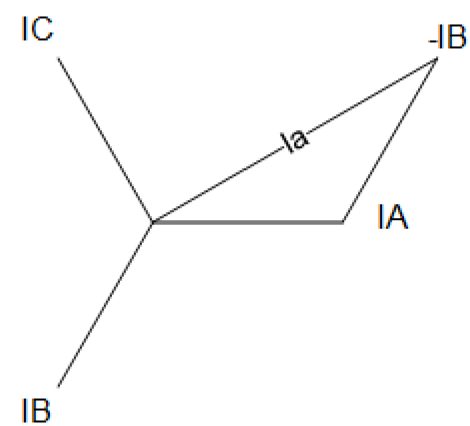
Typically H Winding lags X winding by 30 degrees on ACB rotation

imagination at work

What happens if I swap phases on my H winding:







Swapping phases on the High side changes my transformer from 30 lag to 30 lead

Reversed Phase Causes Motor Thermal Overload Trip

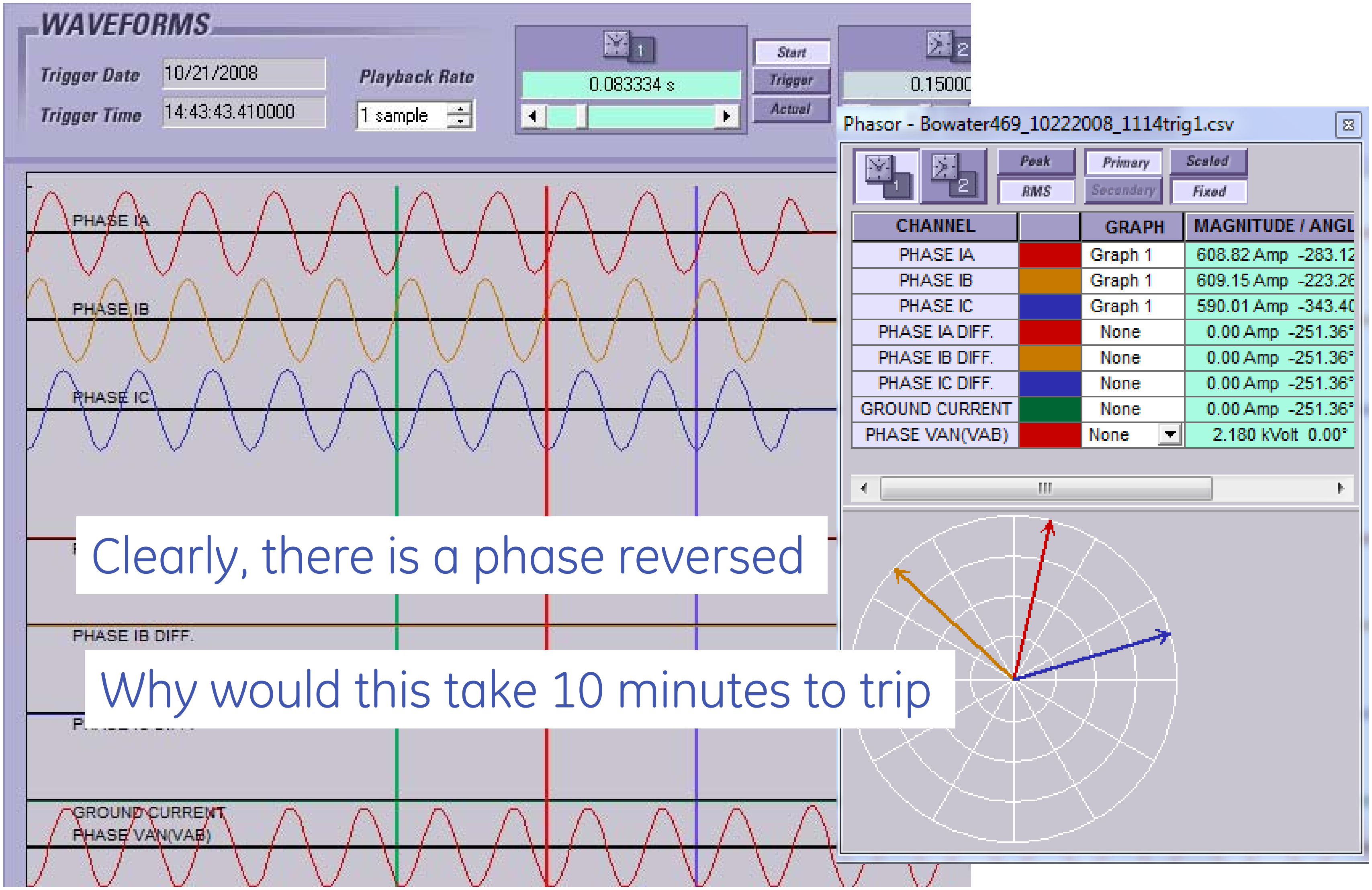
imagination at work

The Story

- New switchgear feeding motor
- When we start the motor, it trips after about 10 minutes.

imagination at work

Waveforms

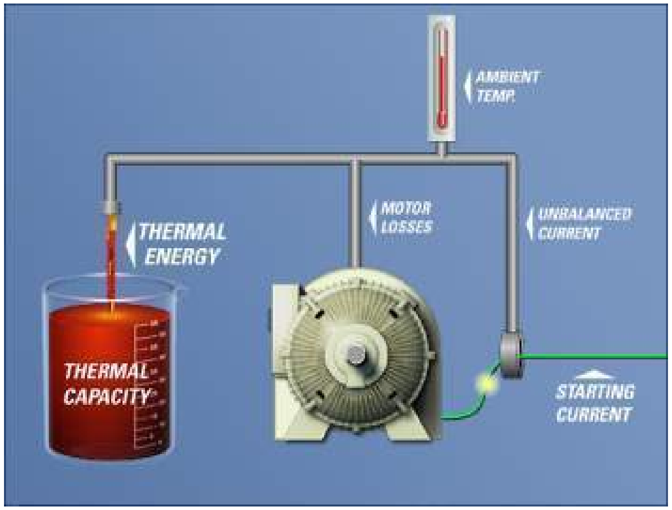


Clearly, there is a phase reversed

Why would this take 10 minutes to trip

Thermal Model – Thermal Capacity Used

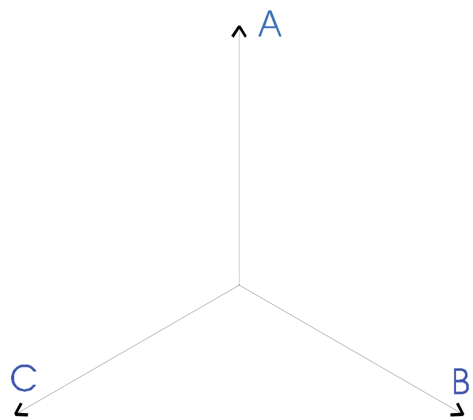
- Thermal Capacity Used (TCU) is a criterion selected in thermal model to evaluate thermal condition of the motor.
- TCU is defined as percentage of motor thermal limit utilized during motor operation.
- A running motor will have some level of thermal capacity used due to Motor Losses.
- Thermal Trip when Thermal Capacity Used equals 100%



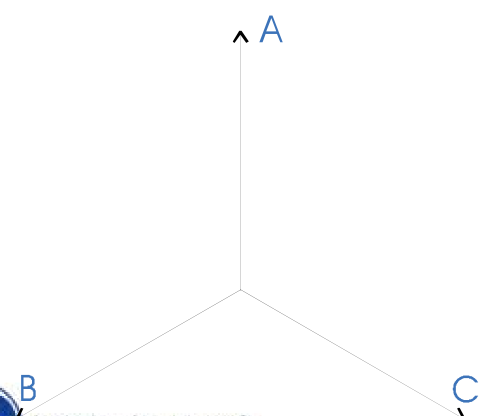
imagination at work

Thermal Model - Current Unbalance Bias

Negative sequence currents (or unbalanced phase currents) will cause additional rotor heating that will be accounted for in Thermal Model.

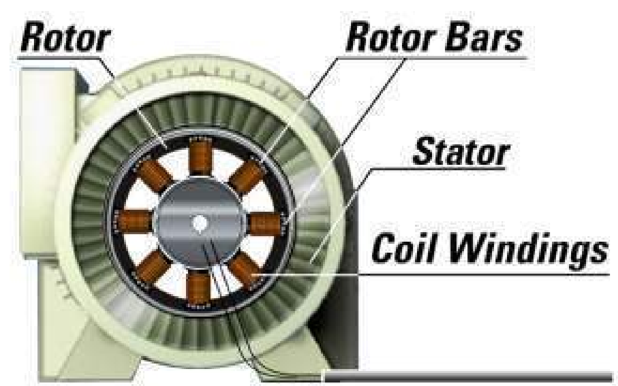


Positive Sequence



Negative Sequence

- Main causes of current unbalance
  - Blown fuses
  - Loose connections
  - Stator turn-to-turn faults
  - System voltage distortion and unbalance
  - Faults



imagination at work

Thermal Model - Current Unbalance Bias

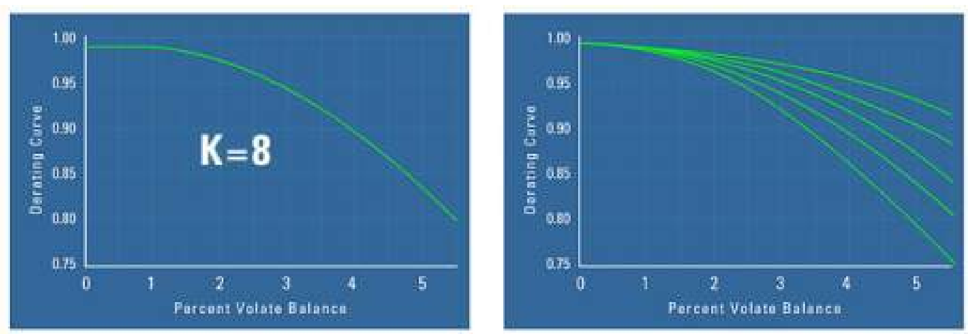
- **Equivalent heating motor current** is employed to bias thermal model in response to current unbalance.

$$I_{EQ} = \sqrt{I_M^2 \times (1 + K \times (I_2 / I_1)^2)}$$

- Im - real motor current; K - unbalance bias factor; I_1 & I_2 - positive and negative sequence components of motor current.
- K factor reflects the degree of extra heating caused by the negative sequence component of the motor current.
- IEEE guidelines for typical and conservative estimates of K.

