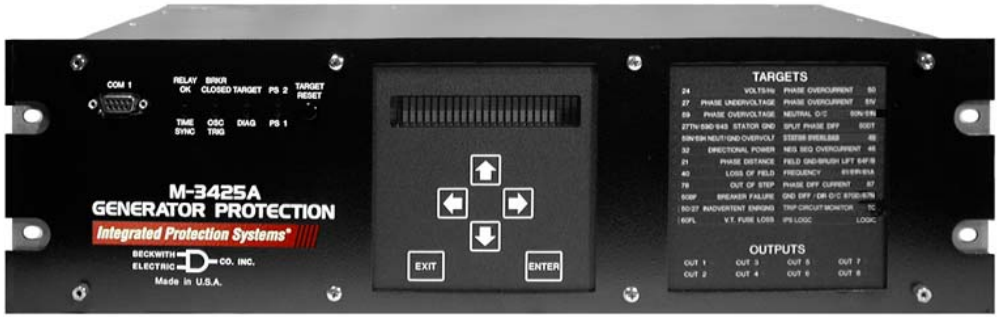
BECKWITH ELECTRIC CO. INC.

Generator Protection: M-3425A



Presenter Contact Info

Drew Welton

Vice President of Sales, Creative Technical Solutions

Beckwith Electric Company

dwelton@beckwithelectric.com

727-317-8899

Drew Welton is the Vice President of Sales & Creative Technical Solutions for Beckwith Electric and provides strategic leadership to the sales management team as well as creative technical solutions to our customers. Mr. Welton joined Beckwith Electric in 2016 as Director of Sales to provide strategic sales leadership and to further develop and execute sales channels.

- North American Regional Manager for OMICRON starting in 1997.
- Regional Sales Manager with Beckwith Electric. He also served as National Sales Director for Substation Automation with AREVA T&D.
- Written numerous articles on substation maintenance testing, and has conducted numerous training sessions for substation technicians and engineers at utilities and universities across North America.
- 20 year Senior Member of IEEE-PES, has been a contributor on a number of PSRC working groups, and presented at a number of industry conferences specific to power system protection and control.
- Graduate of Fort Lewis College, Durango, CO, with a Bachelor's degree in Business Administration.

Presenter Contact Info

Wayne Hartmann

Senior VP, Customer Excellence

Beckwith Electric Company

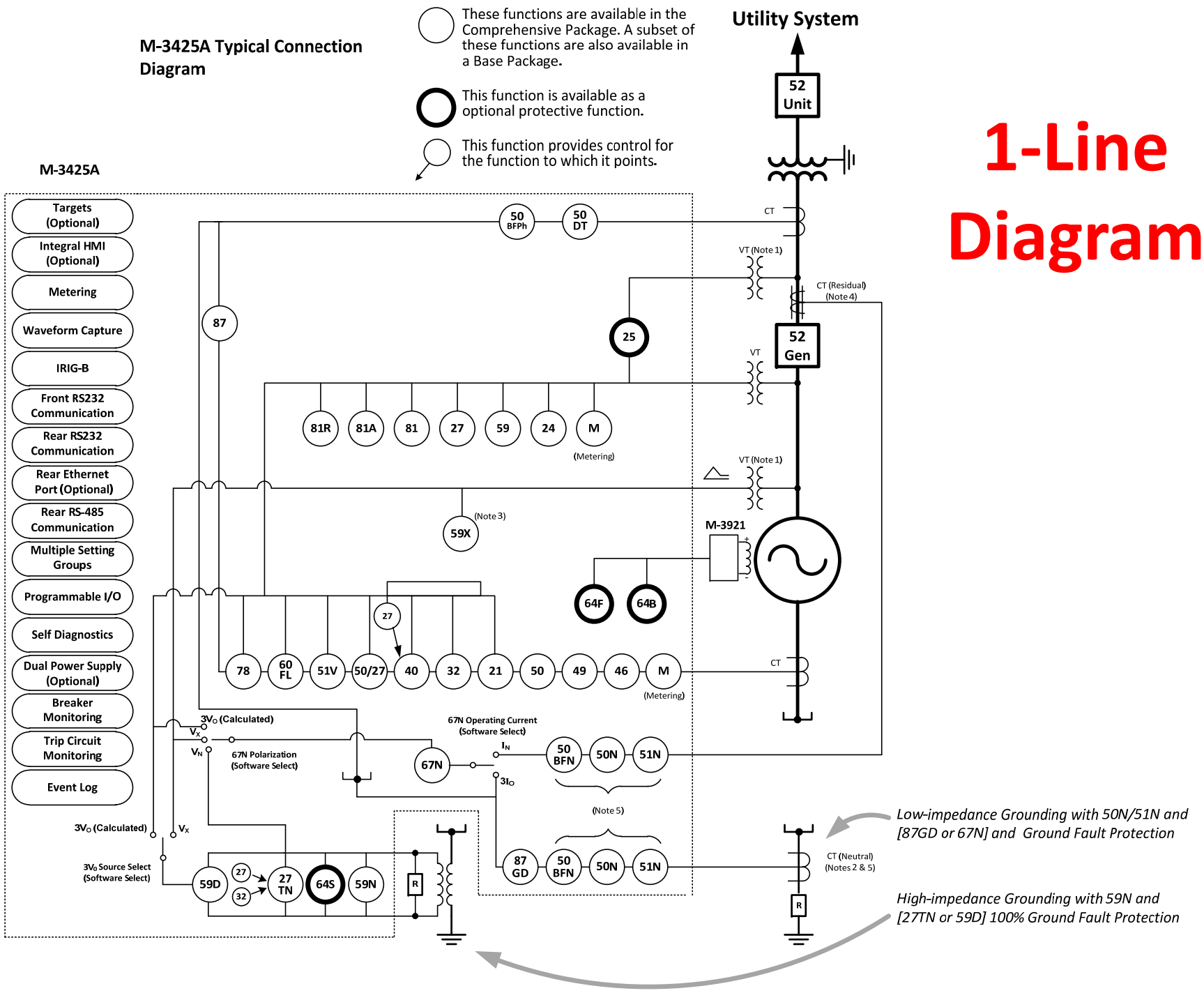
whartmann@beckwithelectric.com

904-238-3844

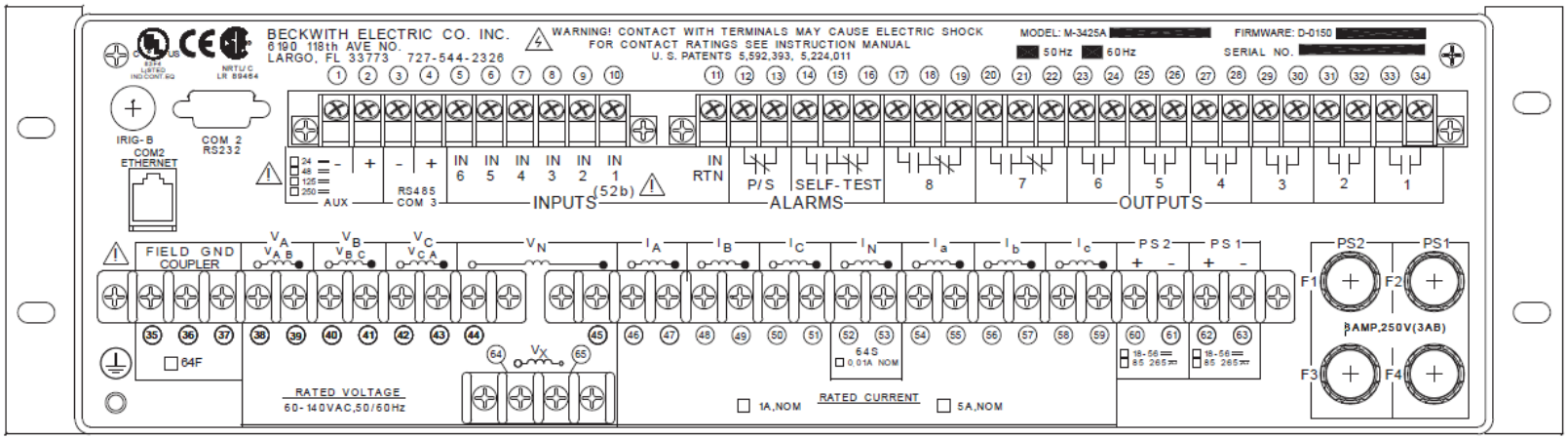
Wayne is the top strategist for delivering innovative technology messages to the Electric Power Industry through technical forums and industry standard development.

- Before joining Beckwith Electric, performed in Application, Sales and Marketing Management capacities at PowerSecure, General Electric, Siemens Power T&D and Alstom T&D.
- Provides training and mentoring to Beckwith Electric personnel in Sales, Marketing, Creative Technical Solutions and Engineering.
- Key contributor to product ideation and holds a leadership role in the development of course structure and presentation materials for annual and regional Protection & Control Seminars.
- Senior Member of IEEE, serving as a Main Committee Member of the Power System Relaying and Control Committee for over 25 years.
  - Chair Emeritus of the IEEE PSRCC Rotating Machinery Subcommittee ('07-'10).
  - Contributed to numerous IEEE Standards, Guides, Reports, Tutorials and Transactions, delivered Tutorials IEEE Conferences, and authored and presented numerous technical papers at key industry conferences.
- Contributed to McGraw-Hill's "Standard Handbook of Power Plant Engineering."