$K = 175 / I_{LRC}^2$ TYPICAL

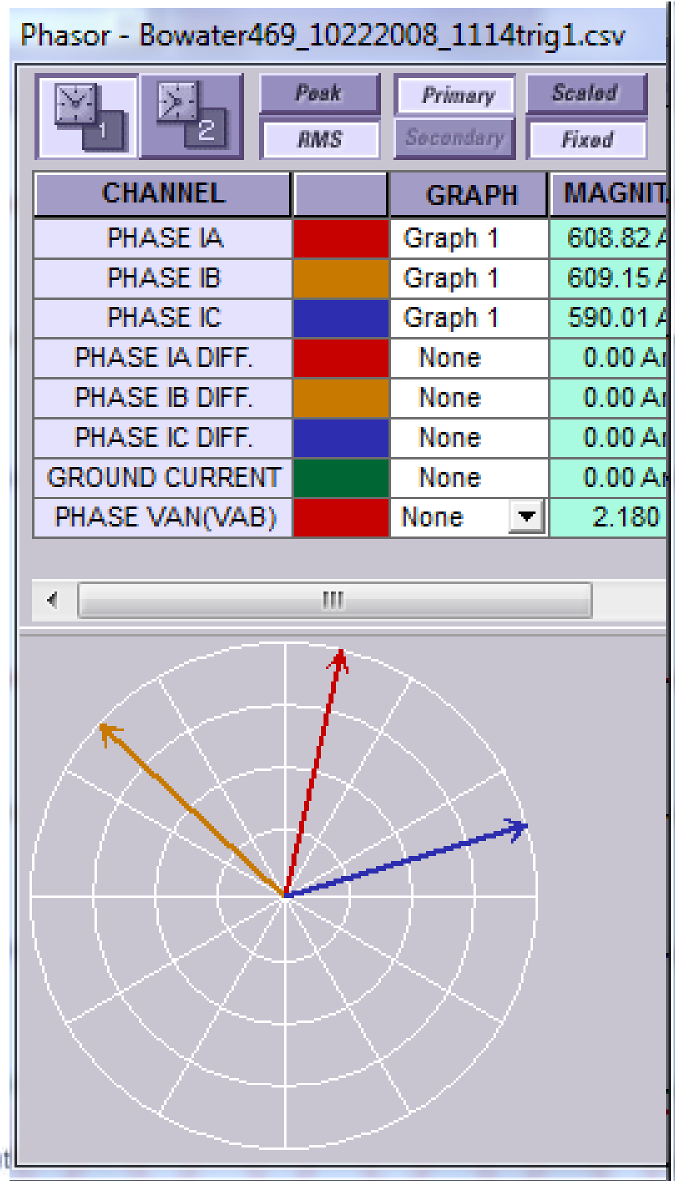
$K = 230 / I_{LRC}^2$ CONSERVATIVE

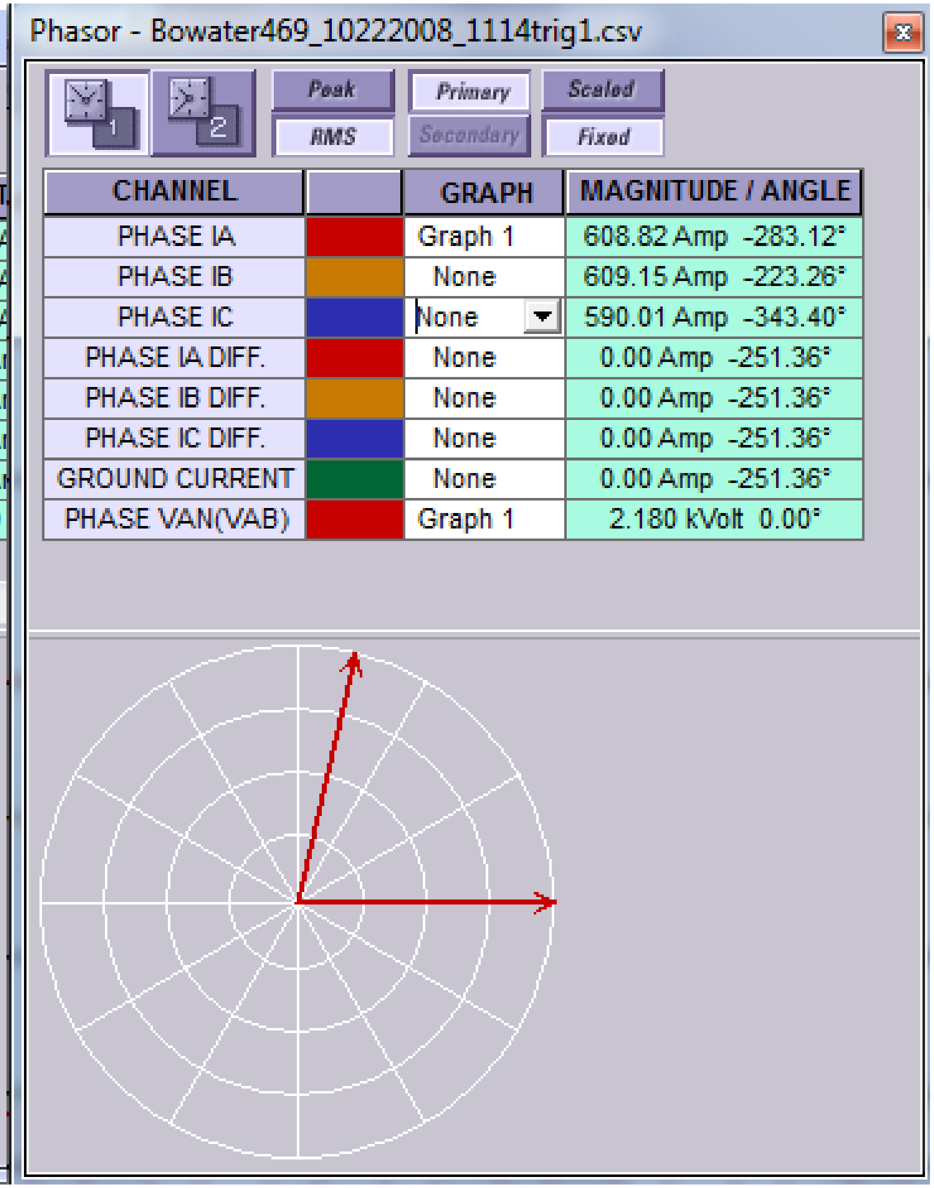


NEMA **Multilin**

Motor Derating Curves

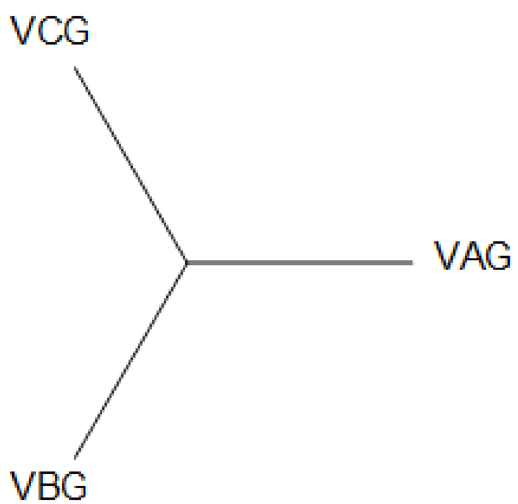
Is the reversed phase the only error here?



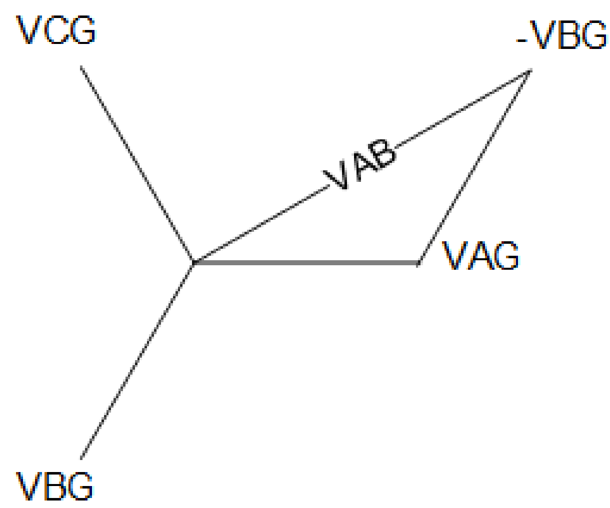


imagination at

VAB voltage relative to VAG



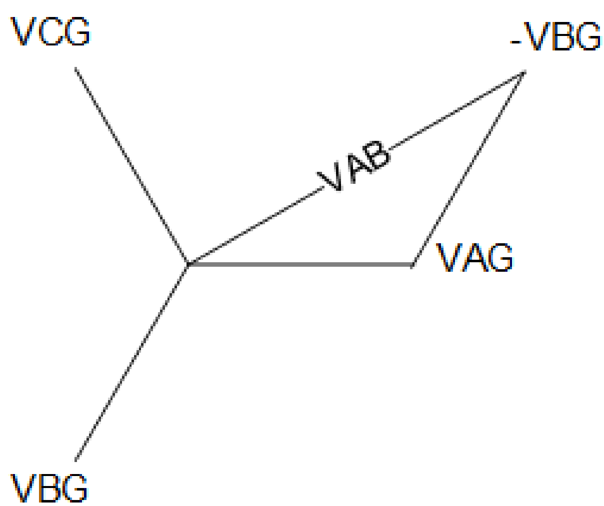
For an ABC rotation, VAG lags VAB by 30 degrees

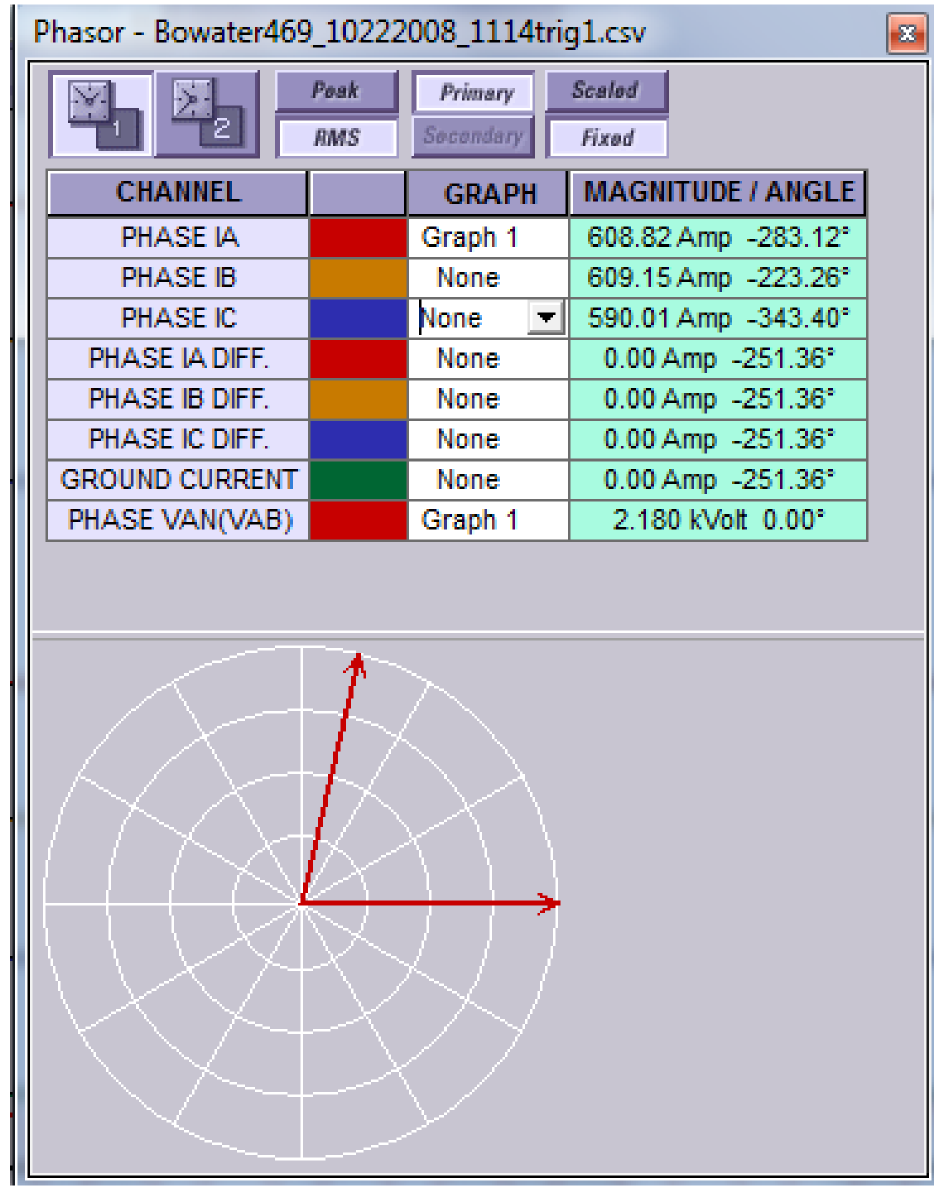


imagination at work

Is the reversed phase the only error here?

For an ABC rotation, VAG lags VAB by 30 degrees



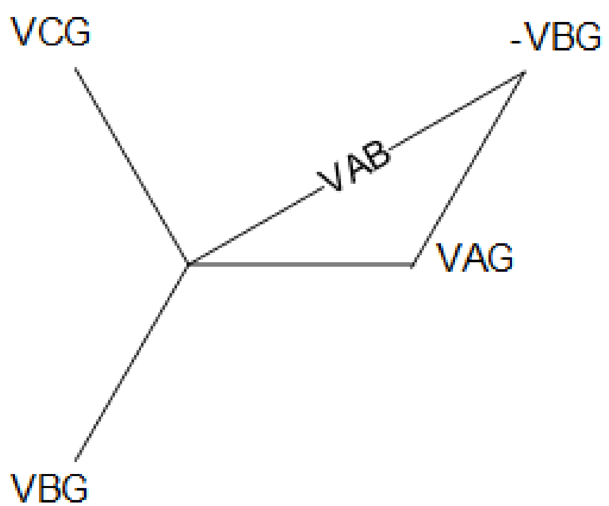


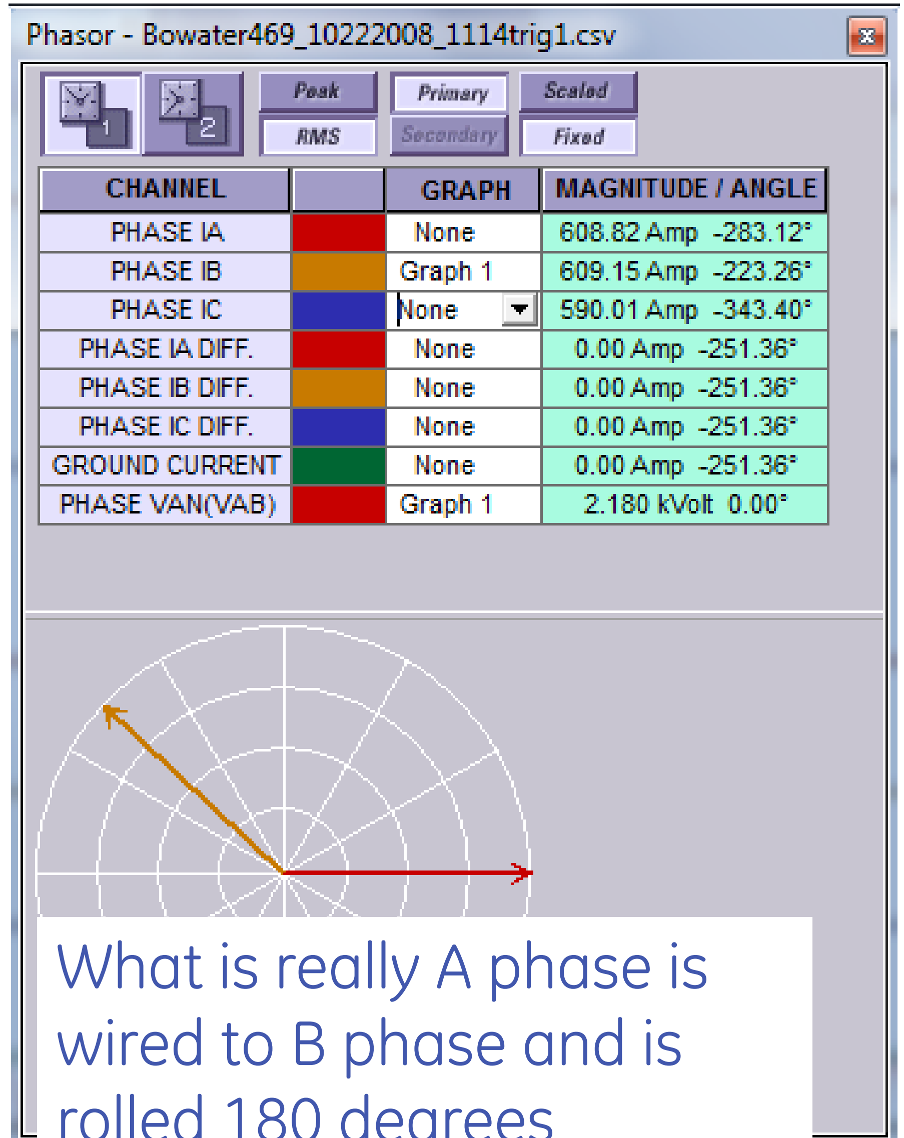
CHANNEL		GRAPH	MAGNITUDE / ANGLE
PHASE IA		Graph 1	608.82 Amp -283.12°
PHASE IB		None	609.15 Amp -223.26°
PHASE IC		None	590.01 Amp -343.40°
PHASE IA DIFF.		None	0.00 Amp -251.36°
PHASE IB DIFF.		None	0.00 Amp -251.36°
PHASE IC DIFF.		None	0.00 Amp -251.36°
GROUND CURRENT		None	0.00 Amp -251.36°
PHASE VAN(VAB)		Graph 1	2.180 kVolt 0.00°

imagination at work

How to fix

For an ABC rotation, VAG lags VAB by 30 degrees





CHANNEL		GRAPH	MAGNITUDE / ANGLE
PHASE IA		None	608.82 Amp -283.12°
PHASE IB		Graph 1	609.15 Amp -223.26°
PHASE IC		None	590.01 Amp -343.40°
PHASE IA DIFF.		None	0.00 Amp -251.36°
PHASE IB DIFF.		None	0.00 Amp -251.36°
PHASE IC DIFF.		None	0.00 Amp -251.36°
GROUND CURRENT		None	0.00 Amp -251.36°
PHASE VAN(VAB)		Graph 1	2.180 kVolt 0.00°

What is really A phase is wired to B phase and is rolled 180 degrees

imagination at work

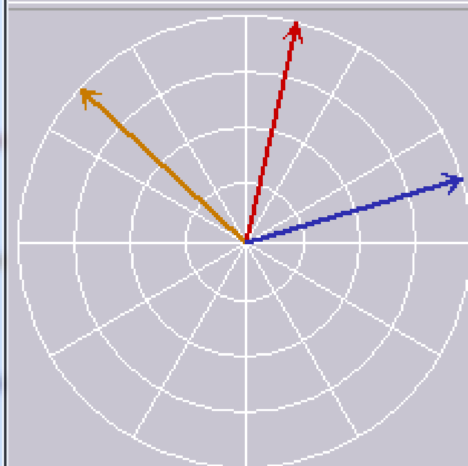
How to fix

- Move wire from B to A and roll 180 degrees
- Move wire from C to B and roll 180 degrees
- Move wire from A to C and don't roll.