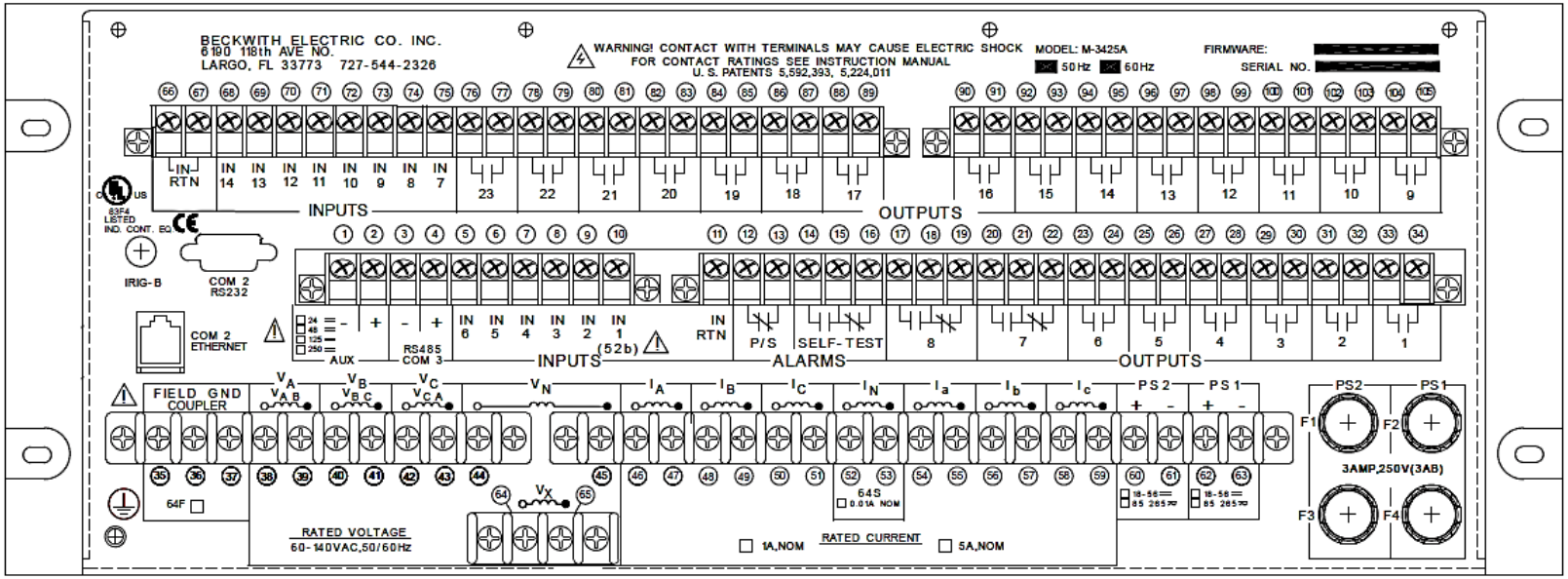
1-Line Diagram



Standard

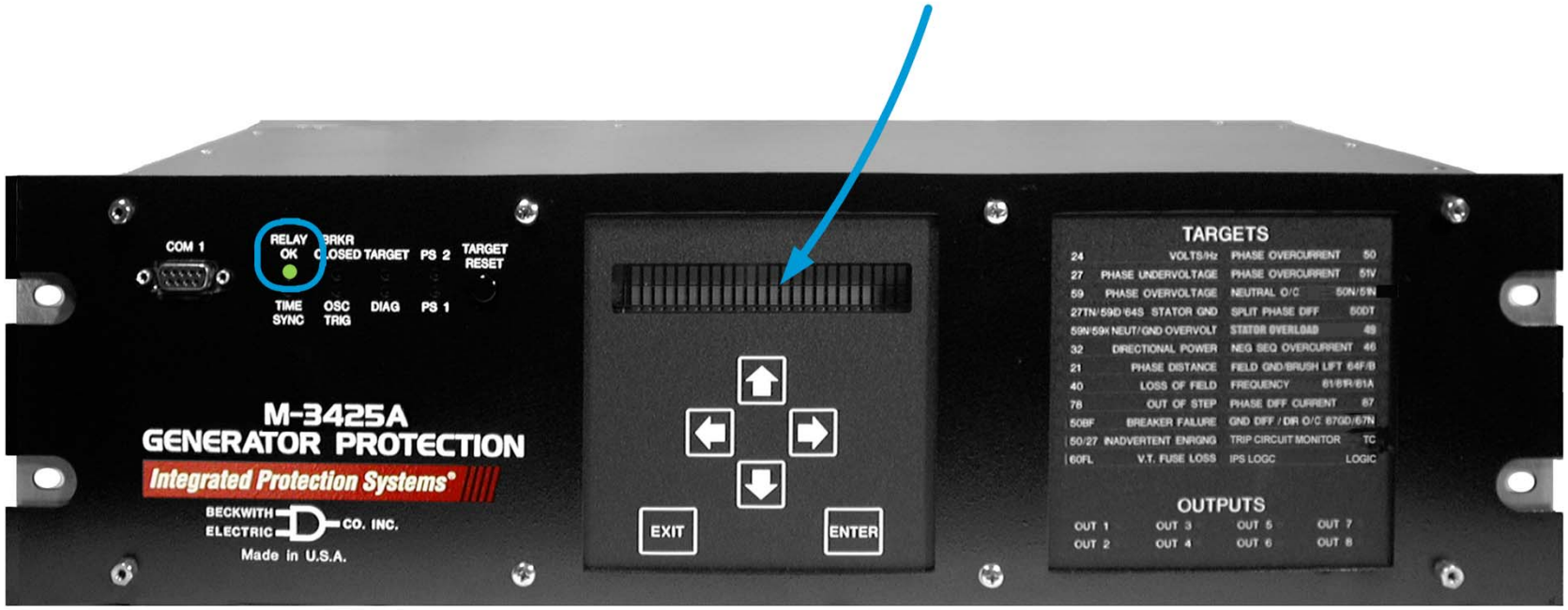


Expanded

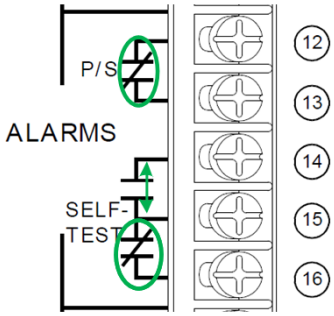


Normal Operation - No Targets

Display dark if there are no active targets

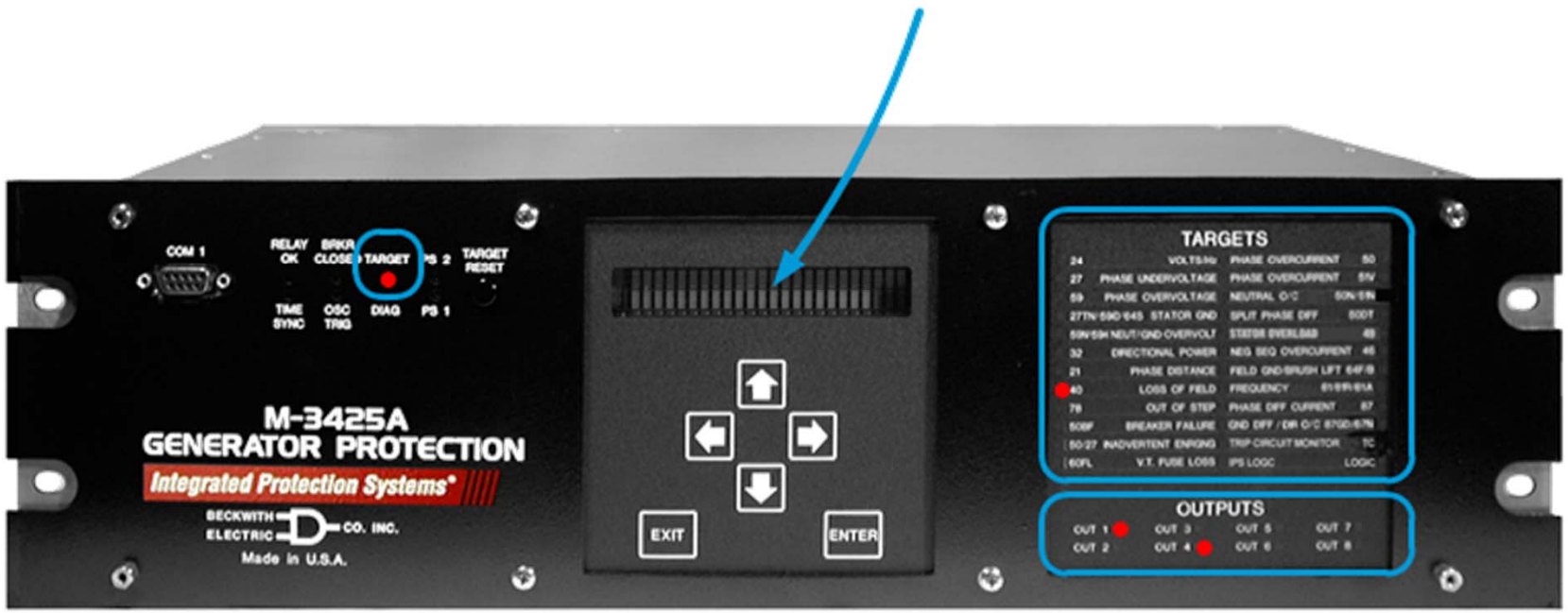


- Power supply fail contact = energized
  - Note: On relays with 2 power supplies installed, both must be powered up to energize this contact.
- Diagnostic Contact = coils energized, “OK” state