Phasor - Bowater469_10222008_1114trig1.csv

Peak | RMS | Primary | Secondary | Scaled | Fixed

CHANNEL		GRAPH	MAGNITUDE / ANGLE
PHASE IA		Graph 1	608.82 Amp -283.12°
PHASE IB		Graph 1	609.15 Amp -223.26°
PHASE IC		Graph 1	590.01 Amp -343.40°
PHASE IA DIFF.		None	0.00 Amp -251.36°
PHASE IB DIFF.		None	0.00 Amp -251.36°
PHASE IC DIFF.		None	0.00 Amp -251.36°
GROUND CURRENT		None	0.00 Amp -251.36°
PHASE VAN(VAB)		None	2.180 kVolt 0.00°



imagination at work

Lessons Learned

- This relay had a rolled phase, but also a lot of other issues
- During start up, verify metered values
  - Negative sequence voltage and current should be small relative to positive sequence quantities
  - Power factor should be as expected 80-90% lagging for induction machines and loads.
  - Phase relationships should be as expected (across transformers)

imagination at work

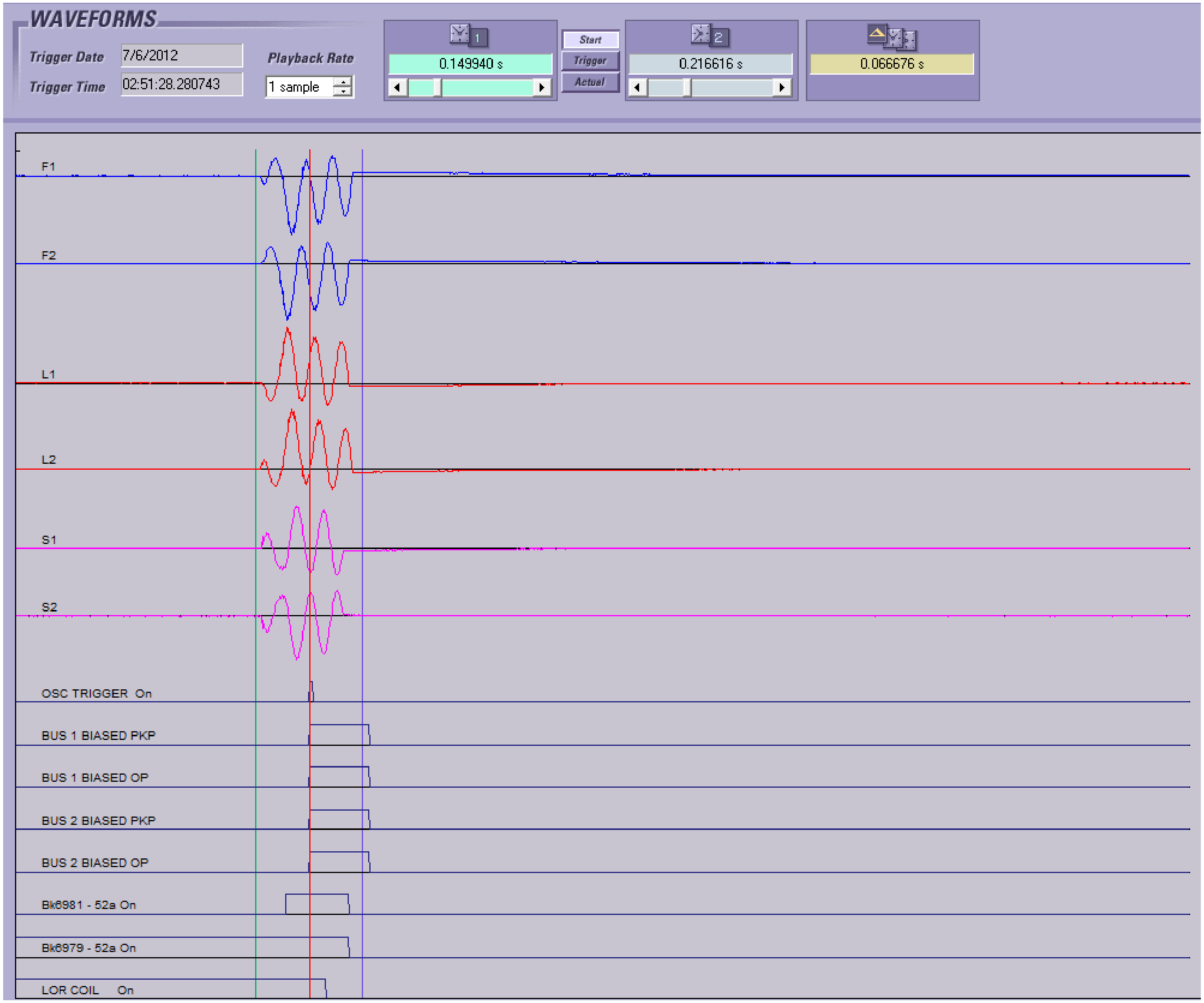
Low Impedance Bus Differential Trip When the Second Breaker is Closed on the Bus

imagination at work

The Story

- We are installing a bus differential
- When we pick up load, we trip

imagination at work



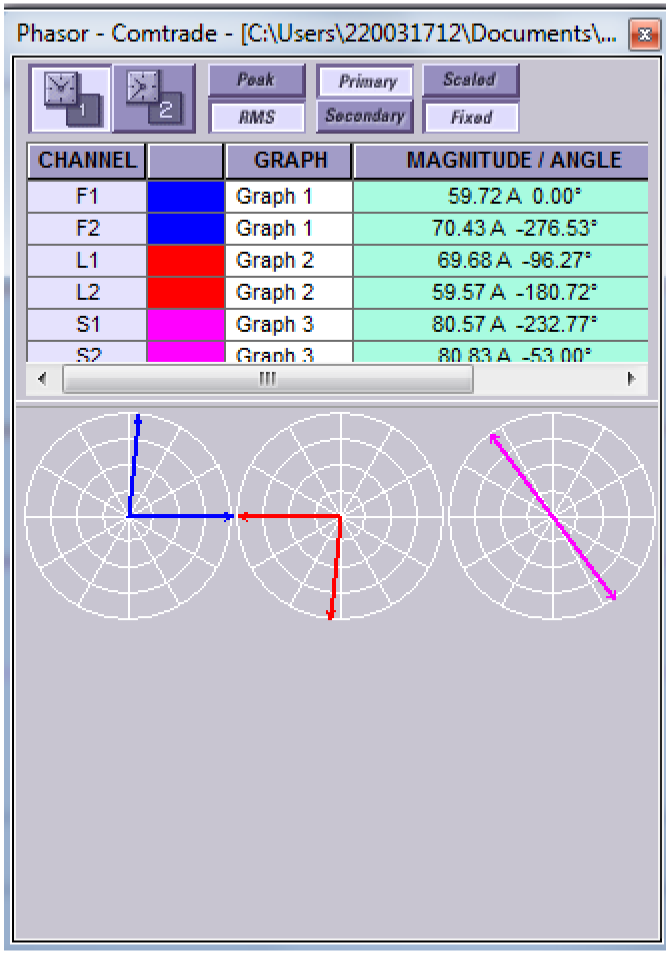
imagination at work

87B Bus Differential Configuration

Save | Restore | Default | Reset | VIEW ALL mode

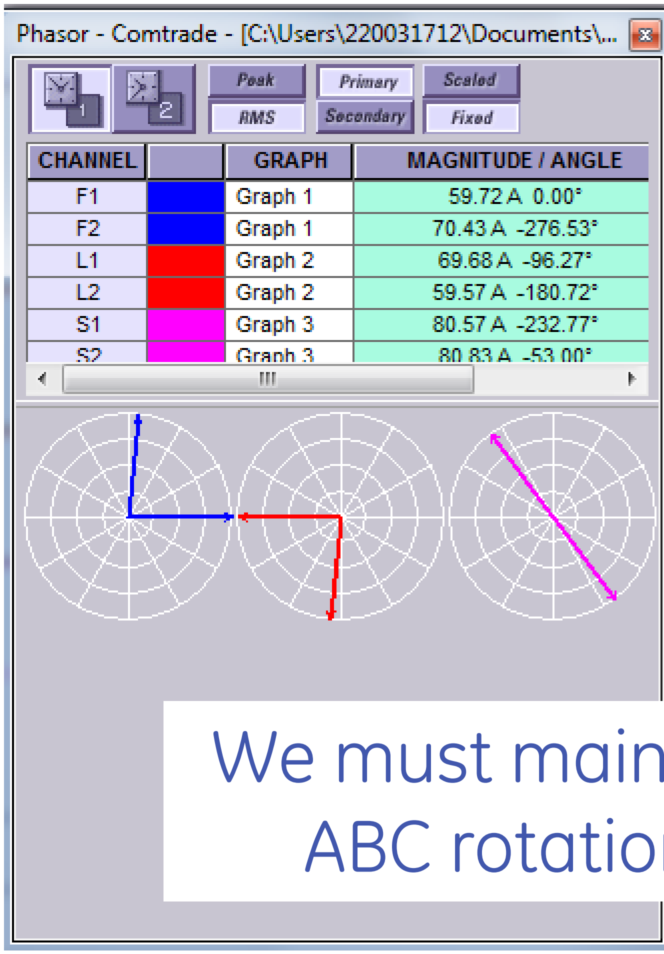
PARAMETER	BUS ZONE 1	BUS ZONE 2	BUS ZONE 3
Bus Zone CT A	F1	L1	S1
Bus Zone Direction A	IN	IN	IN
Bus Zone Status A	ON	ON	ON
Bus Zone CT B	F2	L2	S2
Bus Zone Direction B	IN	IN	IN
Bus Zone Status B	ON	ON	ON
Bus Zone CT C	F3	L3	S3
Bus Zone Direction C	IN	IN	IN
Bus Zone Status C	ON	ON	ON
Bus Zone CT D	F4	L4	S4
Bus Zone Direction D	IN	IN	IN
Bus Zone Status D	OFF	OFF	OFF
Bus Zone CT E	F5	L5	S5
Bus Zone Direction E	IN	IN	IN
Bus Zone Status E	OFF	OFF	OFF
Bus Zone CT F	F6	L6	S6
Bus Zone Direction F	IN	IN	IN
Bus Zone Status F	OFF	OFF	OFF
Bus Zone CT G	F7	L7	S7
Bus Zone Direction G	IN	IN	IN
Bus Zone Status G	OFF	OFF	OFF
Bus Zone CT H	F8	L8	S8
Bus Zone Direction H	IN	IN	IN
Bus Zone Status H	OFF	OFF	OFF

Let's look at the phasors

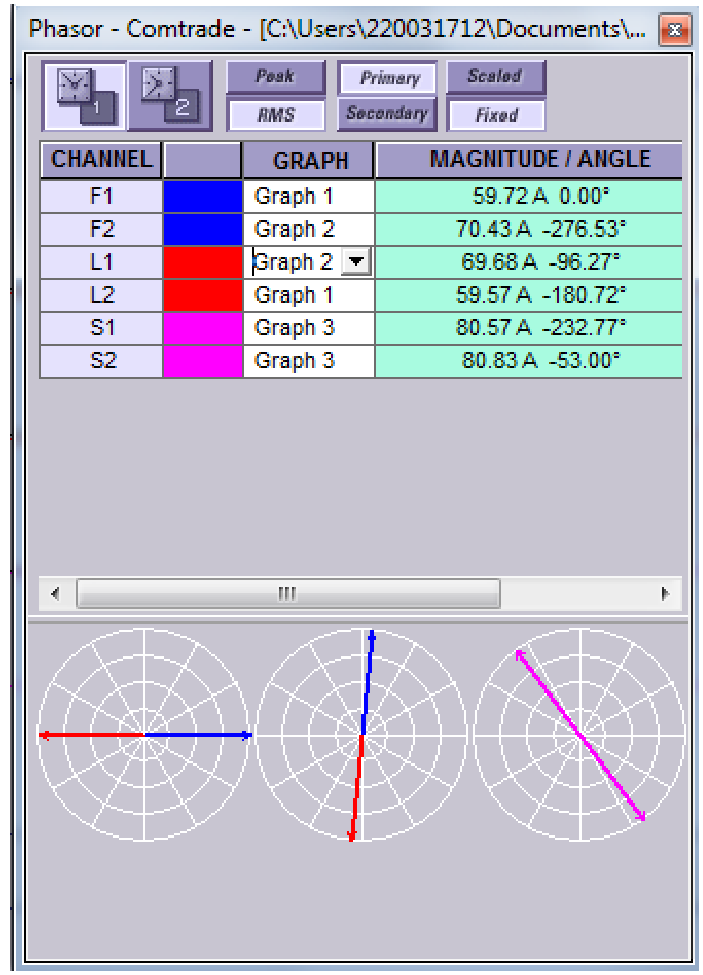


How do we fix this monstrosity?