Tripped

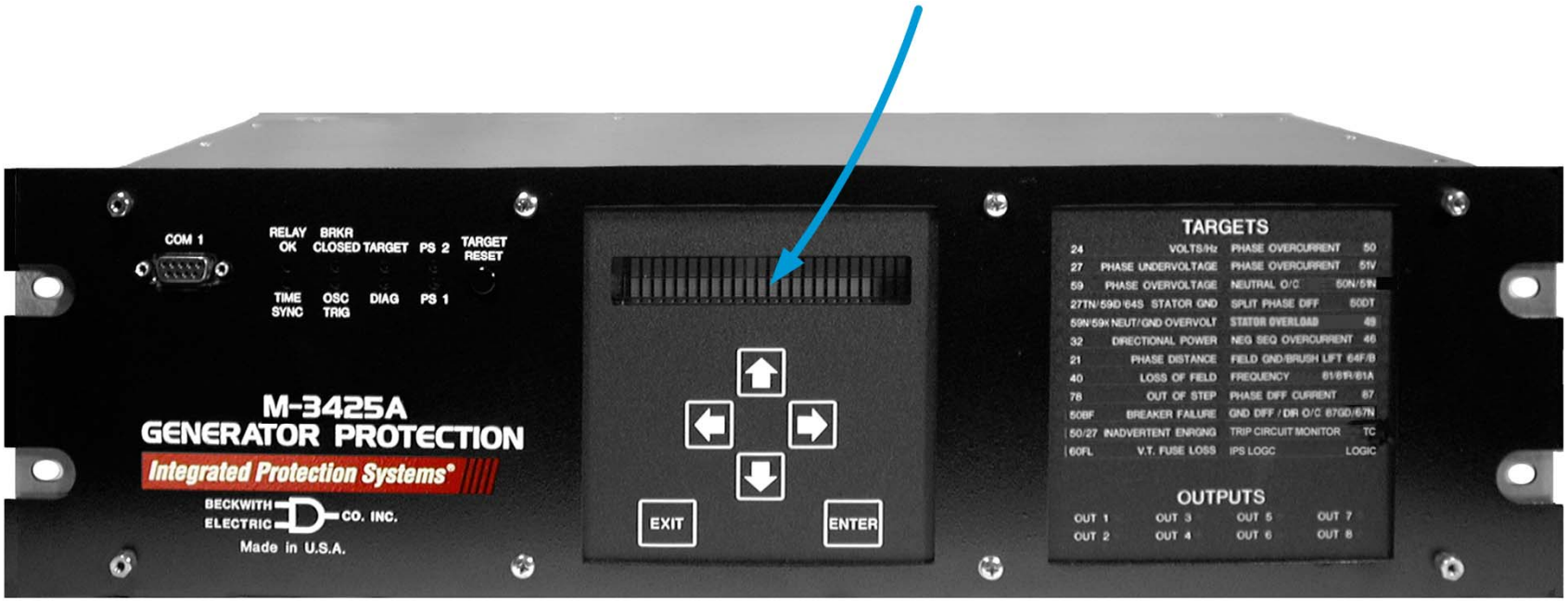
Target, Time, Outputs, Function, Phase



•One or more “OUTPUT” LEDs illuminated

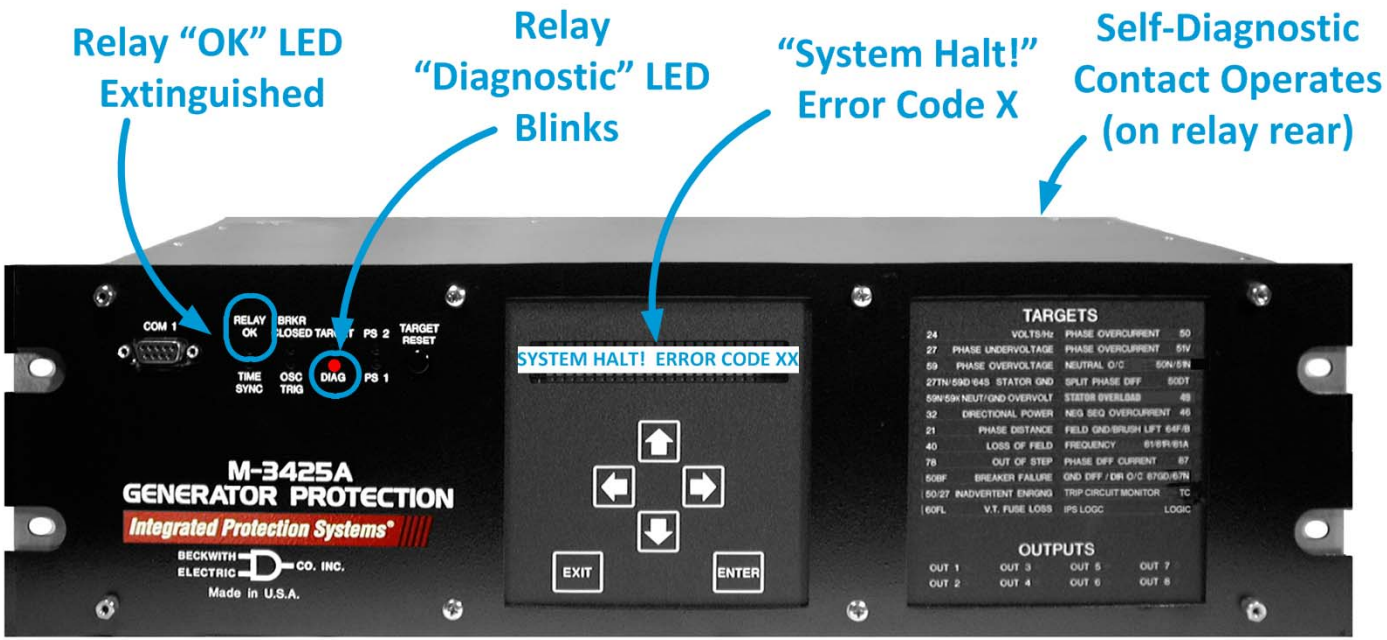
Trip Cleared and Target Present

Target, Time, Outputs, Function, Phase



•All “OUTPUT” LEDs Extinguished

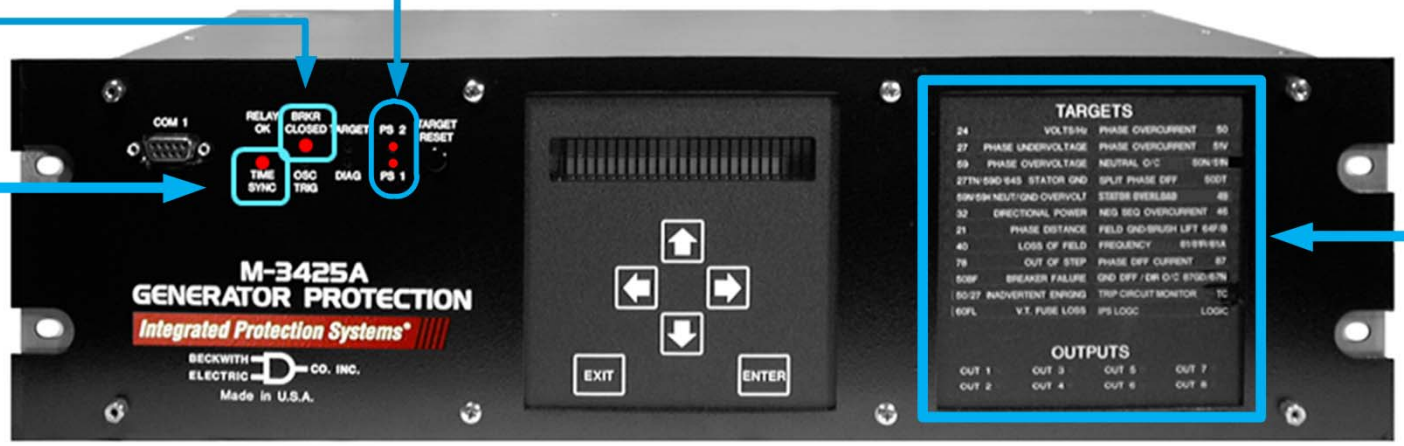
Relay failed internal self diagnostics



- If the "Relay OK LED" is extinguished, the relay is not in service.
  - Contact the factory if a "System Halt" message is displayed or the "Relay OK" LED is extinguished.
- Resetting the relay may temporarily remove the error but may result in a false trip or no trip operation.
- Do not press any HMI buttons while the relay is in diagnostic mode.

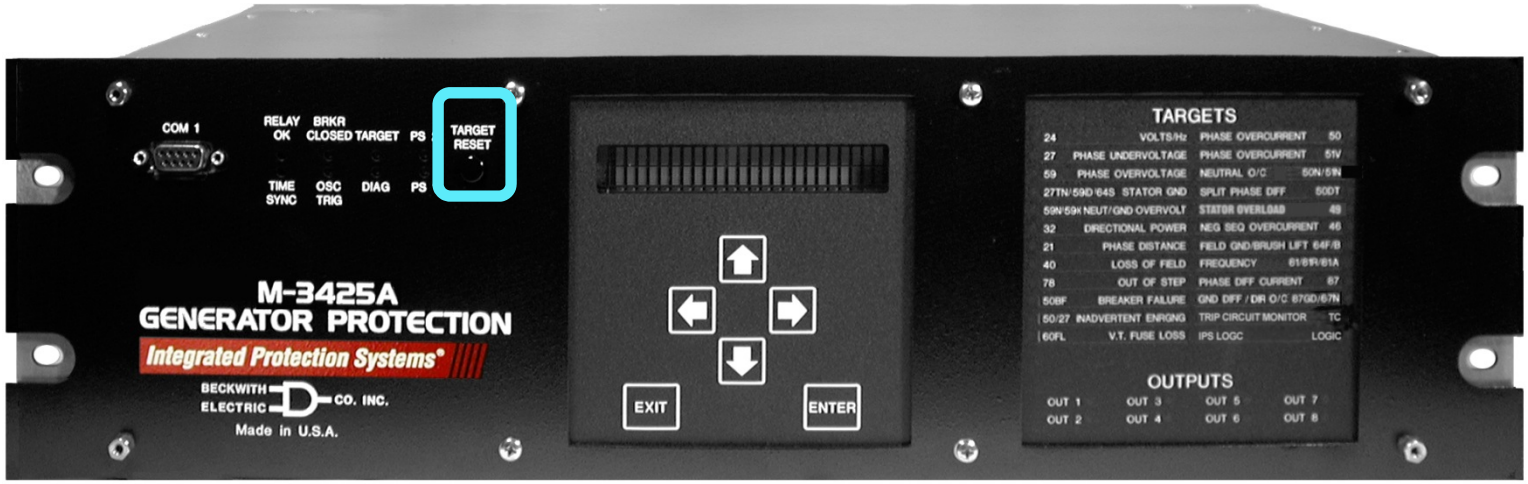
Other front panel indicators

- **Breaker Closed:** Normally on when Input 1 is open
- **PS1 and PS2:** On when the associated power supply is on.



- **Time Sync:** On when IRIG-B signal is applied. No setting is required.
- **Target:** On when most recent event is not reset

Front panel controls



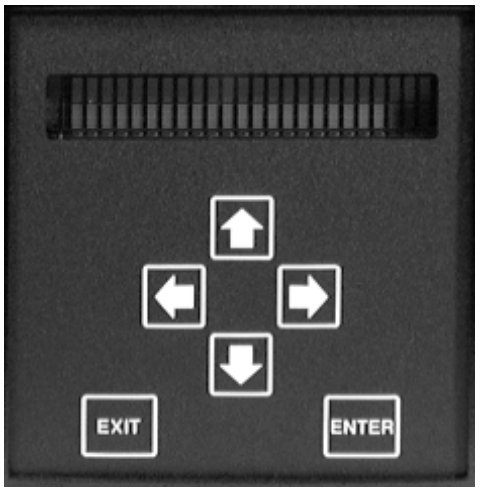
Target Reset Button:

- **Button Released:** Target module and HMI display the most recent event information.
- **Button Pressed and Released:** LED test then targets are reset *IF ALL TRIPPED FUNCTIONS ARE RESET.*
- **Button Pressed and Held:** Target module displays functions that are currently picked up.

Note: Output LED's always display real time status of output contacts.

Front Panel Controls: HMI Operation

- Access by pressing any button after the Power On Self Test terminates.
- The selected menu item appears in capital letters.
- Press the **RIGHT** and **LEFT** arrows to move between menu items.
- Press **ENTER** to move into a submenu or item
- Press **EXIT** move out of a submenu.
- The **UP** and **DOWN** arrows are used to change values.



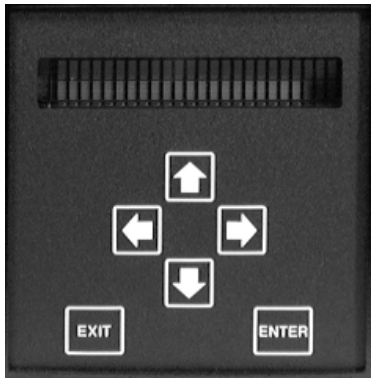
HMI Operation

VOLTAGE RELAY
VOLT curr freq v/hz →

- 27 Phase Undervoltage
- 59 Phase Overvoltage
- 27TN Neutrl Undervolt
- 59X Overvoltage
- 59N Neutral Overvoltage
- 59D Volt. Diff. 3rd Har.

CURRENT RELAY
volt CURR freq v/hz →

- 46 Neg Seq Overcurrent
- 50 Inst Overcurrent
- 50/27 Inadvertent Energing
- 50BF Breaker Failure
- 50DT Def. Time Overcurr
- 50N Inst Overcurrent
- 51N Inv Time Overcurrent
- 49 Stator Overload
- 51V Inv Time Overcurrent
- 87 Differential Overcurr
- 87GD Gnd Diff Overcurr
- 67N Res Dir Overcurr



HMI Operation

FREQUENCY RELAY
volt curr FREQ v/hz →

- 81 Frequency
- 81R Rate of Change Freq
- 81A Frequency Accum.

VOLTS PER HERTZ RELAY
volt curr freq V/HZ →

- 24 Definite Time Volts/Hertz
- 24 Inverse Time Volts/Hertz

POWER RELAY
← PWR lof fuse dist →

- 32 Directional Power

LOSS OF FIELD RELAY
← pwr LOF fuse dist →

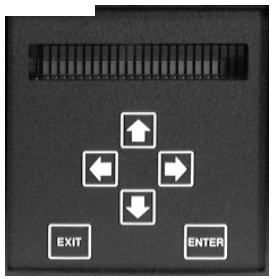
- 40 Loss of Field

V. T. FUSE LOSS RELAY
← pwr lof FUSE dist →

- 60 FL V.T. Fuse Loss

PHASE DISTANCE RELAY
← pwr lof fuse DIST →

- 21 Phase Distance
- 78 Out of Step



HMI Operation

FIELD GROUND RELAY
← FIELD stator sync →

- 64B/F Field Ground

STATOR GROUND RELAY
← field STATOR sync →

- 64S Stator Ground

SYNC CHECK RELAY
← field stator SYNC →

- 25S Sync Check
- 25D Dead Volt

BREAKER MONITOR
← BRKR trpckt ipslog →

- Set Breaker Monitoring
- Preset Accumulators
- Clear Accumulators

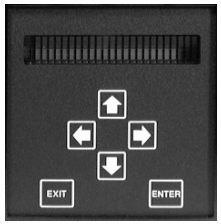
TRIP CIRCUIT MONITOR
← brkr TRPCKT ipslog →

- Trip Circuit Monitoring

IPS LOGIC
← brkr trpckt IPSLOG →

CONFIGURE RELAY
← CONFIG sys stat →

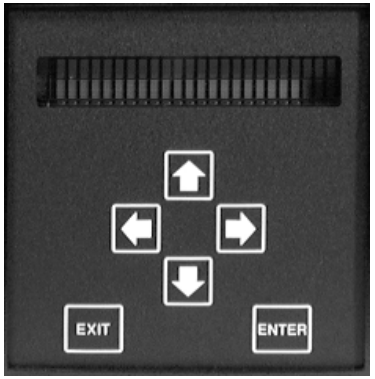
- Voltage Relay
- Current Relay
- Frequency Relay
- Volts per Hertz Relay
- Power Relay
- Loss of Field Relay
- V.T. Fuse Loss Relay
- Phase Distance Relay
- Field Gnd Relay
- Stator Gnd Relay
- Sync Check Relay
- Breaker Mon Relay
- Trip Ckt Mon Relay
- IPSLogic Relay



HMI Operation

SETUP SYSTEM
← config SYS stat →

- Input Activated Profiles
- Active Setpoint Profile
- Copy Active Profile
- Nominal Voltage
- Nominal Current
- V. T. Configuration
- Delta-Y Transform
- Phase Rotation
- 59/27 Magnitude Select
- 50DT Split-phase Diff.
- Pulse Relay
- Latched Outputs
- Relay Seal-in Time
- Active Input State
- V.T. Phase Ratio
- V.T. Neutral Ratio
- V.T. VX Ratio
- C.T. Phase Ratio
- C.T. Neutral Ratio



STATUS
← config sys STAT →

- Voltage Status
- Current Status
- Frequency Status
- V/Hz Status
- Power Status
- Impedance Status
- Sync Check Status
- Breaker Mon Acc Status
- 81A Accumulators Status
- In/Out Status
- Timer Status
- Relay Temperature
- Counters
- Time of Last Power Up
- Error Codes
- Checksums

VIEW TARGET HISTORY
← TARGETS osc_rec comm →

- View Target History
- Clear Target History

HMI Operation

OSCILLOGRAPH RECORDER
← targets OSC_REC comm →

- View Record Status
- Clear Records
- Recorder Setup

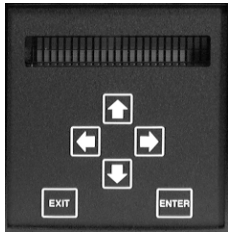
COMMUNICATION
← targets osc_rec COMM →

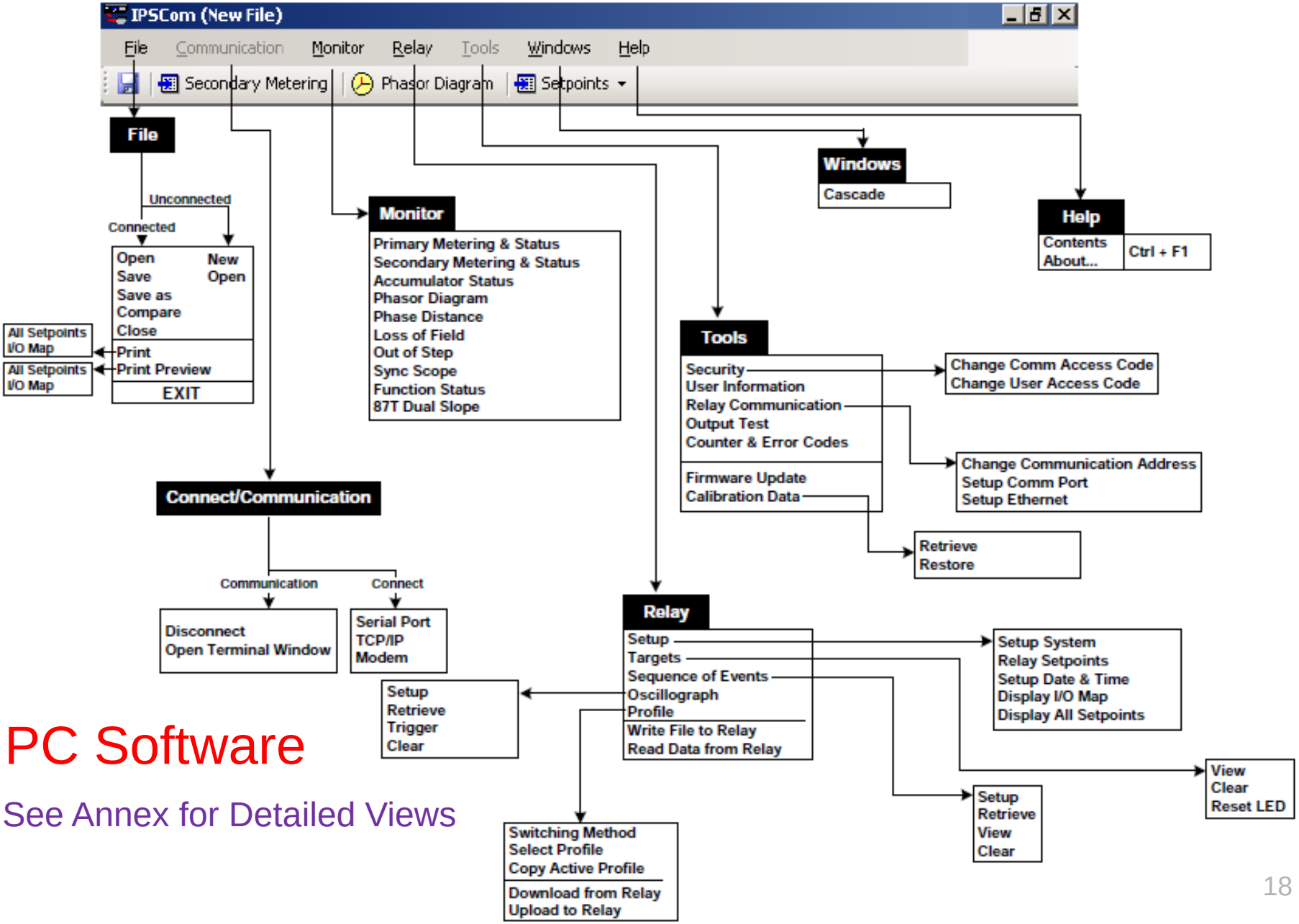
- COM1 Setup
- COM2 Setup
- COM3 Setup
- Communication Address
- Response Time Delay
- Communication Access Code
- Ethernet Setup
- Ethernet IP Address

SETUP UNIT
← SETUP exit

- Software Version
- Serial Number
- Alter Access Codes
- User Control Number
- User Logo Line 1
- User Logo Line 2
- Clear Output Counters
- Clear Alarm Counter
- Date & Time
- Clear Error Codes
- Ethernet Firmware Ver.
- Diagnostic Mode

EXIT LOCAL MODE
← setup EXIT



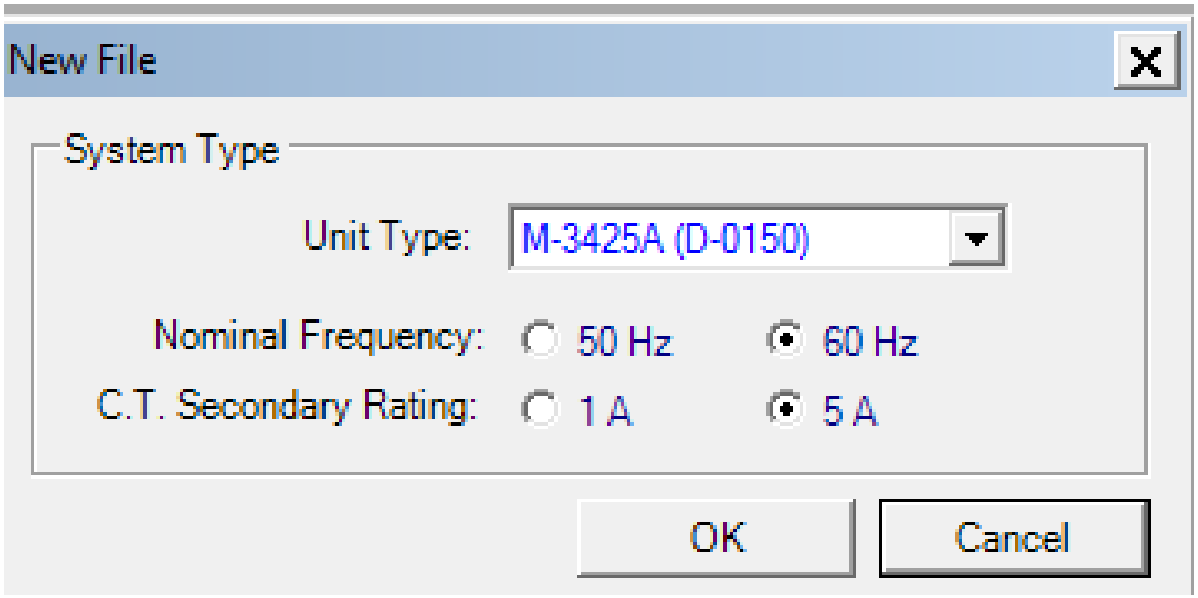


PC Software

See Annex for Detailed Views

Working Offline

•Used to create, view, or modify relay setting files



For a new Setting file:

- •Select File\New
- •Set Unit type, frequency, CT, and Phase Rotation

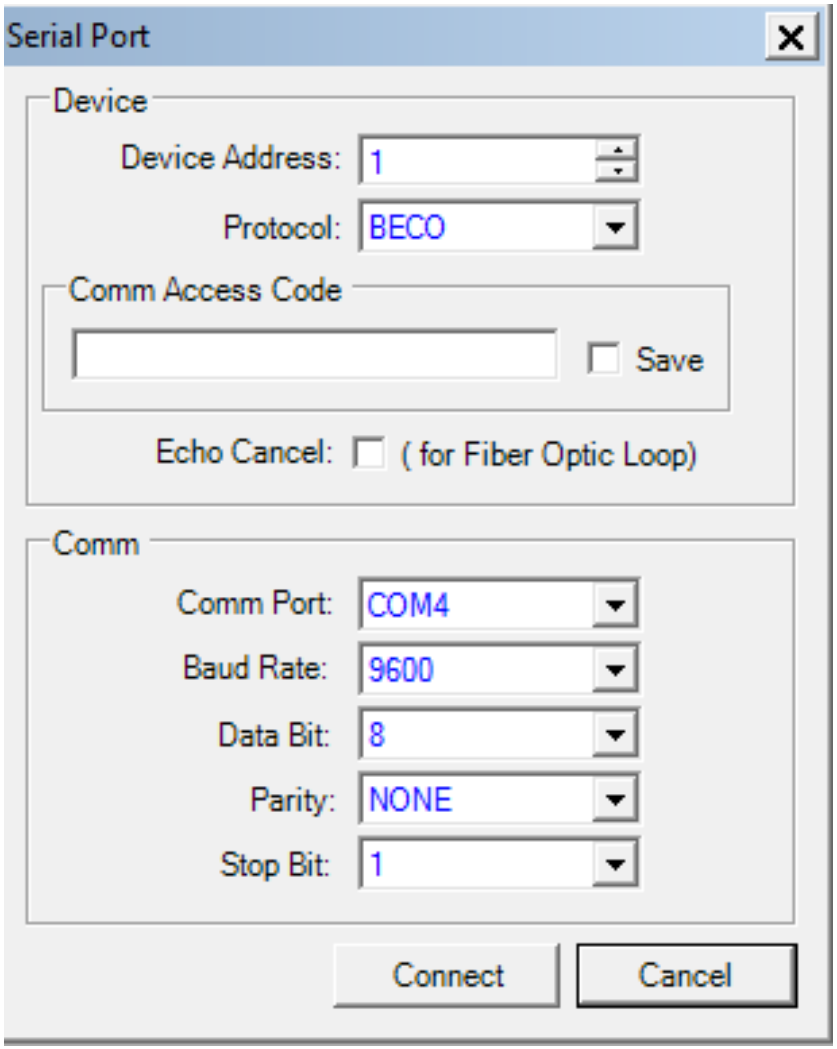
•For and Existing File:

- •Select File\Open
- •Pick the file to be opened

•To Save, use the Save or Save As commands

Working Online

•Used to communicate directly with a relay via 232, 485, modem, or TCP/IP



- PC Port - Serial port on the PC
- The following must be set to match the relay settings :
  - Baud Rate-9600 standard
  - Access Code-Defaults disabled
  - Address-232/485 network address
- For Modem or TCP/IP communications, press the appropriate buttons and set the parameters

Periodic Maintenance: General

All our relays incorporate self diagnostic hardware and continuously run a number of self diagnostic routines.

We highly recommend the relay self test contact as well as the power supply fail contact be connected as your application dictates.