Corrective action required



We must maintain ABC rotation



imagination at work

Paralleling Switchgear Trip

imagination at work

The Story

- This relay trips every time I close the breaker
- It is tripping on Overcurrent.
- You need to send me a new relay because this one is obviously bad.

imagination at work

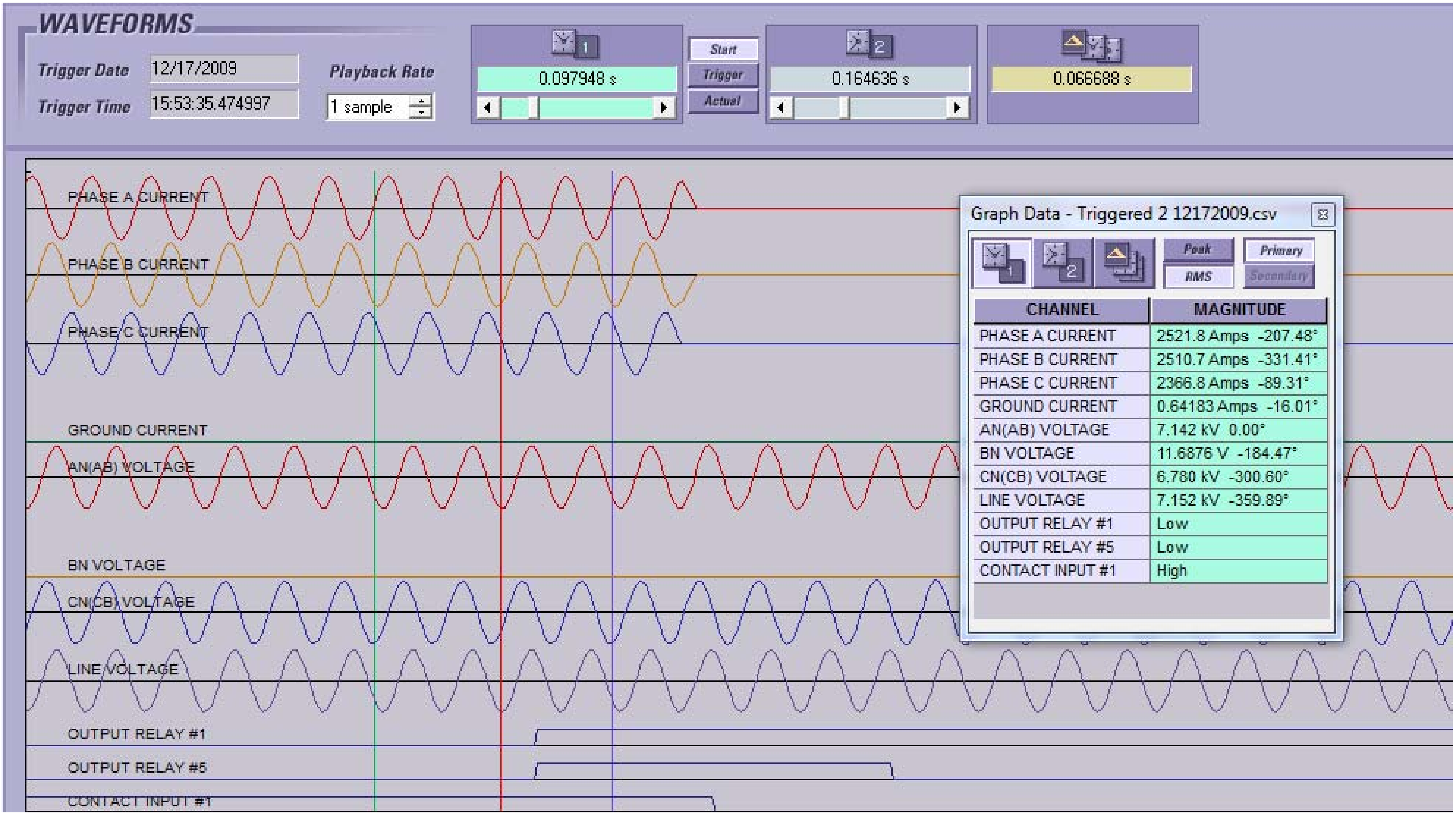
Events

Event	Date	Time	Cause of Event
19	12/17/2009	15:53:35.475	Trigger Data Logger
18	12/17/2009	15:53:35.475	Trigger Trace Memory
17	12/17/2009	15:53:35.475	Trip: Phase ABC - Phase Time OC 1
14	12/10/2009	17:53:30.495	Trigger Data Logger
13	12/10/2009	17:53:30.494	Trigger Trace Memory
12	12/10/2009	17:53:30.494	Trip: Phase ABC - Phase Time OC 1

Select Events 17

Event Parameter	Value
Date of Event	12/17/2009
Time of Event	15:53:35.475
Cause of Event	Trip: Phase ABC - Phase Time OC 1
Phase A Current Magnitude(A)	2470 Amp
Phase A Current Angle(Lag)	209 ° Lag
Phase B Current Magnitude(A)	2520 Amp
Phase B Current Angle(Lag)	330 ° Lag
Phase C Current Magnitude(A)	2456 Amp
Phase C Current Angle(Lag)	91 ° Lag
Ground Current Magnitude(A)	0 Amp
Ground Current Angle(Lag)	0 ° Lag
A-N (A-B) Voltage Magnitude(kV)	6.98 kV
A-N (A-B) Voltage Angle(Lag)	0 ° Lag
B-N (B-C) Voltage Magnitude(kV)	7.02 kV
B-N (B-C) Voltage Angle(Lag)	120 ° Lag

Waveforms

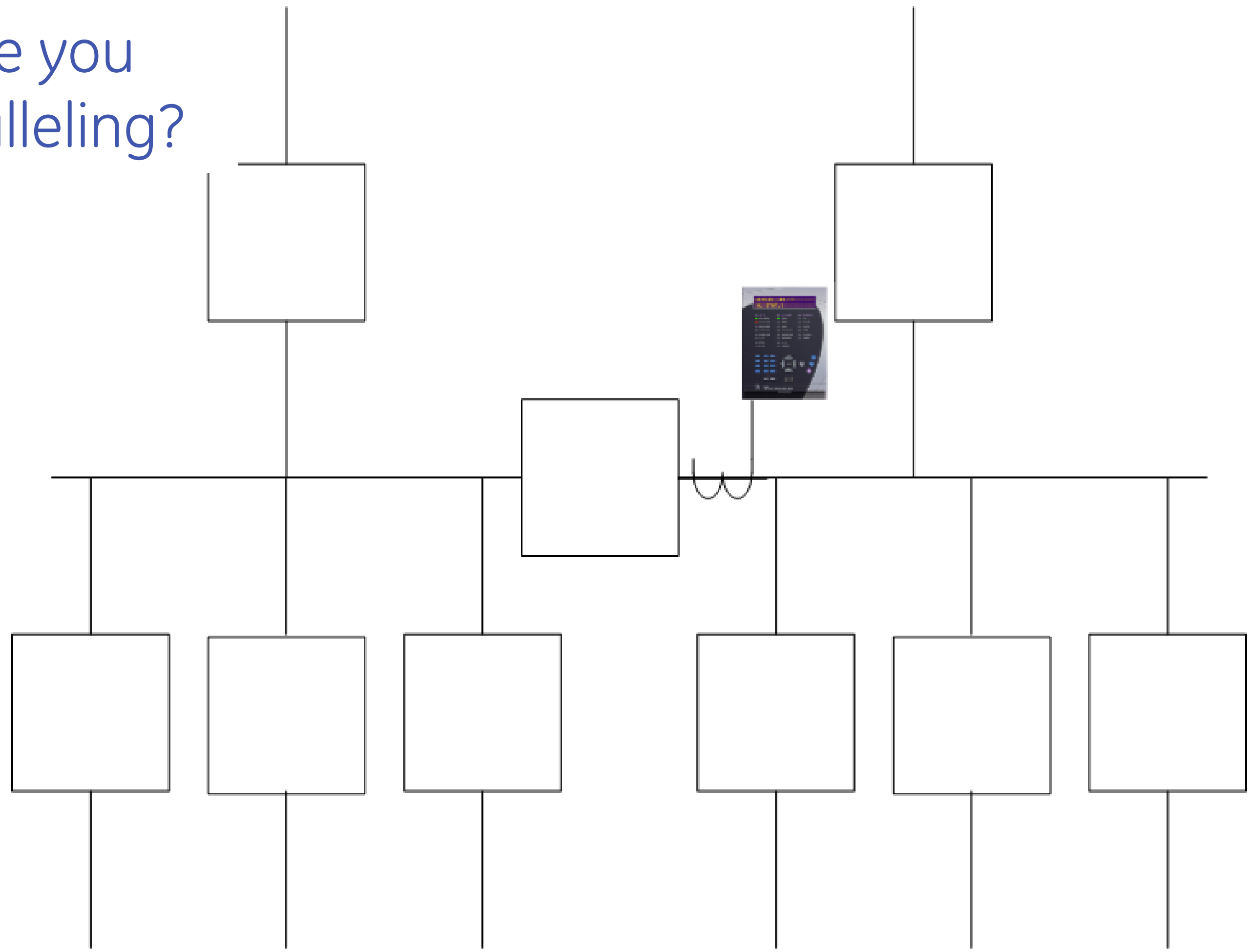

WAVEFORMS
Trigger Date
12/17/2009
Trigger Time
15:53:35.474997
Playback Rate
1 sample
0.097948 s
Start
Trigger
Actual
0.164636 s
0.066688 s
PHASE A CURRENT
PHASE B CURRENT
PHASE C CURRENT
GROUND CURRENT
AN(AB) VOLTAGE
BN VOLTAGE
CN(CB) VOLTAGE
LINE VOLTAGE
OUTPUT RELAY #1
OUTPUT RELAY #5
CONTACT INPUT #1
Graph Data - Triggered 2 12172009.csv
Peak
RMS
Primary
Secondary
CHANNEL
MAGNITUDE
PHASE A CURRENT
2521.8 Amps -207.48°
PHASE B CURRENT
2510.7 Amps -331.41°
PHASE C CURRENT
2366.8 Amps -89.31°
GROUND CURRENT
0.64183 Amps -16.01°
AN(AB) VOLTAGE
7.142 kV 0.00°
BN VOLTAGE
11.6876 V -184.47°
CN(CB) VOLTAGE
6.780 kV -300.60°
LINE VOLTAGE
7.152 kV -359.89°
OUTPUT RELAY #1
Low
OUTPUT RELAY #5
Low
CONTACT INPUT #1
High

How Microprocessor Relays Fail

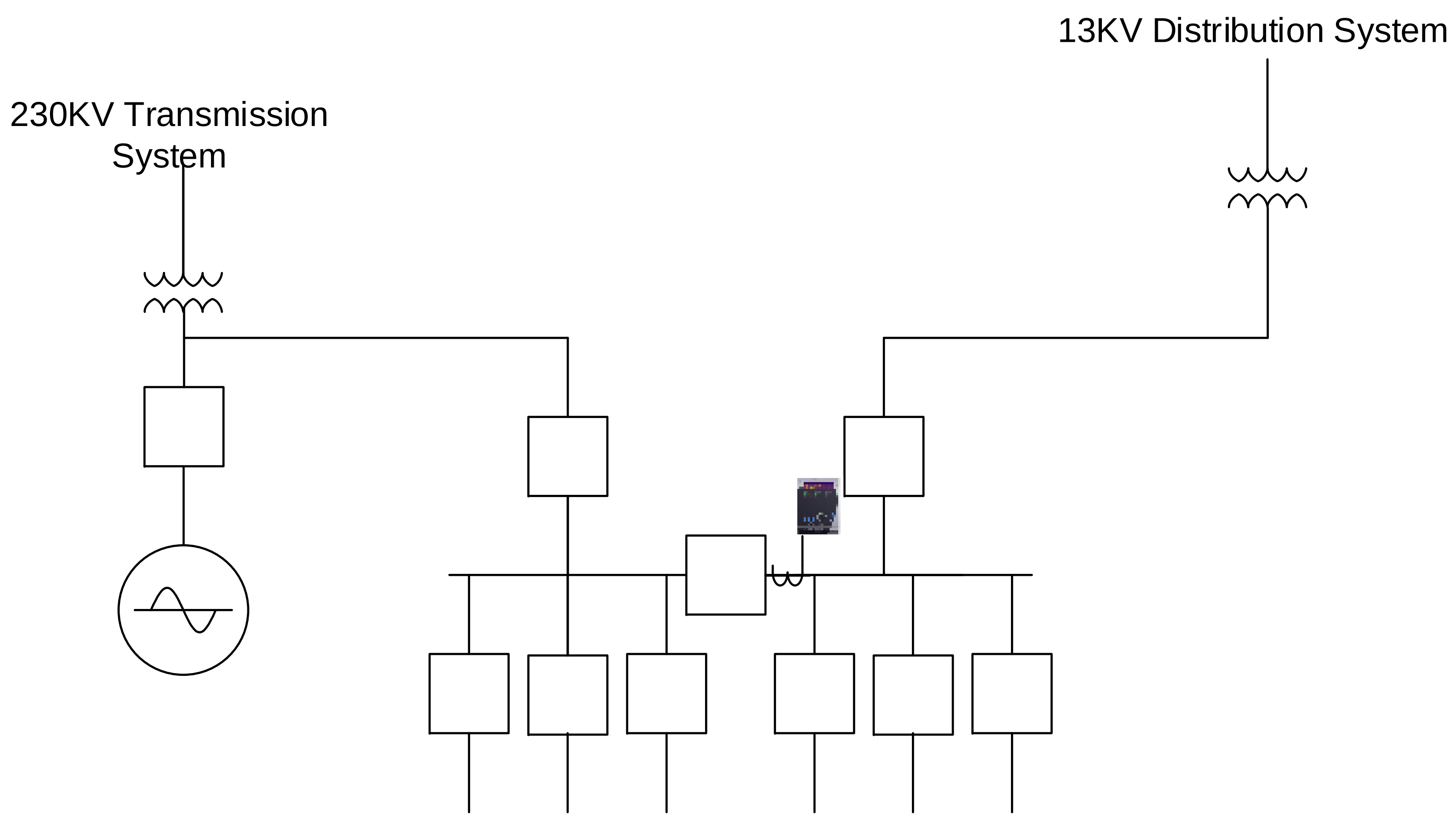
- Power Supplies – Failures there most likely mean the relay is dead with no lights.
- Processor failures – Failures there cause an alarm which takes the relay out of service and illuminates an alarm LED.
- DSP failures – Failures there are rare, would typically raise an alarm and would show distorted metering values.
- Safe to say, this relay has NO problems, it is doing what it is suppose to do.

Where is this relay and when is it tripping?

So what are you actually paralleling?