Our minimum recommended periodic maintenance focuses on those components that cannot be checked by the internal diagnostic routines:

Periodic Maintenance: Critical Checks

Each Maintenance Outage:

1) **Relay Trip Test**: *Use the diagnostic feature to force a trip. Verify the breaker opens.*

2) **Relay Diagnostics**: *Perform relay diagnostic checks which check the operation of the status inputs and outputs.*

3) **Breaker Position Sen**sing: *Verify the breaker's position contact is working correctly.*

Digital Relay Self-Diagnostics

What it covers:

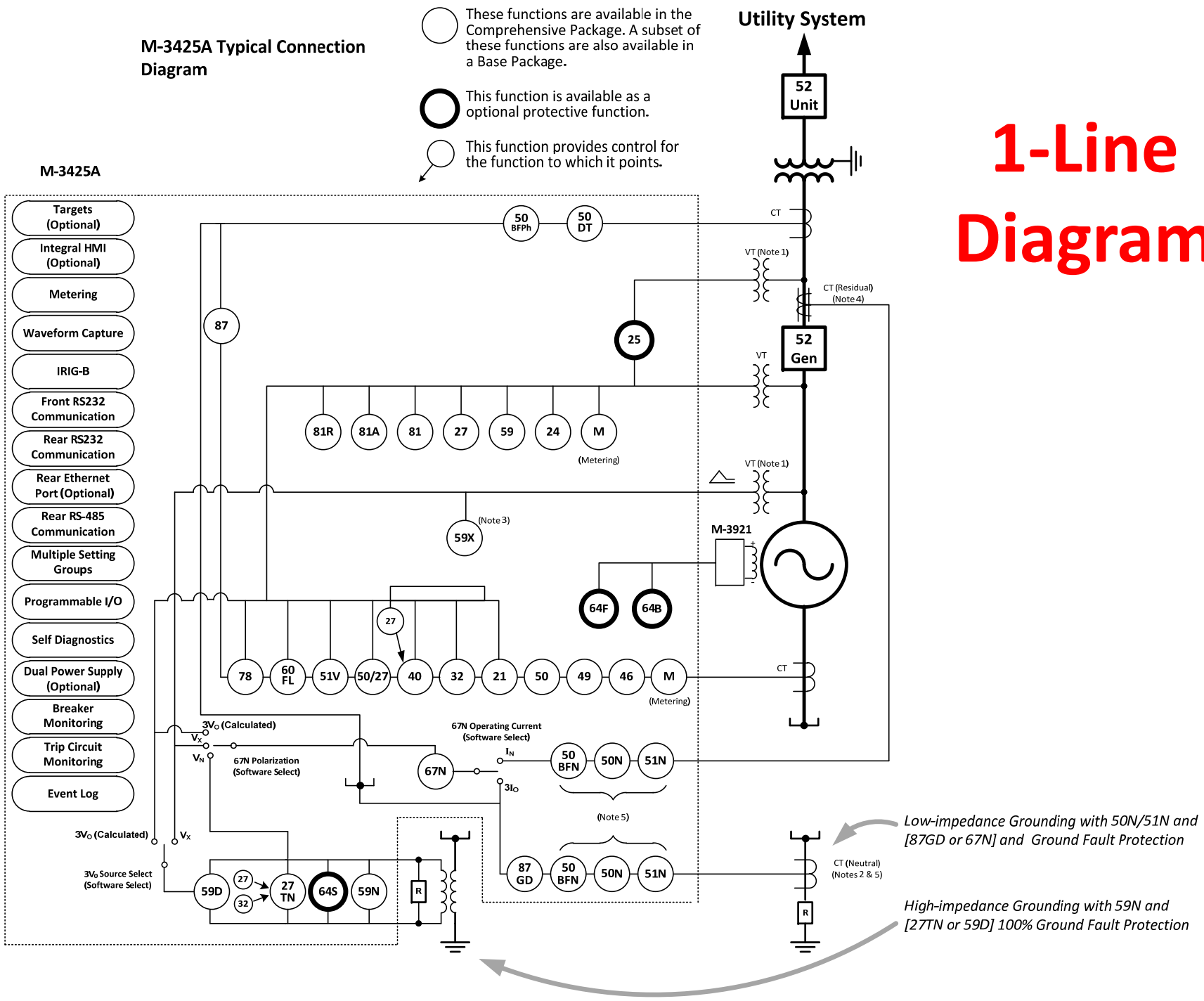
- Microprocessor hand-shaking
- ADC
- Power supply
- Communication failures
- Watchdogs
- Firmware flash failures

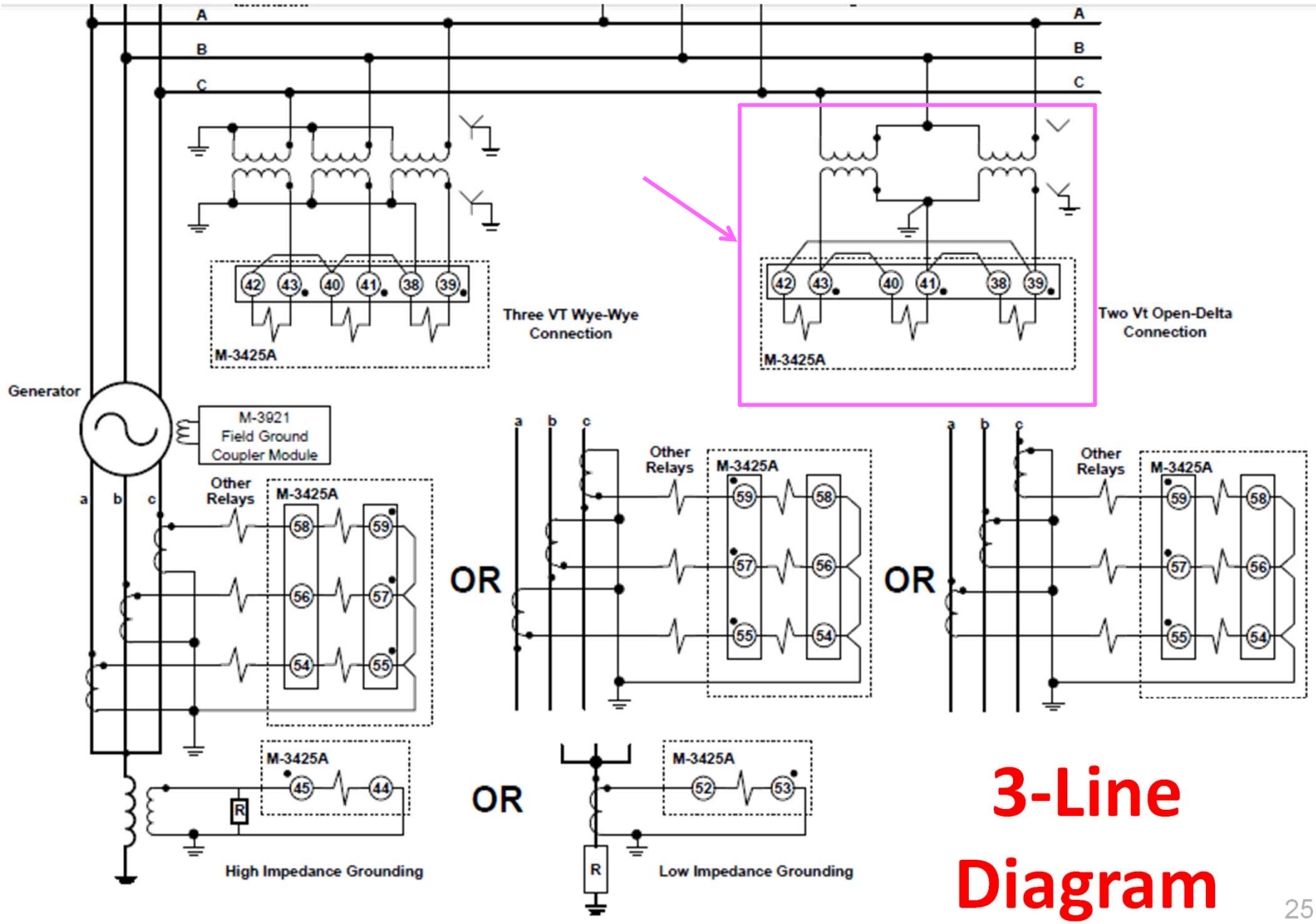
What it does not cover:

- Relay contacts
- Internal CT PT circuits
- Improper wiring
- **Misapplied logic**
- **Incorrect settings**

- In all cases, relay failures covered by self-diagnostics can alert operators through an alarm contact.
- The relay can then take itself out of service to avoid misoperations.

1-Line Diagram





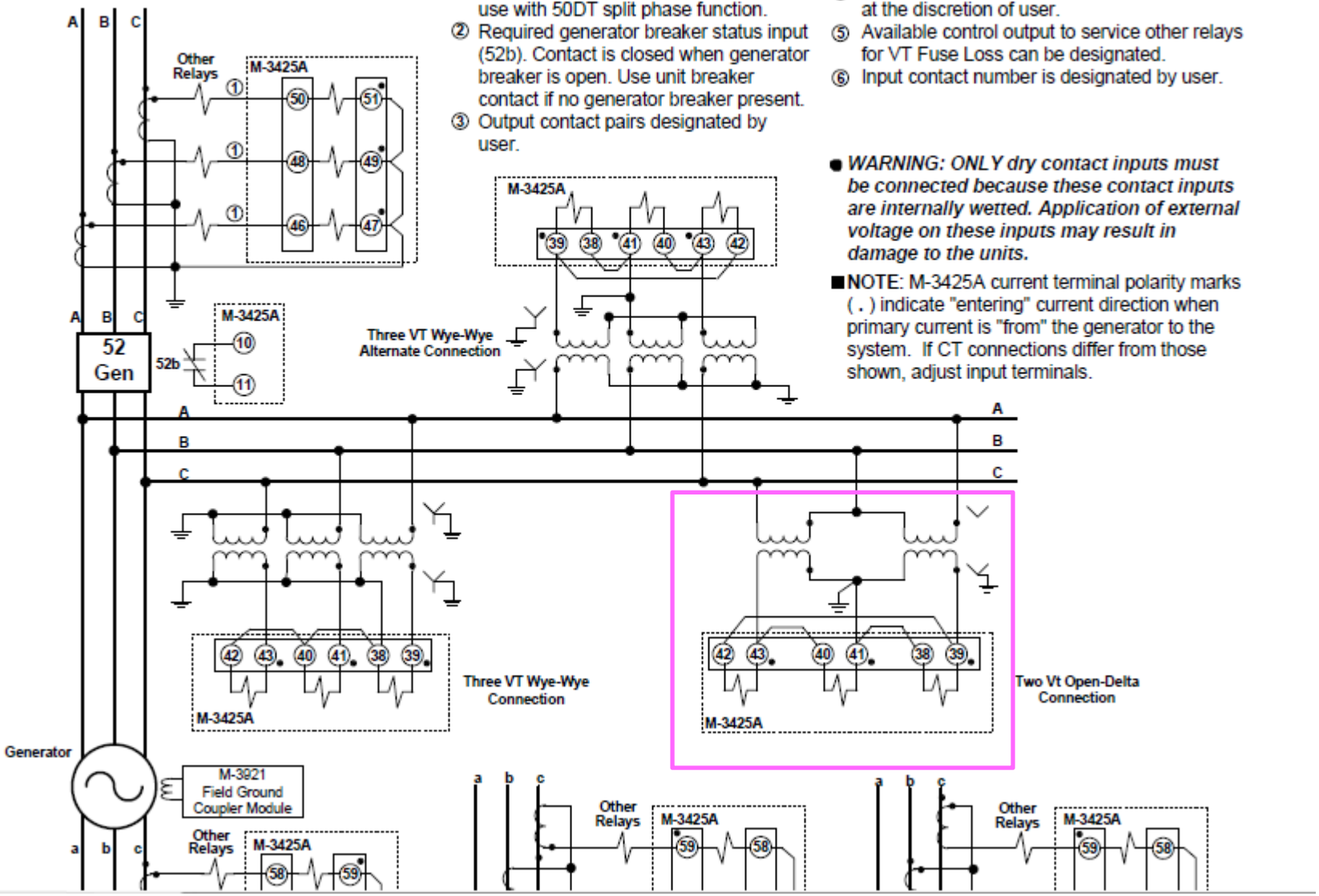
3-Line Diagram

3-Line Diagram Partial: A

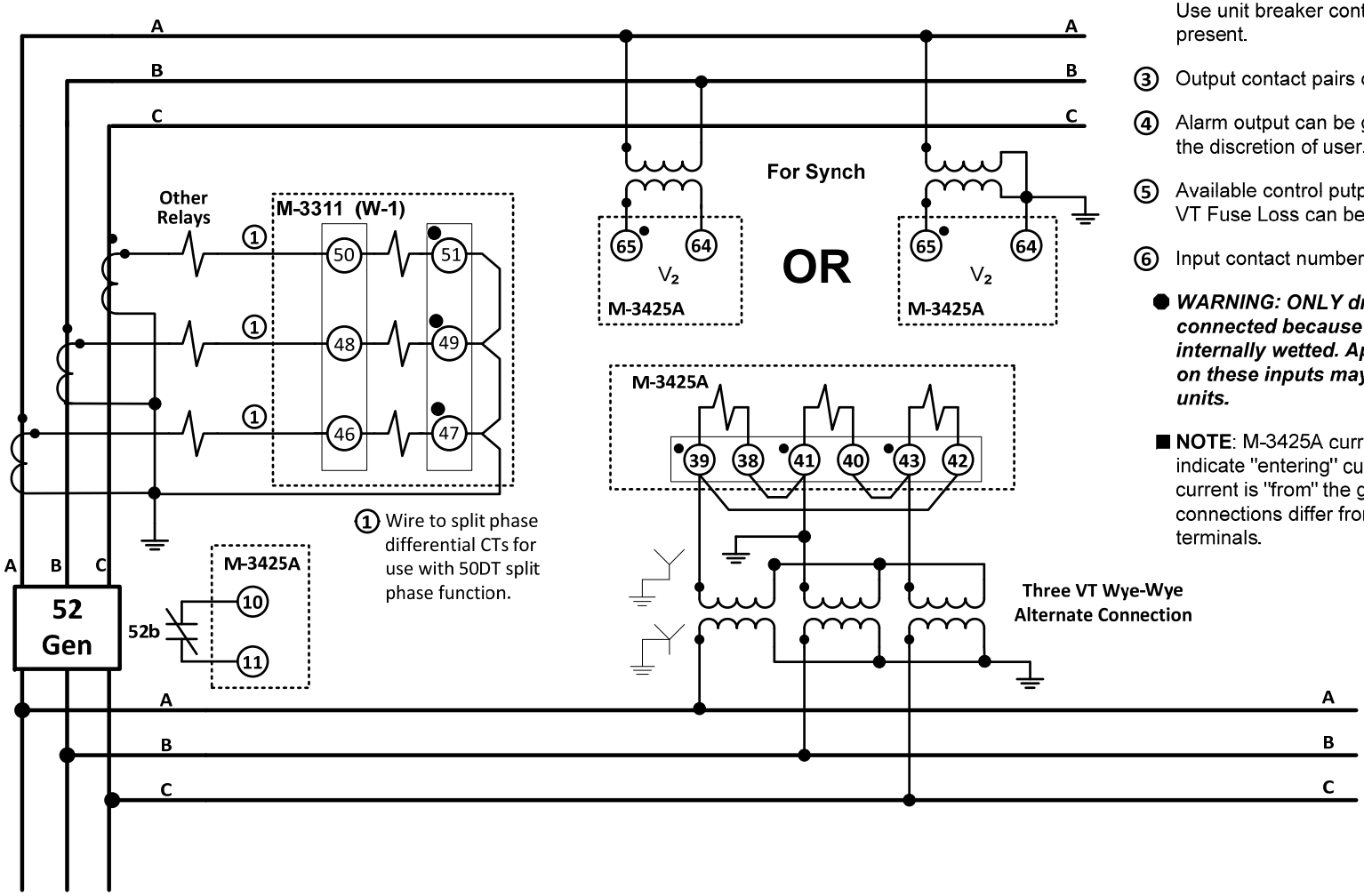
① Wire to split phase differential CTs for use with 50DT split phase function.
② Required generator breaker status input (52b). Contact is closed when generator breaker is open. Use unit breaker contact if no generator breaker present.
③ Output contact pairs designated by user.
④ Alarm output can be grouped to a single alarm at the discretion of user.
⑤ Available control output to service other relays for VT Fuse Loss can be designated.
⑥ Input contact number is designated by user.

- *WARNING: ONLY dry contact inputs must be connected because these contact inputs are internally wetted. Application of external voltage on these inputs may result in damage to the units.*

■ NOTE: M-3425A current terminal polarity marks (.) indicate "entering" current direction when primary current is "from" the generator to the system. If CT connections differ from those shown, adjust input terminals.



3-Line Diagram Partial: B



① Wire to split phase differential CTs for use with 50DT split phase function.

② Required generator breaker status unput (52b). Contact is closed when generator breaker is open. Use unit breaker contact if no generator breaker present.

③ Output contact pairs designated by user.

④ Alarm output can be grouped to a single alarm at the discretion of user.

⑤ Available control putput to service other relays for VT Fuse Loss can be designated.

⑥ Input contact number is designated by user.

● ***WARNING: ONLY dry contacts must be connected because these contact inputs are internally wetted. Application of external voltag on these inputs may result in damage to the units.***

■ **NOTE**: M-3425A current terminal polarity marks (. indicate "entering" current direction when primary current is "from" the generator to the system. If CT connections differ from those shown, adjust input terminals.

M-3425A Pre-startup Tasks

1. Energize the relay

- Verify which power supply installed by checking the marks on the back of the relay
- Apply the proper voltage and check the following:
  - Power supply contact drops out (if 2 power supplies are installed, both must be energized to clear power fail contact)
  - Diagnostic contact drops out after POST testing completes
  - “Relay OK” LED on/flashing

Note: Do not press any buttons while the Power On Self Test is in process.

M-3425A Pre-startup Tasks

1. Energize the relay
2. Set the clock
3. ***Install the relay setting using IPScom***

From a File:

- Connect to the relay
- Relay Menu ⇒ Write File To Relay
- Use the browsing control to select the file
  - Note: The file save must be for the same relay type and have the same phase rotation for this feature to work
- Relay Menu ⇒ Setup ⇒ Sequence of Events ⇒ Setup. Enter the settings
- Relay Menu ⇒ Setup ⇒ Oscillograph ⇒ Setup. Enter the settings

M-3425A Pre-startup Tasks

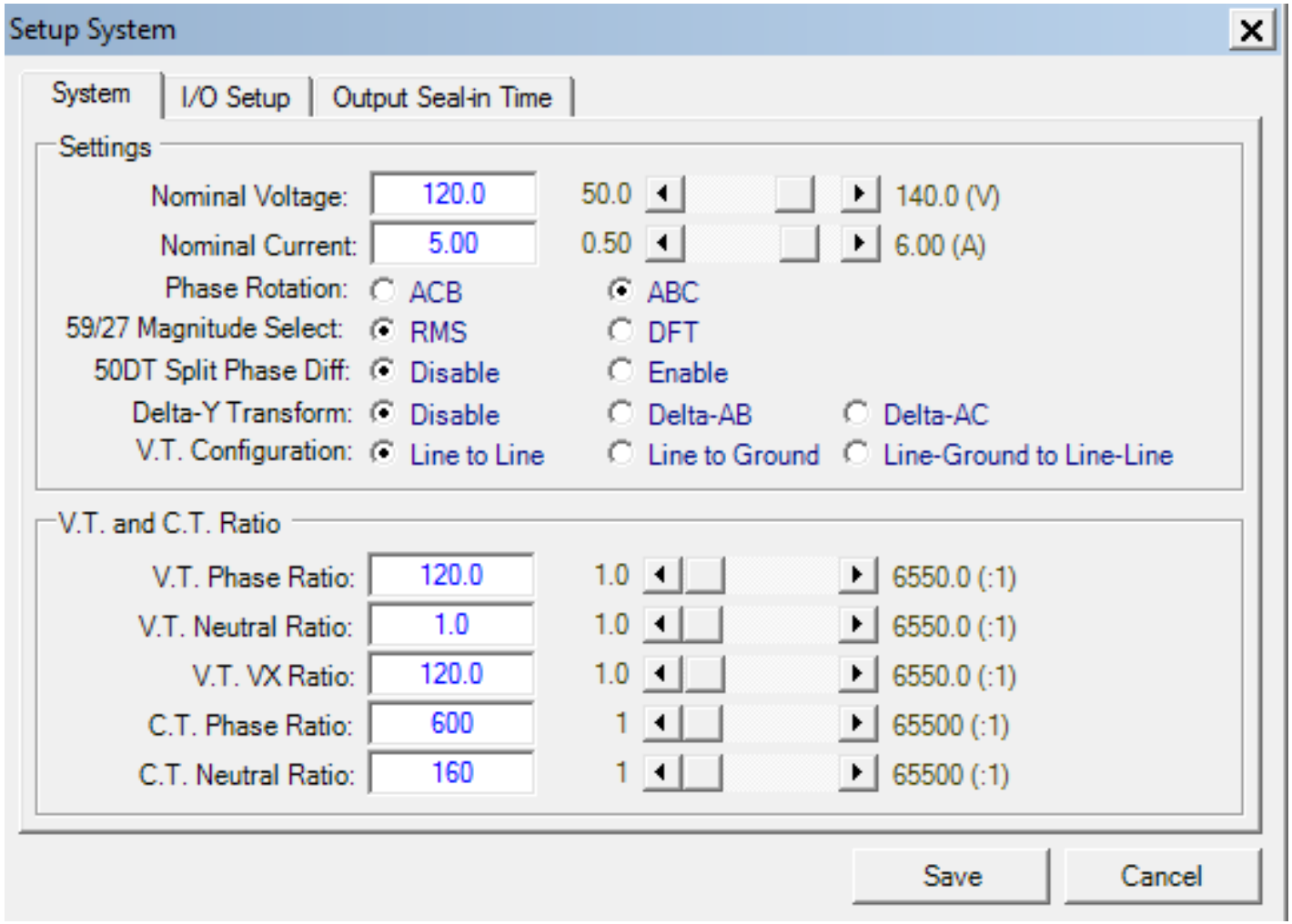
1. Energize the relay
2. Set the clock
3. ***Install the relay setting using IPScom***

From a Setting Sheet:

- Connect to the relay
- Relay Menu ⇒ Setup ⇒ Setup System. *Enter the settings*.
- Relay Menu ⇒ Setup ⇒ Setpoints ⇒ Configure. *Enter the settings.*
- Relay Menu ⇒ Setup ⇒ Sequence of Events ⇒ Setup. *Enter the settings*.
- Relay Menu ⇒ Setup ⇒ Oscillograph ⇒ Setup. *Enter the settings*
- Save the file by selecting File ⇒ Save As.

System Setup Settings:

These settings are used throughout the relay.



Basic Settings (cont.):

VT Configuration	Nominal Voltage	Used
L-G	V_{nom} = GEN V_{LL}/ (1.732*VTR)	(21, 32, 40, 46, 50/27, 51V)
L-L	V_{nom} = GEN V_{LL}/ (VTR)	
L-G to L-L	V_{nom} = GEN V_{LL}/ (VTR)	

Nominal Current

I_{nom} = GEN VA / (1.732* GEN V_{LL}*CTR)

(21, 32, 40, 46, 50/27, 51V, 87)

Delta-Y Transform (21, 51V):

Determines calculation used for 21 and 51V functions

Basic Settings (cont.):

Input Active State (all functions using blocking or external initiate):

- Sets the input logic to assert when connected contact is closed or open.
  - Note: For element blocking when GEN CB is open
    - *52/*b should be set to *active closed*
    - *52/a* to *active open*.