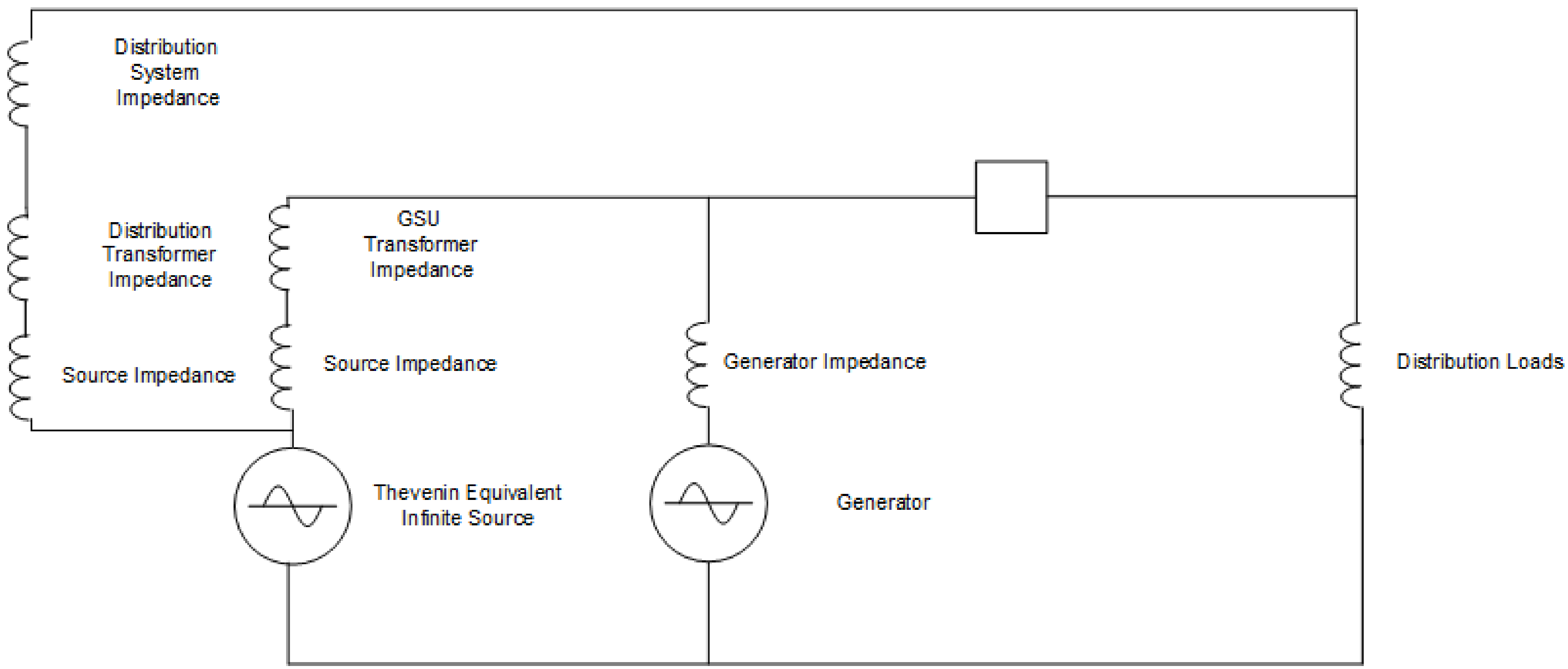


So what are you actually paralleling?



imagination at work

Equivalent Circuit



Since Parallel:

$Z_{dist}I_{dist}=Z_{tran}I_{tran}$

$Z_{dist}/Z_{tran}=I_{tran}/I_{dist}$

If $Z_{dist}>>Z_{tran}$

Then $I_{tran}>>I_{dist}$

imagination at work

Possible Solutions

- Can't really raise the TOC pickup setting on the tie breaker 750 and can't really make the time delay longer
- Could add controls to trip a selected breaker after all three are closed.
- Never parallel these two sources. Add mechanical interlocks to prevent parallel of all three sources.

imagination at work

Synchronous Motor Trip on Power Factor

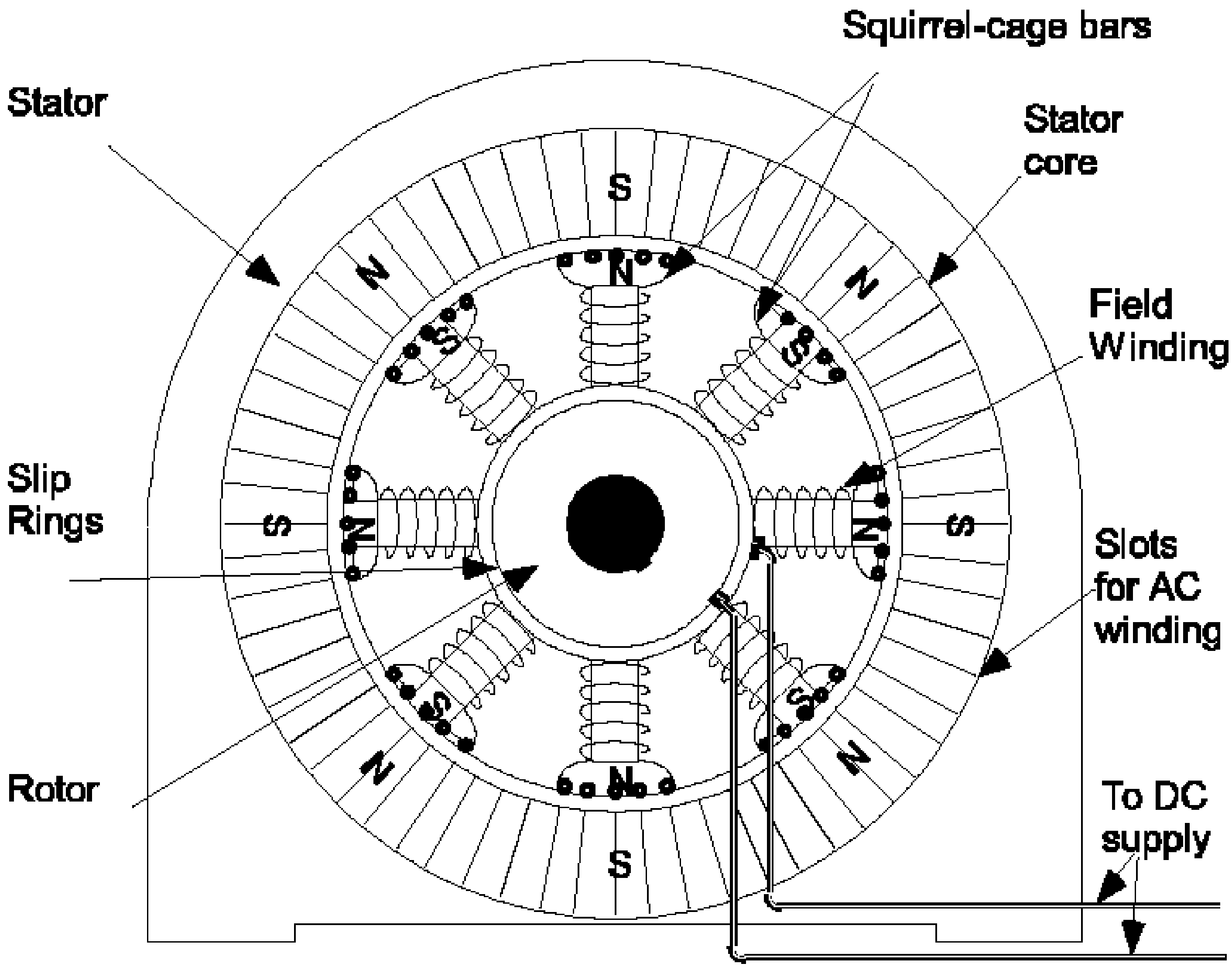
imagination at work

The Story

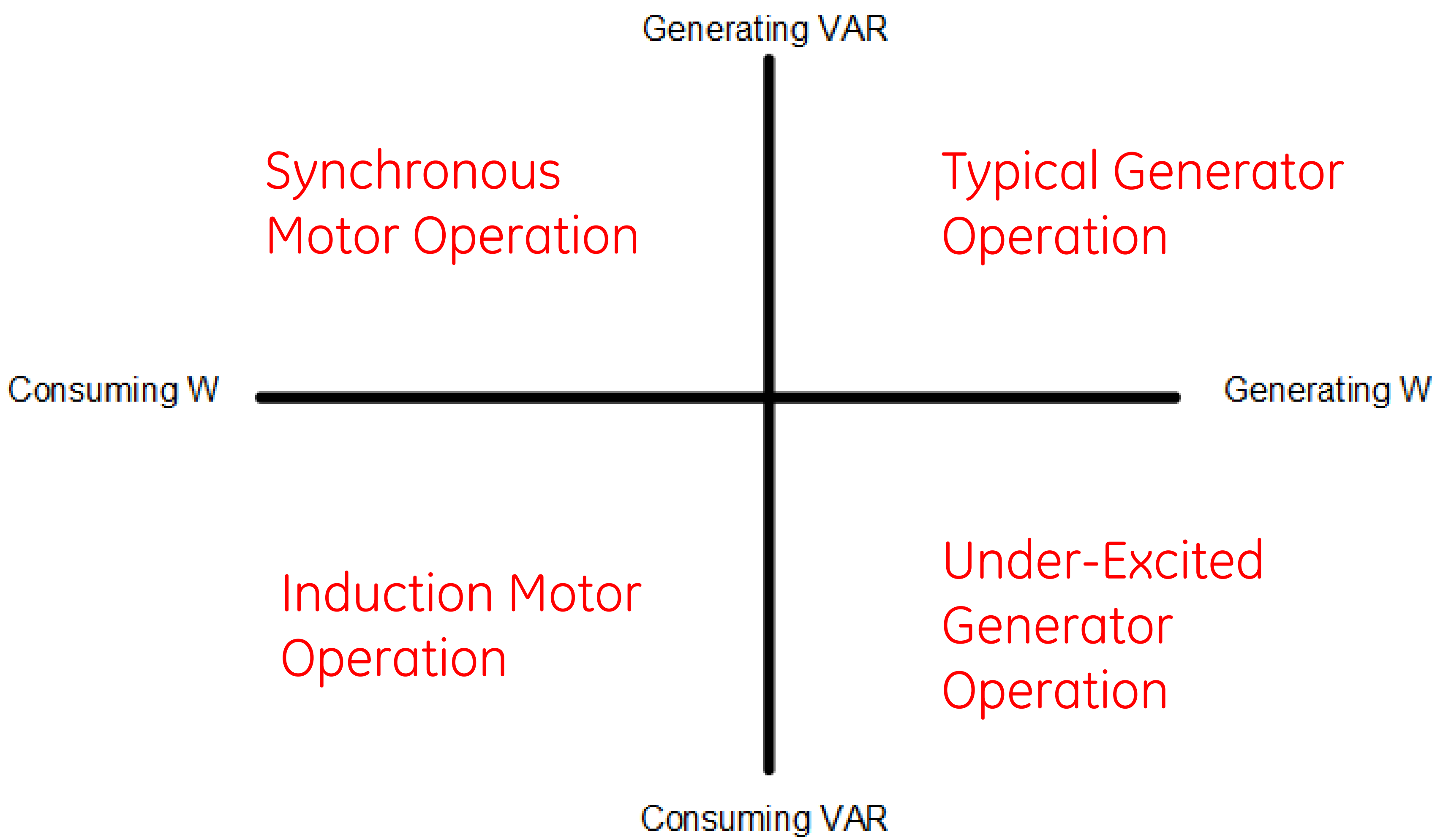
- Synchronous motor is tripping on power factor pull-out
- Four of these compressors at the facility and is only happening to this compressor
- Started happening after we had the motor rebuilt.

imagination at work

Synchronous Motor Theory



Machine Excitation

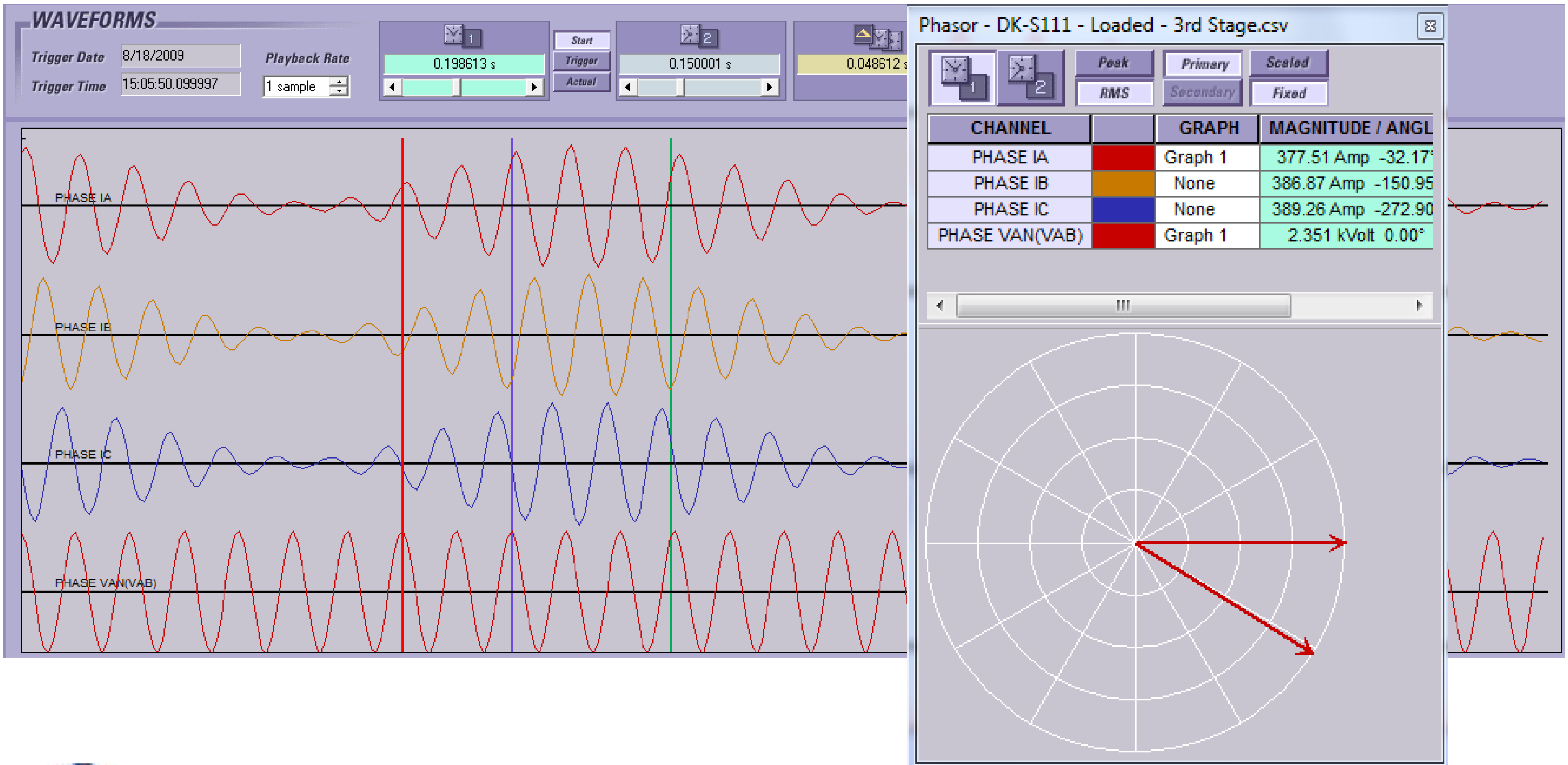


Synchronous Machines

- In an induction motor, the more load you have, the larger your slip.
- In a synchronous motor, slip=0. The more load you have (without increasing excitation) the greater your (negative) power factor.
- To prevent slipping a pole (pull-out protection) you use power factor protection to trip when your load changes beyond what your exciter can keep up with.