VT Configuration

- Line-to-Ground: Used with Y connected VTs
- Line-to-Line: Used with Delta or Open Delta VTs
- Line-to-Ground to Line-to-Line: Used with Y connected VTs
  - With this setting the relay internally calculates the equivalent phase to phase voltage and uses that voltage for trip decisions while maintaining L-G voltages for the oscillography.
  - *In High-Z Grounded Generators, this setting prevents the 59 and 27 elements from tripping on stator ground faults.*

Basic Settings (cont.):

59/27 Magnitude Select:

- Adjusts the calculation used for the overvoltage, undervoltage, and the inadvertent energization element.
- In generator applications, this should be set to RMS

RMS averages the most recent 8 cycles of data

- If the voltage is 0V, there are no zero crossings and the relay holds the most recent values for 30cyc.
- After this time the relay performs the measurement on the most recent 8 cycles of data.
- This results in accurate measurements over a wide frequency but sacrifices speed.

DFT averages the most recent 16 samples (16.7mSec at 60Hz) and calculates the voltage once per cycle.

- This results in faster operation but accuracy is limited to a narrower frequency range.

Basic Settings (cont.):

Phase Rotation:
This setting adjusts nominal phase rotation.

- We do not recommend reversing the CT and PT connections to change the rotation.
- Using the software switch will result in proper phase targeting.

50DT Split phase Differential:
Used for split phase hydro applications.

- Changes IA, IB, and IC metering labels
- Disables 87G

Relay Seal In Time:

- *Normal* : Sets the minimum amount of time a relay output contact will be closed after tripping element deassertion.
- *Pulse* : Sets the relay output contact closure time duration regardless of if the tripping element maintains assertion.
- *Latched*: Relay output contact will remain closed until relay is reset

Connect the relay voltages for today's training:

M-34XX Test Connection for L-L

Test Set	M-3425A
Va	Va +
Vb	Vb +
Vc	Vc +
Vn	No connection

On the relay only:
Jumper -Va to +Vb
Jumper -Vb to +Vc
Jumper -Vc to +Va

The test set voltage is a LN voltage, but the relay "sees" a LL voltage.

M-3425A Pre-startup Tasks

Connect the relay currents for today's training:

M-34XX Test Connection

Test Set currents 1	M-3425A
IA	IA +
IB	IB +
IC	IC +
IN	Jumper

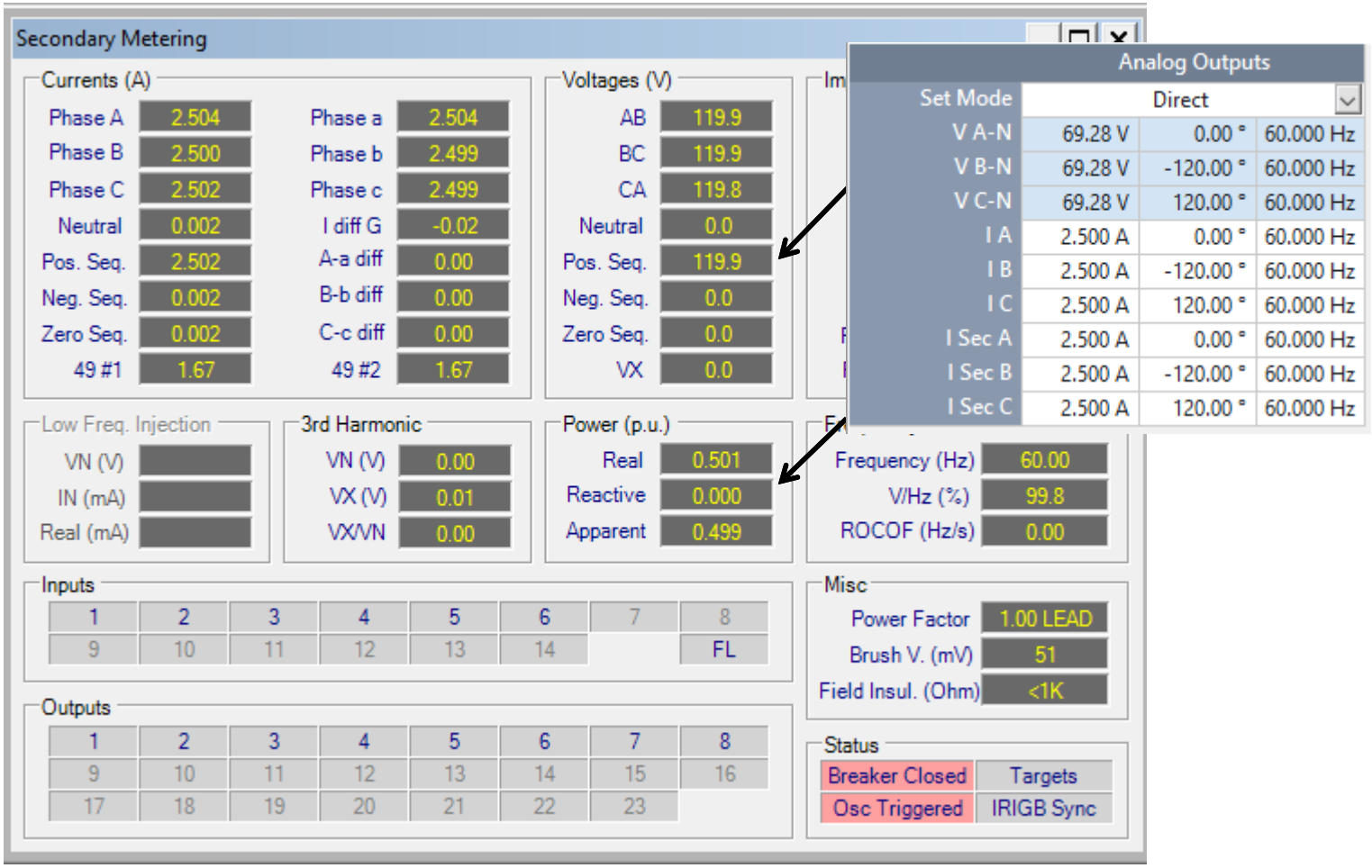
Differential Currents

Test Set currents 2	M-3425A
IA	Ia +
IB	Ib +
IC	Ic +
IN	Jumper

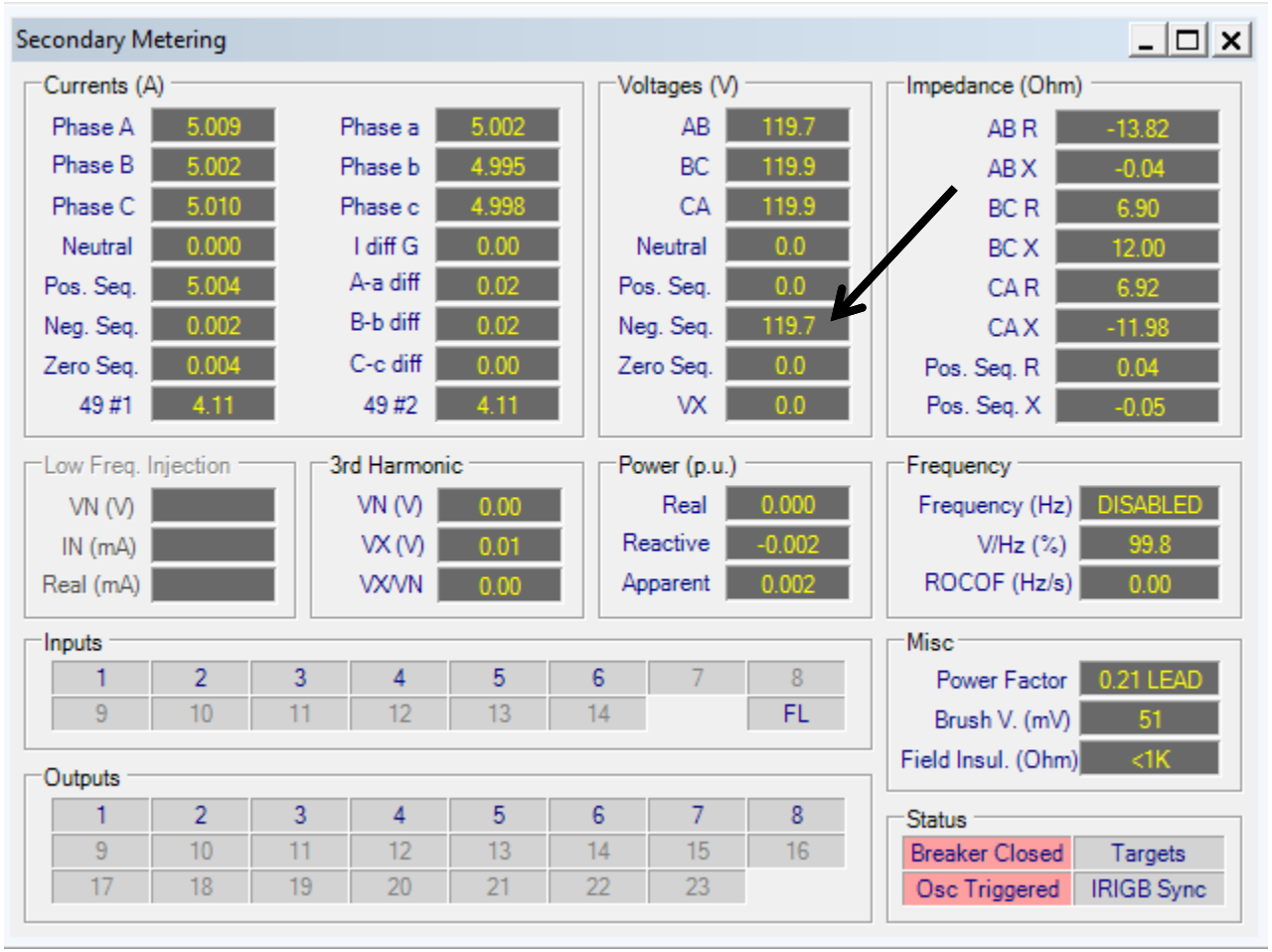
Balance currents for all voltage-type tests,
or disable 87 elements