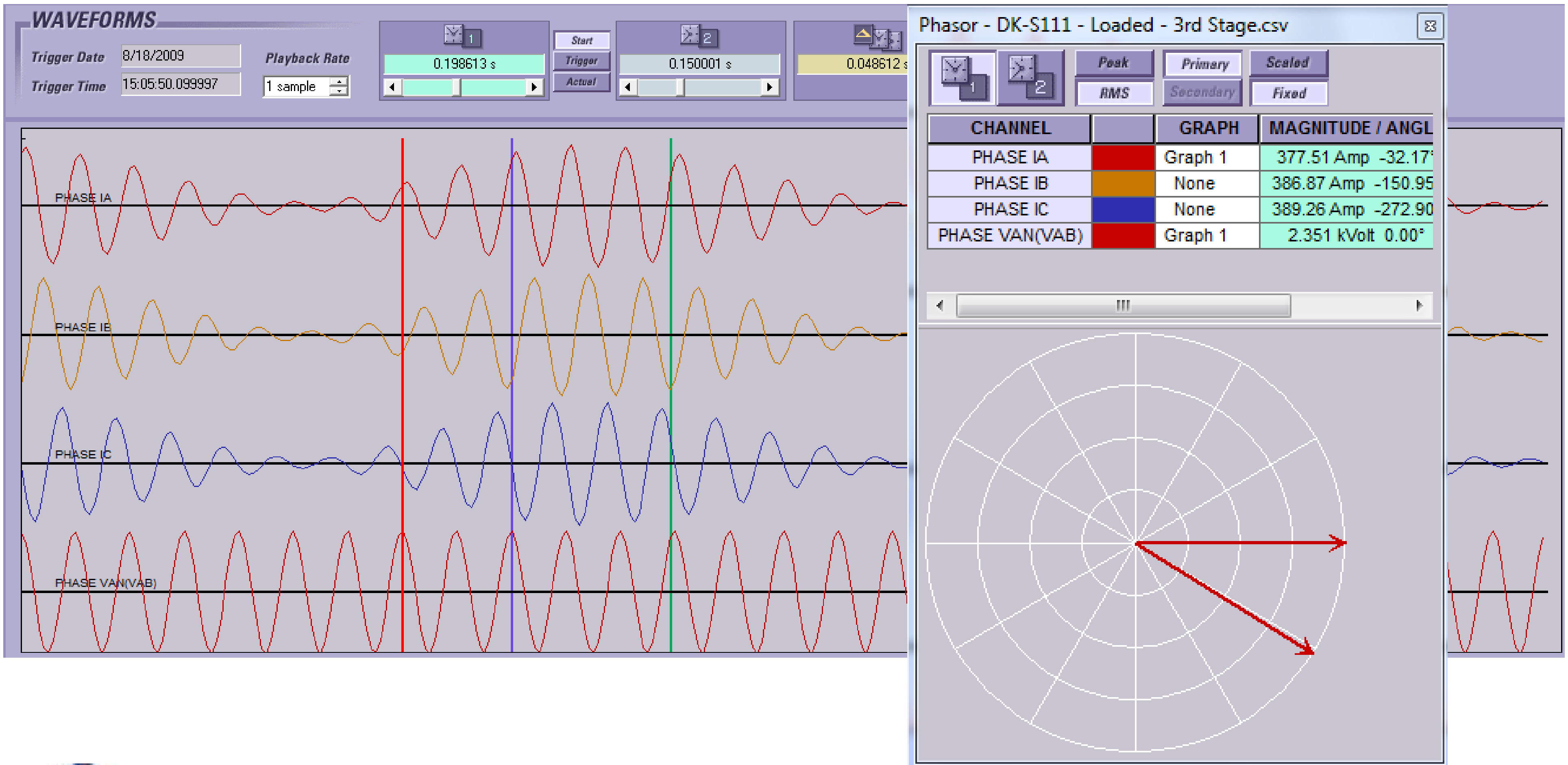
imagination at work

Reciprocal Compressors



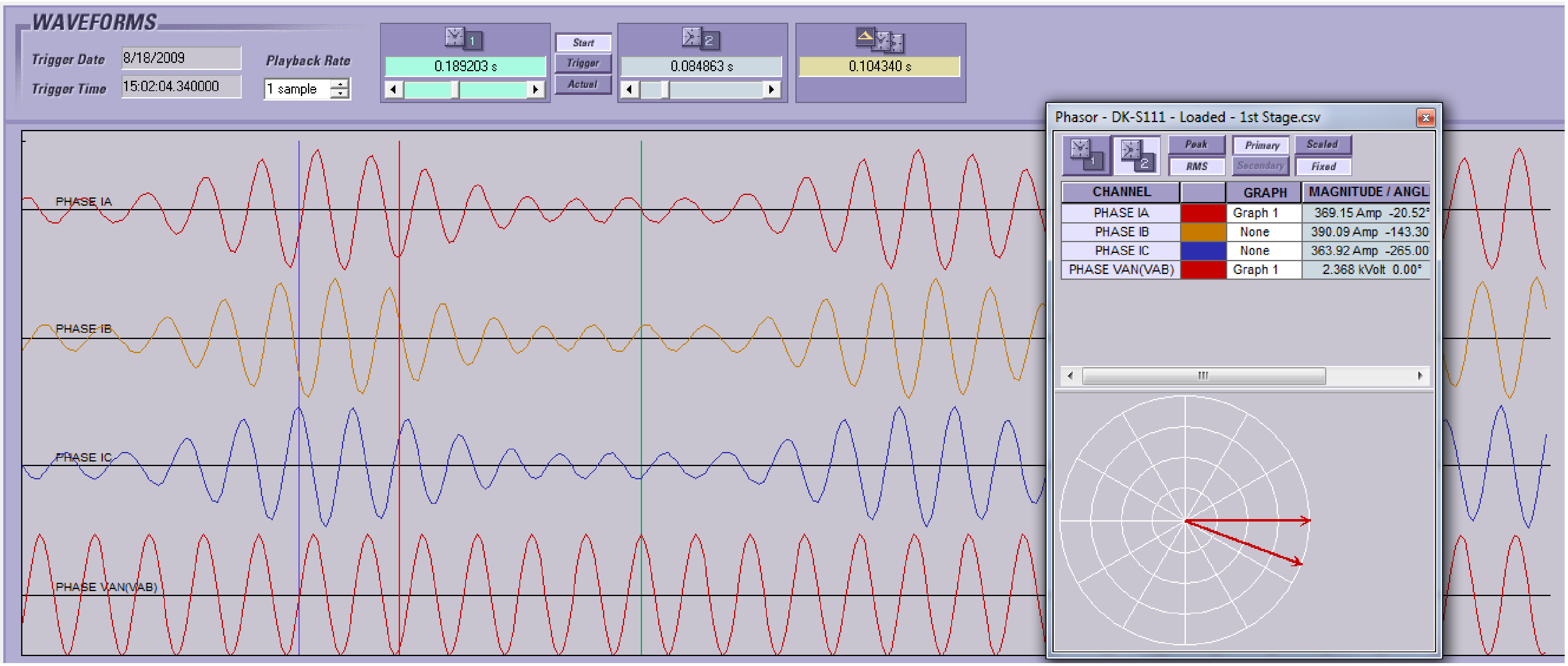
imagination at work

Reciprocal Compressors

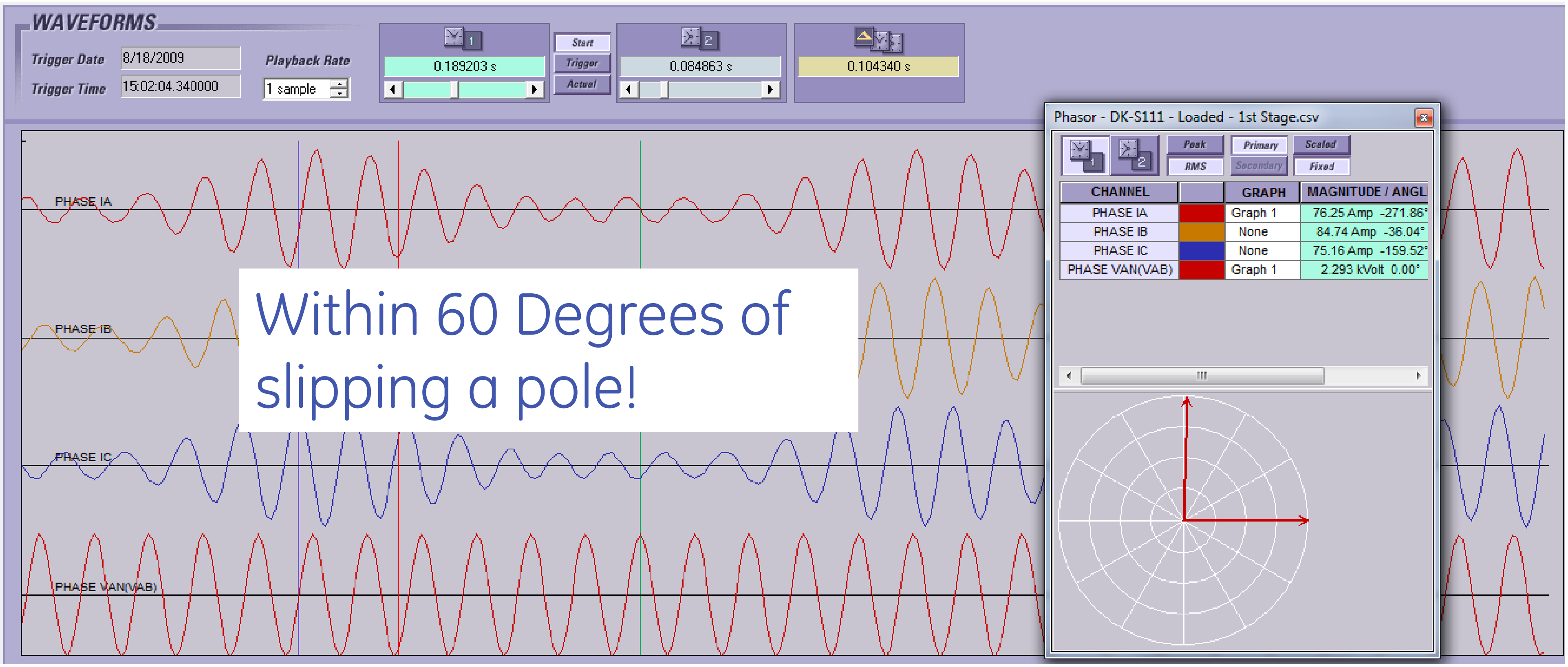


imagination at work

The Problem Compressor – Loaded Cycle



The Problem Compressor – Un-Loaded Cycle



Within 60 Degrees of slipping a pole!

imagination at work

Problem

- This cannot be fixed with relay settings.
- Must talk to motor manufacture about why this compressor behaves this way.
- A mechanical problem was causing the issue.

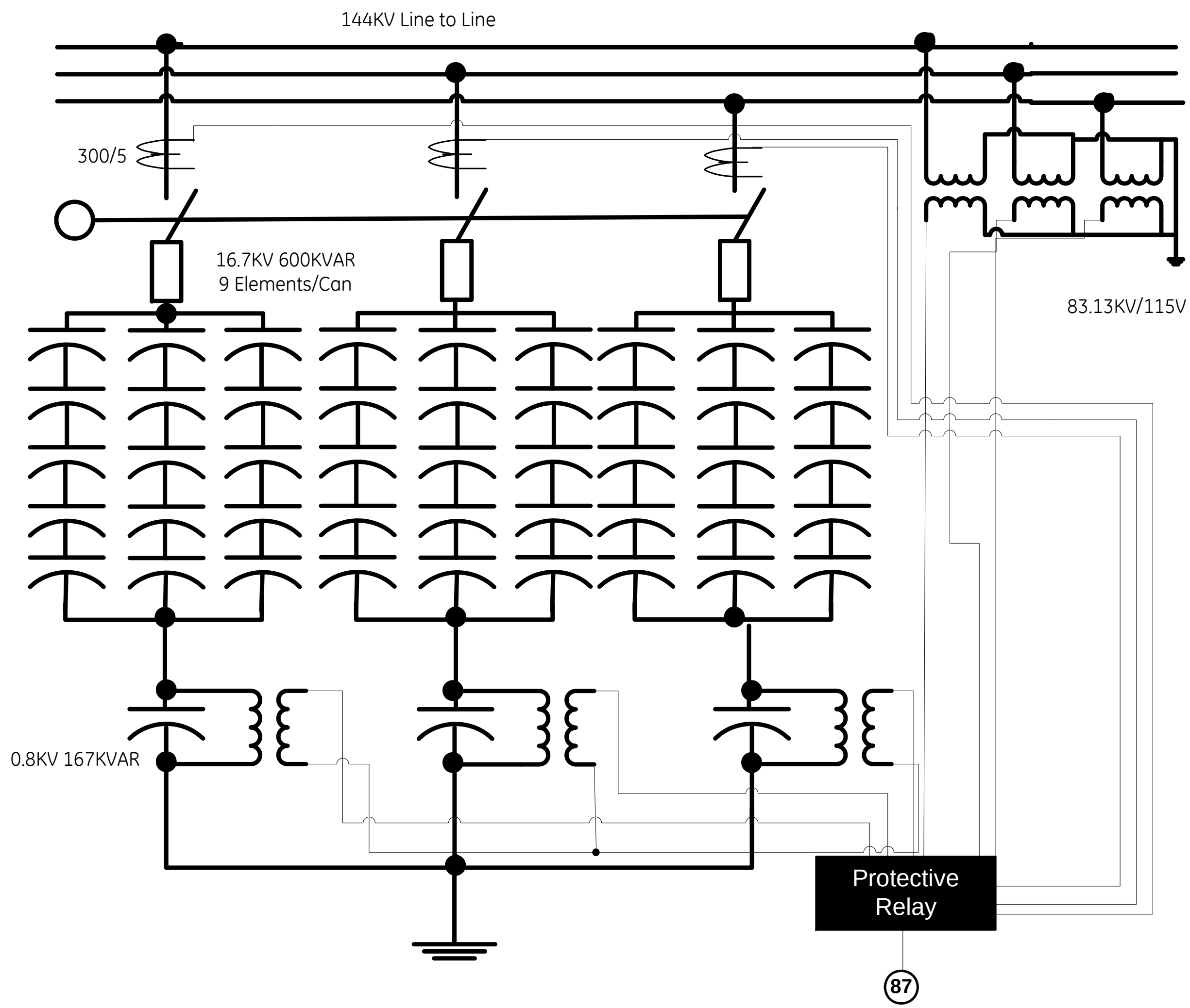
Substation heat pumps drops bus voltage by 1kV causes capacitor bank trip

The Story

- This relay is tripping on B phase voltage differential.
- Two relays in the station and they are both tripping on B phase voltage differential.
- The redundant relays are not tripping.

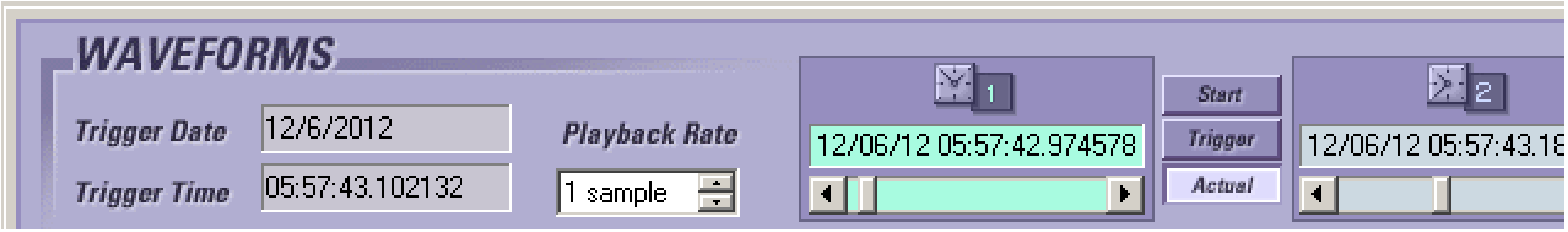
imagination at work

Six Capacitor Banks – 2 Relays

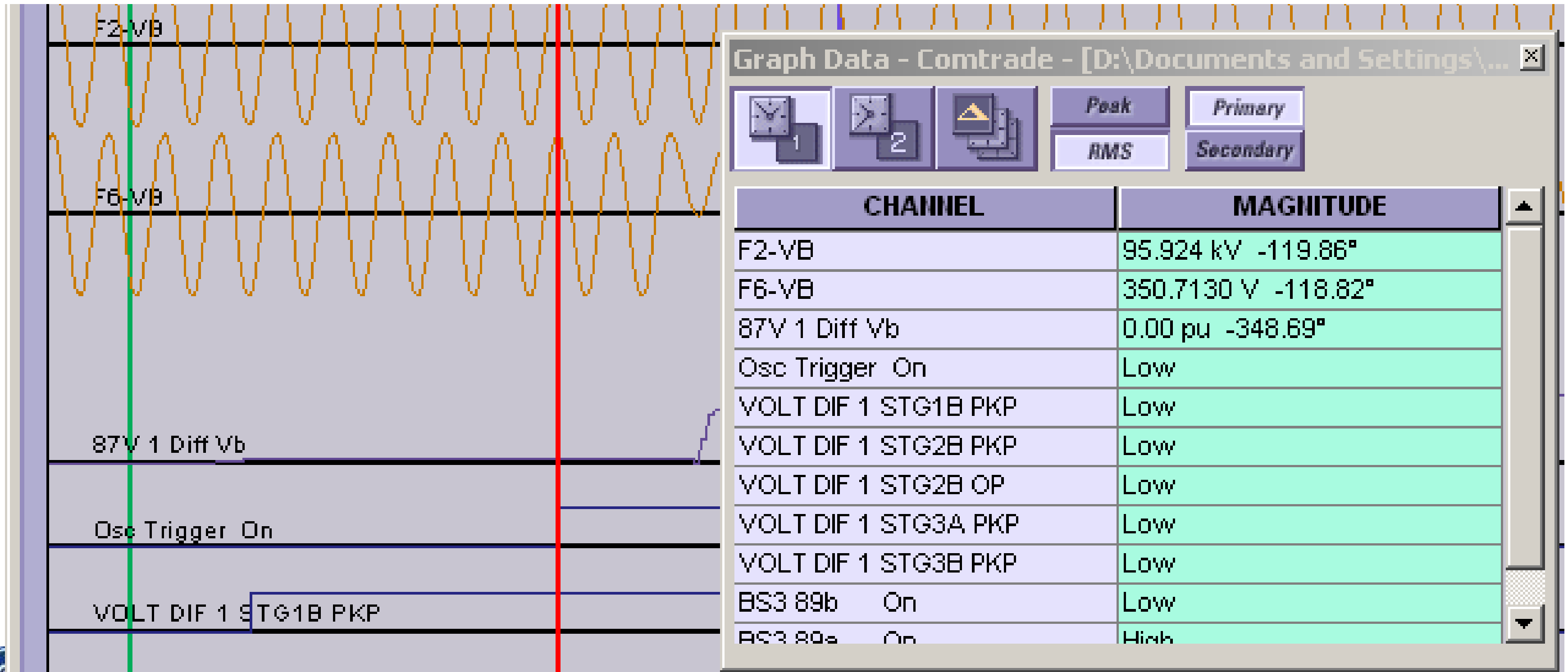


imagination at work

Pre-Fault Values of the Trip



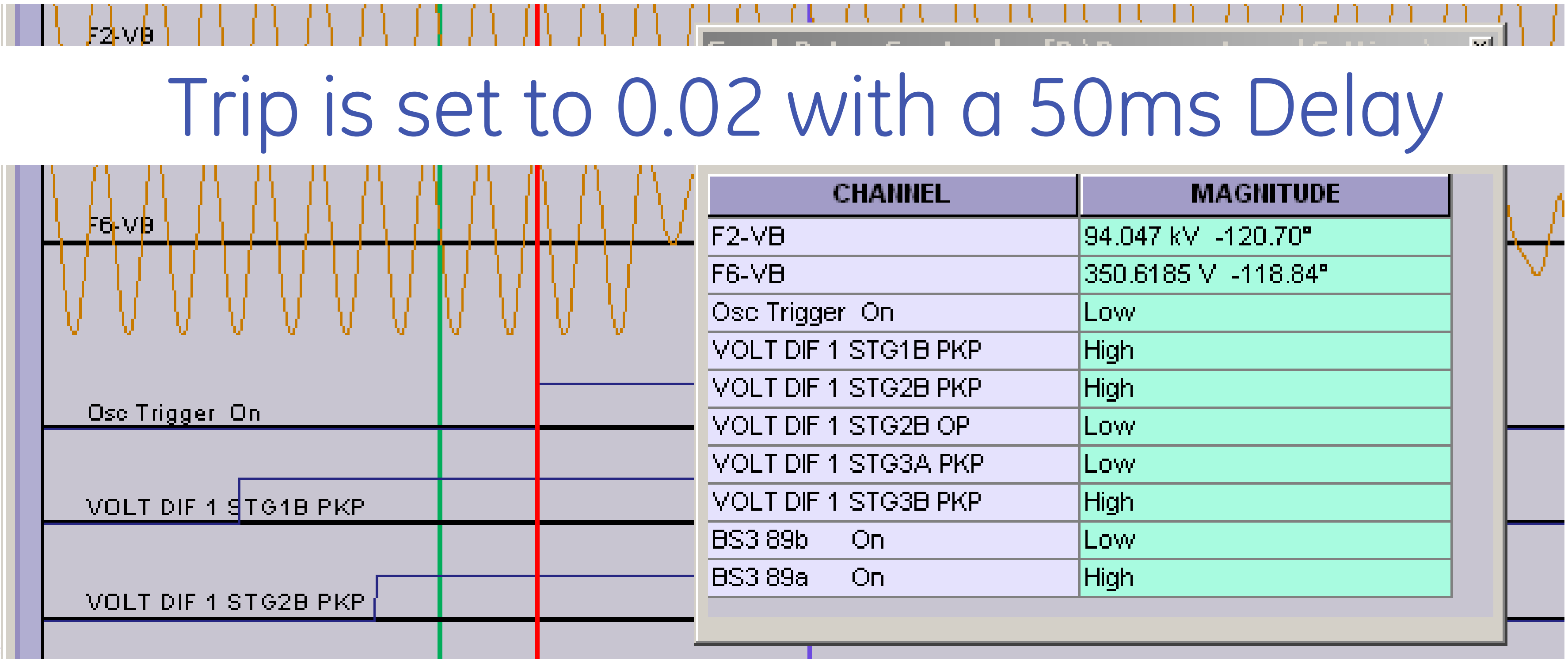
95,924-274(350.7130)=171=0.002pu



Fault Values of the Trip

94047-274(350.6185)=2022=0.022

Trip is set to 0.02 with a 50ms Delay



CHANNEL	MAGNITUDE
F2-VB	94.047 kV -120.70°
F6-VB	350.6185 V -118.84°
Osc Trigger On	Low
VOLT DIF 1 STG1B PKP	High
VOLT DIF 1 STG2B PKP	High
VOLT DIF 1 STG2B OP	Low
VOLT DIF 1 STG3A PKP	Low
VOLT DIF 1 STG3B PKP	High
BS3 89b On	Low
BS3 89a On	High

Event Records

0 days 0 h : 0 m : 0.243662 s

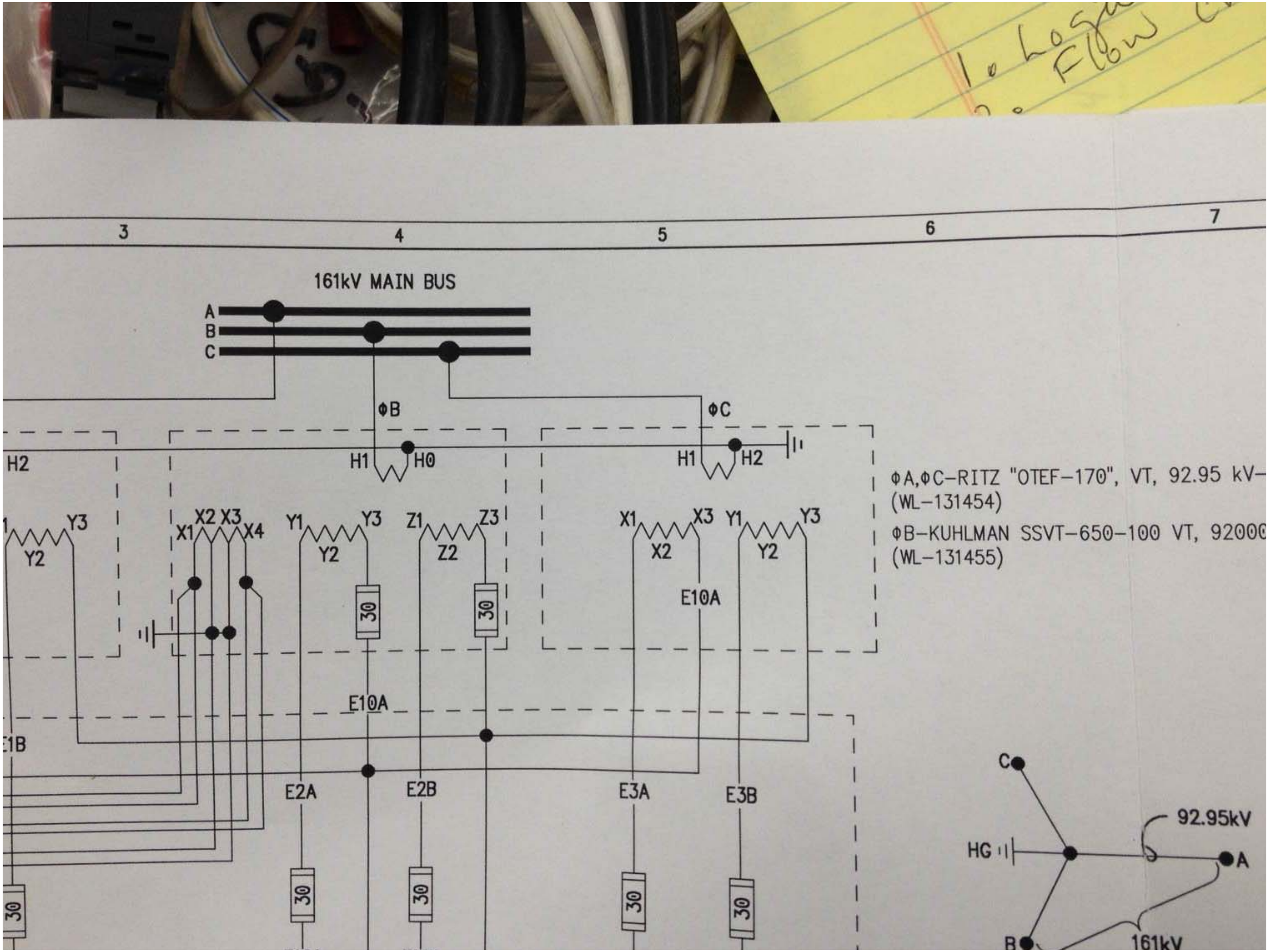
Event Number	Date/Time	Cause	Data
14869	Dec 06 2012 09:39:10.059863	VOLT DIF 1 STG1B PKP	
14868	Dec 06 2012 09:39:10.057780	VOLT DIF 1 STG3B PKP	
14867	Dec 06 2012 09:34:42.158641	VOLT DIF 1 DPO	
14866	Dec 06 2012 09:34:41.939957	VOLT DIF 1 STG1B PKP	
14865	Dec 06 2012 09:34:41.937874	VOLT DIF 1 STG3B PKP	
14864	Dec 06 2012 09:09:40.170983	VOLT DIF 1 DPO	
14863	Dec 06 2012 09:09:39.941888	VOLT DIF 1 STG1B PKP	
14862	Dec 06 2012 09:09:39.937723	VOLT DIF 1 STG3B PKP	
14861	Dec 06 2012 09:04:47.548600	VOLT DIF 1 DPO	
14860	Dec 06 2012 09:04:47.340254	VOLT DIF 1 STG1B PKP	
14859	Dec 06 2012 09:04:47.334000	VOLT DIF 1 STG3B PKP	
14858	Dec 06 2012 08:30:45.022783	VOLT DIF 1 DPO	
14857	Dec 06 2012 08:30:44.824911	VOLT DIF 1 STG1B PKP	
14856	Dec 06 2012 08:30:44.818661	VOLT DIF 1 STG3B PKP	
14855	Dec 06 2012 08:25:36.661146	VOLT DIF 1 DPO	
14854	Dec 06 2012 08:25:36.409093	VOLT DIF 1 STG1B PKP	
14853	Dec 06 2012 08:25:36.402841	VOLT DIF 1 STG3B PKP	
14852	Dec 06 2012 08:10:57.612625	VOLT DIF 1 DPO	
14851	Dec 06 2012 08:10:57.441826	VOLT DIF 1 STG1B PKP	
14850	Dec 06 2012 08:10:57.435578	VOLT DIF 1 STG3B PKP	
14849	Dec 06 2012 08:07:05.098656	VOLT DIF 1 DPO	
14848	Dec 06 2012 08:07:04.861241	VOLT DIF 1 STG1B PKP	
14847	Dec 06 2012 08:07:04.854994	VOLT DIF 1 STG3B PKP	
14846	Dec 06 2012 07:46:07.766480	VOLT DIF 1 DPO	
14845	Dec 06 2012 07:46:07.581104	VOLT DIF 1 STG1B PKP	
14844	Dec 06 2012 07:46:07.574854	VOLT DIF 1 STG3B PKP	
14843	Dec 06 2012 06:36:56.390804	VOLT DIF 1 DPO	
14842	Dec 06 2012 06:36:56.147116	VOLT DIF 1 STG1B PKP	
14841	Dec 06 2012 06:36:56.140867	VOLT DIF 1 STG3B PKP	
14840	Dec 06 2012 06:30:17.260222	VOLT DIF 1 DPO	
14839	Dec 06 2012 06:30:17.064404	VOLT DIF 1 STG1B PKP	
14838	Dec 06 2012 06:30:17.058150	VOLT DIF 1 STG3B PKP	

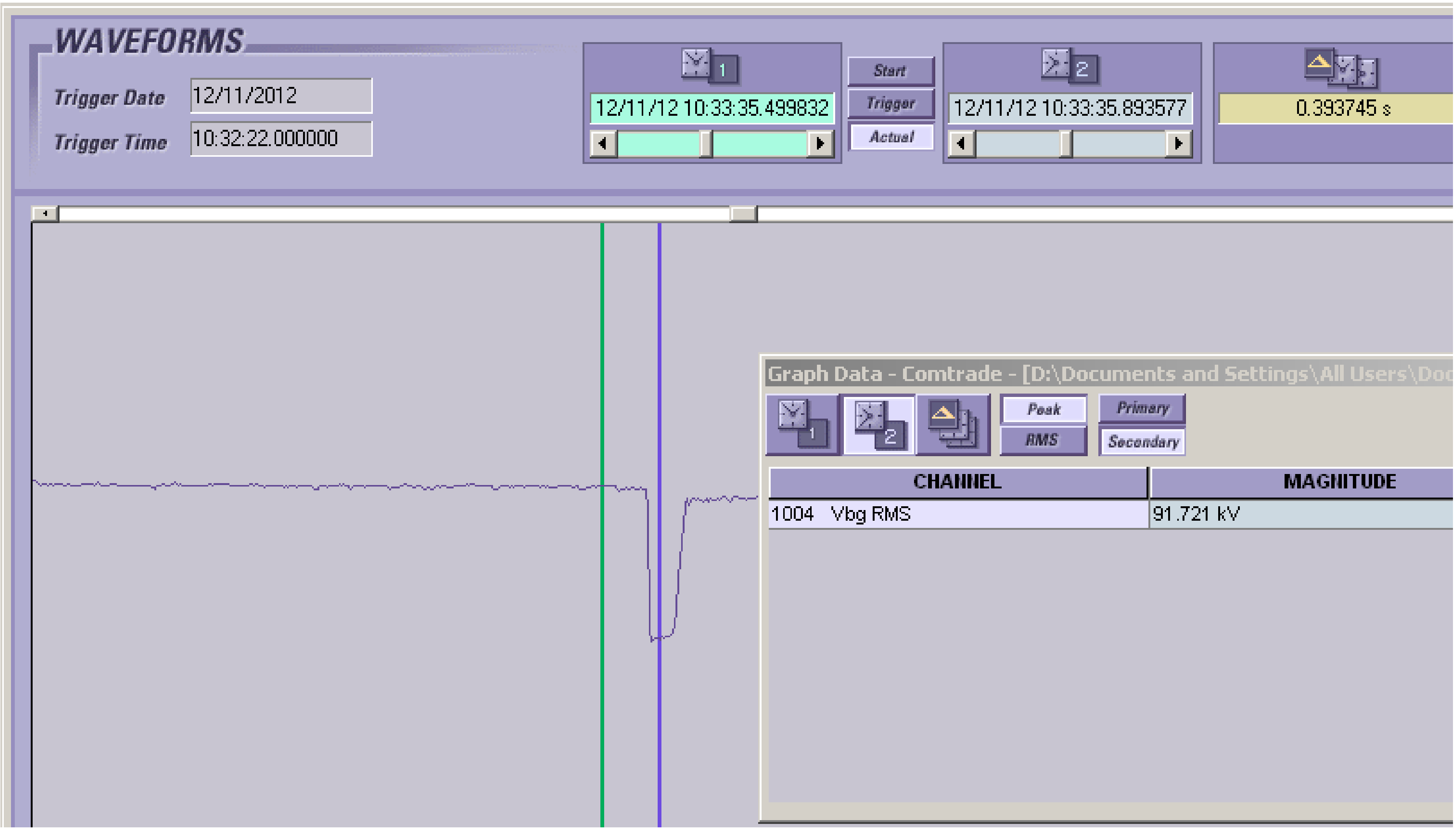
Event Records

14846	Dec 06 2012 07:46:07.766480	VOLT DIF 1 DPO	
14845	Dec 06 2012 07:46:07.581104	VOLT DIF 1 STG1B PKP	
14844	Dec 06 2012 07:46:07.574854	VOLT DIF 1 STG3B PKP	
14843	Dec 06 2012 06:36:56.390804	VOLT DIF 1 DPO	
14842	Dec 06 2012 06:36:56.147116	VOLT DIF 1 STG1B PKP	
14841	Dec 06 2012 06:36:56.140867	VOLT DIF 1 STG3B PKP	
14840	Dec 06 2012 06:30:17.260222	VOLT DIF 1 DPO	
14839	Dec 06 2012 06:30:17.064404	VOLT DIF 1 STG1B PKP	
14838	Dec 06 2012 06:30:17.058150	VOLT DIF 1 STG3B PKP	

407	Dec 06 2012 07:46:07.766474	VOLT DIF 1 DPO	
406	Dec 06 2012 07:46:07.581100	VOLT DIF 1 STG1B PKP	
405	Dec 06 2012 07:46:07.579020	VOLT DIF 1 STG3B PKP	
404	Dec 06 2012 06:36:56.386634	VOLT DIF 1 DPO	
403	Dec 06 2012 06:36:56.149212	VOLT DIF 1 STG1B PKP	
402	Dec 06 2012 06:36:56.142947	VOLT DIF 1 STG3B PKP	
401	Dec 06 2012 06:30:17.253968	VOLT DIF 1 DPO	
400	Dec 06 2012 06:30:17.070645	VOLT DIF 1 STG1B PKP	
399	Dec 06 2012 06:30:17.064396	VOLT DIF 1 STG3B PKP	

One of these things isn't like the others!


3
4
5
6
7
161kV MAIN BUS
A
B
C
ΦB
ΦC
H1
H0
H1
H2
H2
X1
X2
X3
X4
Y1
Y2
Y3
Z1
Z2
Z3
X1
X2
X3
Y1
Y2
Y3
30
E10A
E10A
E1B
E2A
E2B
E3A
E3B
ΦA,ΦC-RITZ "OTEF-170", VT, 92.95 kV-
(WL-131454)
ΦB-KUHLMAN SSVT-650-100 VT, 92000
(WL-131455)
C
HG
A
B
92.95kV
161kV


WAVEFORMS
Trigger Date
12/11/2012
Trigger Time
10:32:22.000000
1
12/11/12 10:33:35.499832
Start
Trigger
Actual
2
12/11/12 10:33:35.893577
0.393745 s
Graph Data - Comtrade - [D:\Documents and Settings\All Users\Doc
1
2
Peak
RMS
Primary
Secondary
CHANNEL
MAGNITUDE
1004 Vbg RMS
91.721 kV

( )W48H1-A00	WMCB-08A	230/208	60	1	[illegible]	60	N/A
( )W48H1-A0Z	EHWH04-A04	230/208	60	1	58	70	37/2
( )W48H1-A04	EHWH42-A05	230/208	60	1	63	90	37/5
( )W48H1-A05	EHWH42-A10	230/208	60	1	89	90	37/5
(X)W48H1-A10BPXXXE	EHWH42-A15	230/208	60	1	89	125	59/5
( )W48H1-A15	EHWH04-A20	230/208	60	1	111		
( )W48H1-A20							

SHORT-CIRCUIT CURRENT: 5KA RMS SYMMETRICAL

BRANCH CIRCUIT SELECT CURRENT 23.1 OPERATING VOLTAGE RANGE: 197 VAC MIN. 253 VAC MA

SERIAL NUMBER 343D122899483-02

SUITABLE FOR OUTDOOR USE ALL MOTORS ARE THERMALLY PROTECTED

-- ELECTRICAL RATINGS --

	VAC	HZ	PH	HP	FLA	LRA	RLA
COMPRESSOR	230/208	60	1			131/131	19.5/21.2
OUTDOOR MOTOR	230/208	60	1	1/3	2.5		
INDOOR MOTOR	230/208	60	1	1/2	3.3		
WERV-A5A	230/208	60	1		2.2	(OPTIONAL)	
HEATER PACKAGE				KW	FLA		
EHWH04-A04	240/208	60	1	4/3	16.7/14.4		
EHWH42-A05	240/208	60	1	5/3.75	20.8/18.1		
EHWH42-A10	240/208	60	1	10/7.5	41.6/36.2		
EHWH42-A15	240/208	60	1	15/11.25	62.5/54.1		
EHWH04-A20	240/208	60	1	20/15	83.2/72.1		

-- FACTORY REFRIGERANT --

FACTORY CHARGED R410A: 144 OZ. DESIGN PRESSURE PSIG 449 HIGH 238 LOW

-- CLEARANCES --

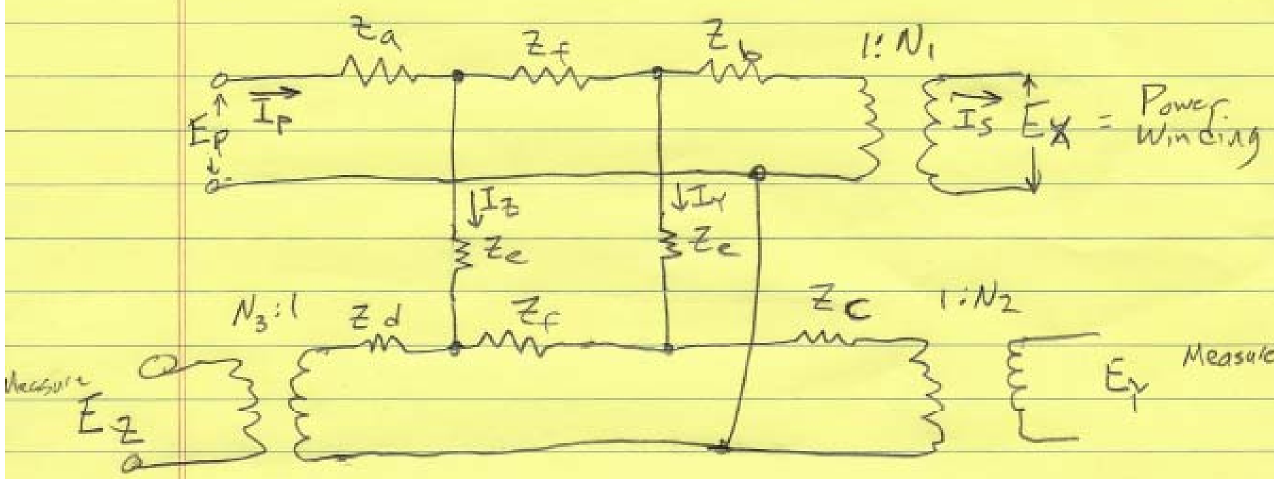
UNIT CASING SUITABLE FOR 0 INCH CLEARANCE.

OUTLET DUCT CLEARANCE 1/4 INCH MINIMUM FOR AT LEAST FIRST 3 FEET OF DUCT. REFER TO INSTALLA
INSTRUCTIONS FOR ADDITIONAL CLEARANCE INFORMATION. MAXIMUM OUTLET AIR TEMPERATURE: 200
THIS MODEL HAS BEEN TESTED AT STATIC PRESSURES FROM 0 TO .5 IN. WATER COLUMN. CONSULT
INSTALLATION INSTRUCTIONS FOR MAXIMUM PERMITTED STATIC PRESSURE FOR SPECIFIC EQUIPMENT APPL

INSTALLER: WHEN INSTALLING OPTIONAL BARD HEATER PACKAGE: PERMANENTLY MARK THIS SERIAL PLA
SHOW THE INSTALLED HEATER PACKAGE.

(1) ONLY BARD HEATER PACKAGES LISTED ABOVE ARE SUITABLE FOR USE WITH THIS UNIT. USE OF AN
HEATER PACKAGE VOIDS WARRANTY AND COULD CAUSE SAFETY HAZARD

Four Winding Xfmr eqivalent circuit
(comes from section 55 of Westinghouse T&D Reference Book)



Assume I_Z and I_Y are magnitizing only (since they are measurement windings) $I_Z = I_Y \to 0$

$$E_Z = \frac{E_p - Z_a I_p - \overset{0}{I_Z}(Z_d + Z_e)}{N_3} = \frac{E_p - Z_a I_p}{N_3}$$

$$E_Y = \frac{E_p - Z_a I_p - Z_f(I_p - \overset{0}{I_Z}) - \overset{0}{I_Y}(Z_e + Z_c)}{N_2} = \frac{E_p - Z_a I_p - Z_f(I_p}{N_2}$$

if $I_Z = I_Y \to 0$ then $I_s = I_p N_1$ or $I_p = I_s / N$
if I_s increases, so does I_p
Therefore E_Z and Z_Y decrease as I_s increases.

What can I do to prevent nuisance trips when the heat pump kicks on?

- Capacitor Bank Protection is set very sensitive. In this case at 2%.
- Can interlock the heat pump contactor with an 89B contact (humor intended)
- Can add a standard VT to provide voltages for protection.

imagination at work

How would this effect other relaying

- Phase and Ground Distance Protection:
  - Could cause an element to over-reach if a fault occurred at the same instance of a heat pump start.
  - Probably wouldn’t affect steady state conditions unless extremely heavily loaded line.

How would this effect other relaying

- Bus Under-voltage:
  - Probably would be unaffected because of the duration.

imagination at work

Lessons Learned

- Capacitor Bank Protection requires very sensitive settings.
- VT error can influence those setting.
- We still spend most of our time talking about instrument transformers.

imagination at work

Questions ?

imagination at work

Thank You For the Time

imagination at work