Apply nominal quantities and check the metering

Delta-Connected PTs with Line-Line Relay Setting

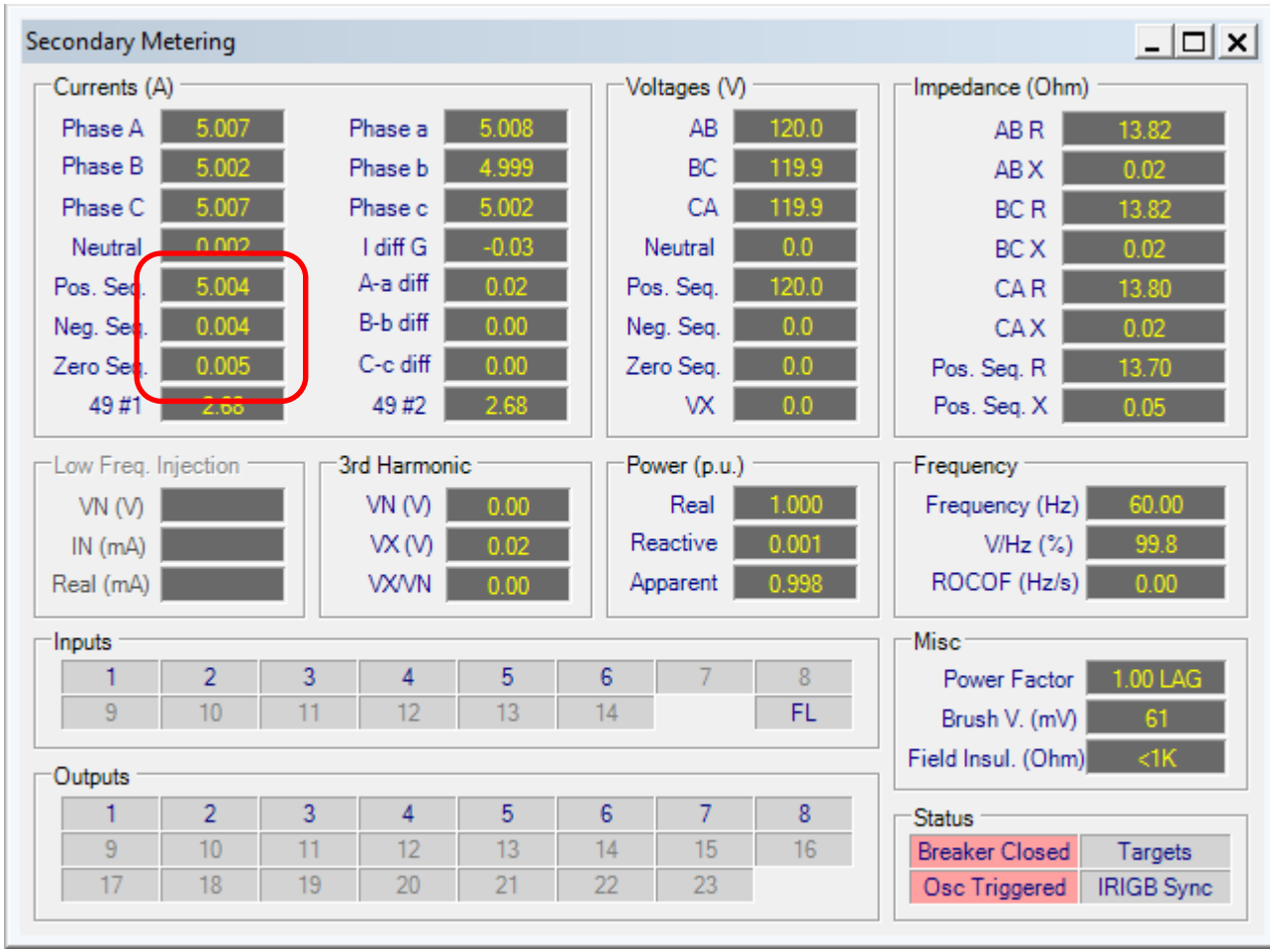


Incorrect Wiring: VA and VB Rolled

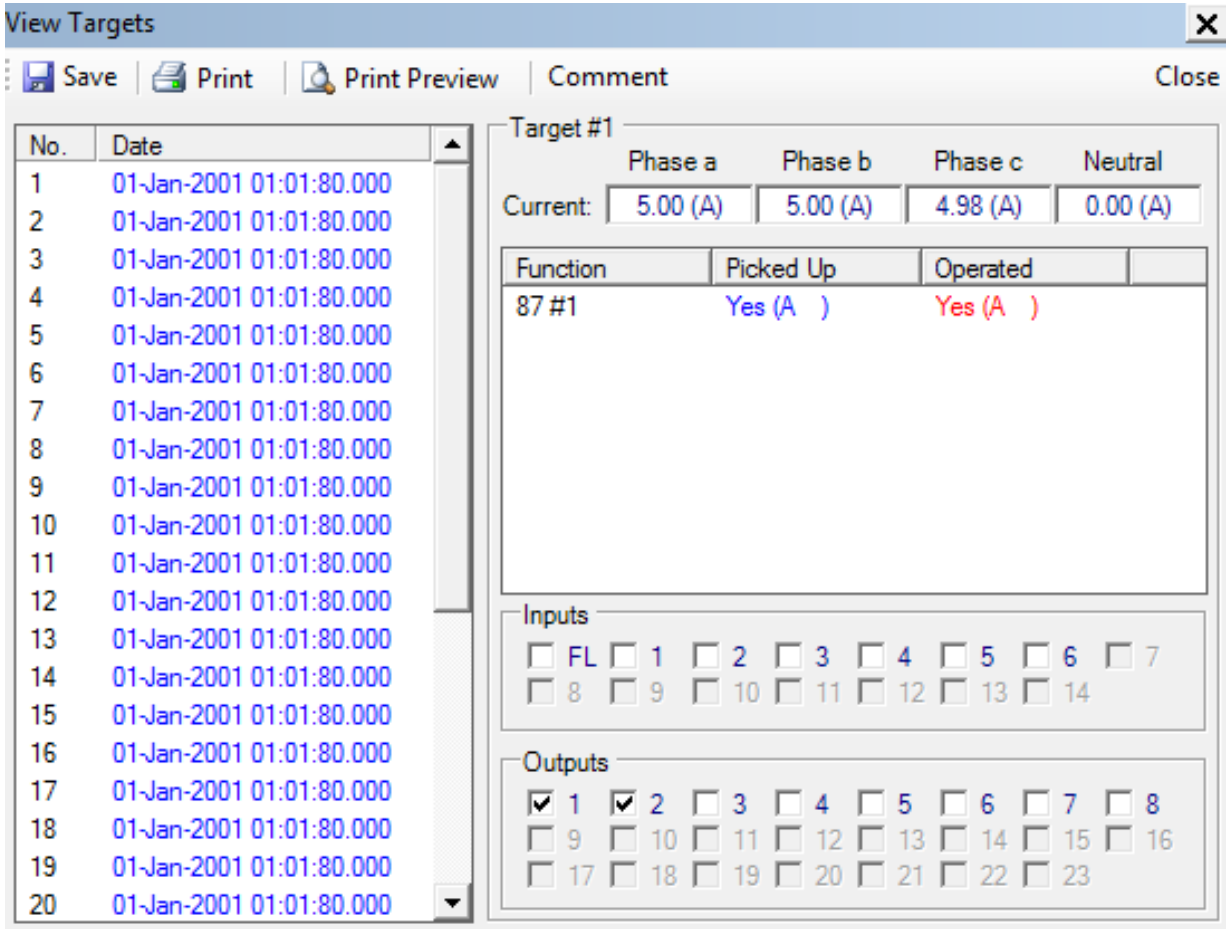


What shows the relay is wired wrong?

Correct Wiring

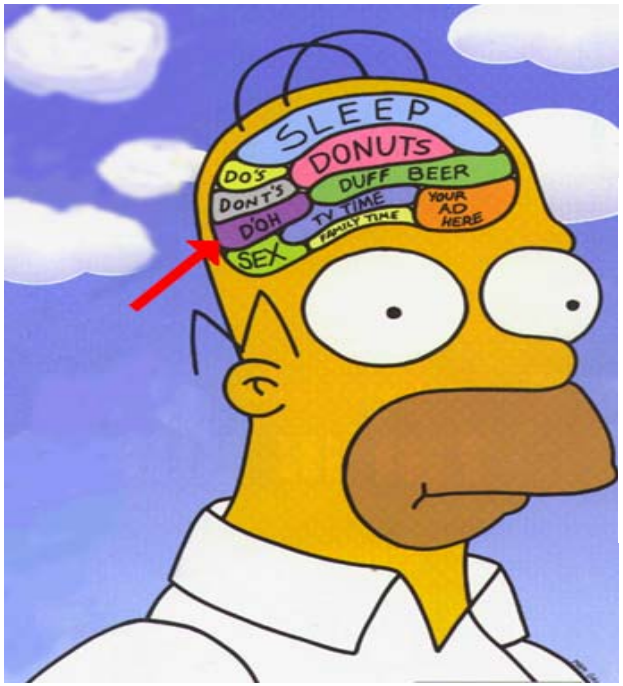


CT wiring wrong?



- Differential (87) Trip!

How Do We Test?



"Thinking logically as to how a relay responds in a faulted condition helps to visualize a proper test sequence"
--Drew Welton

How Do We Test?

Utilize proper test sequences to avoid associated logic settings:

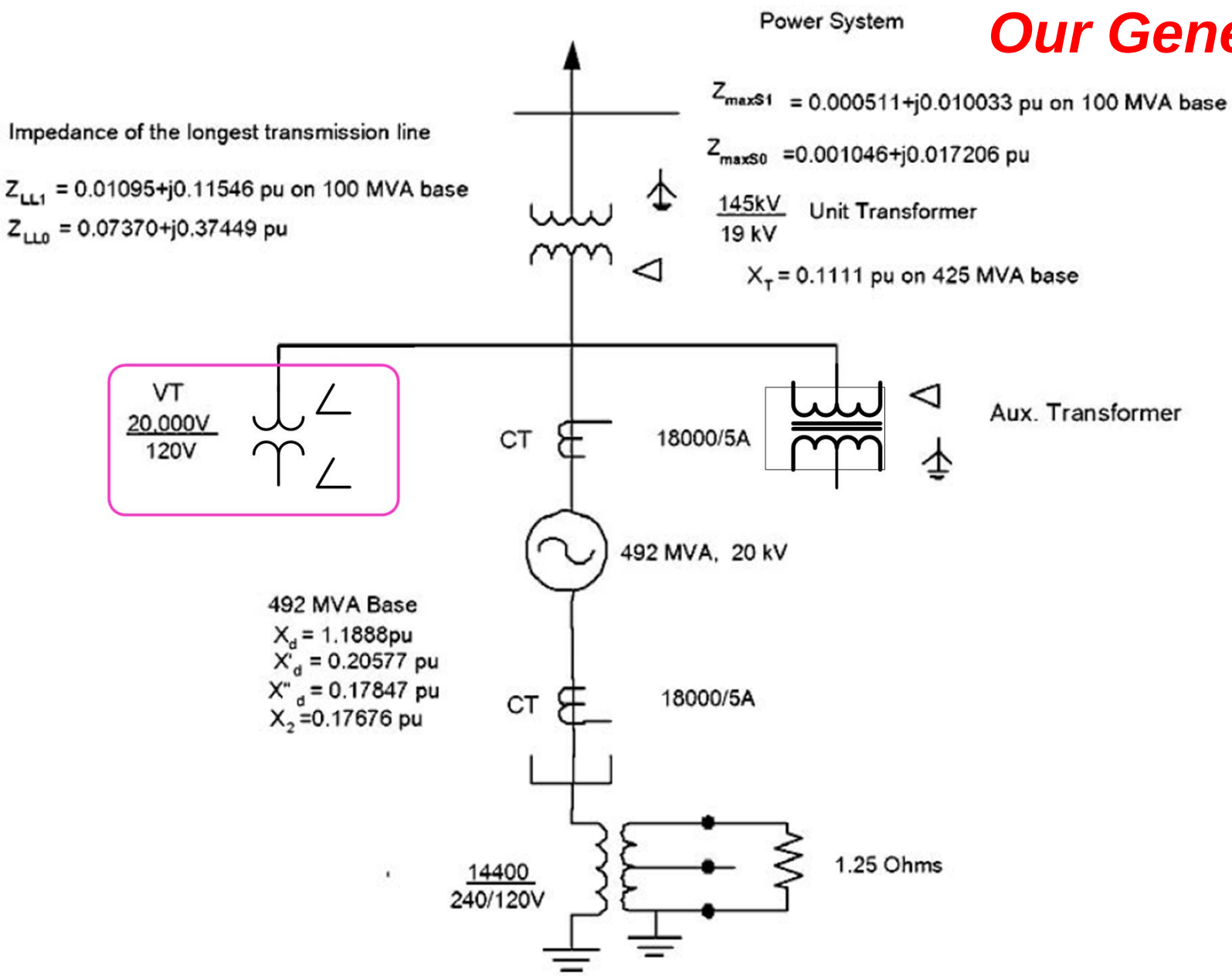
1. Apply proper pre-fault conditions
   - Nominal V, I
   - 52/a=closed, 52/b=open, contacts in non-faulted state
   - Apply long enough for reset from lockouts if needed
2. Faulted values applied
3. Post-fault State
   - V, I faulted value removed (I=0), (V=0 or Nominal, location of the VT)
   - Breaker contact status changes (52/a=open, 52/b=closed)

43

Overall Test Plan

1. Pre-Startup Tasks and Relay Setup
2. Loss of Field (40)
3. Phase Differential Current (87)
4. Fuse Loss (50FL)
5. Neutral Overvoltage (59N)
   - (time permitting)
6. Oscillography and SOE Demo

Our Generator



40: Loss of Field Application

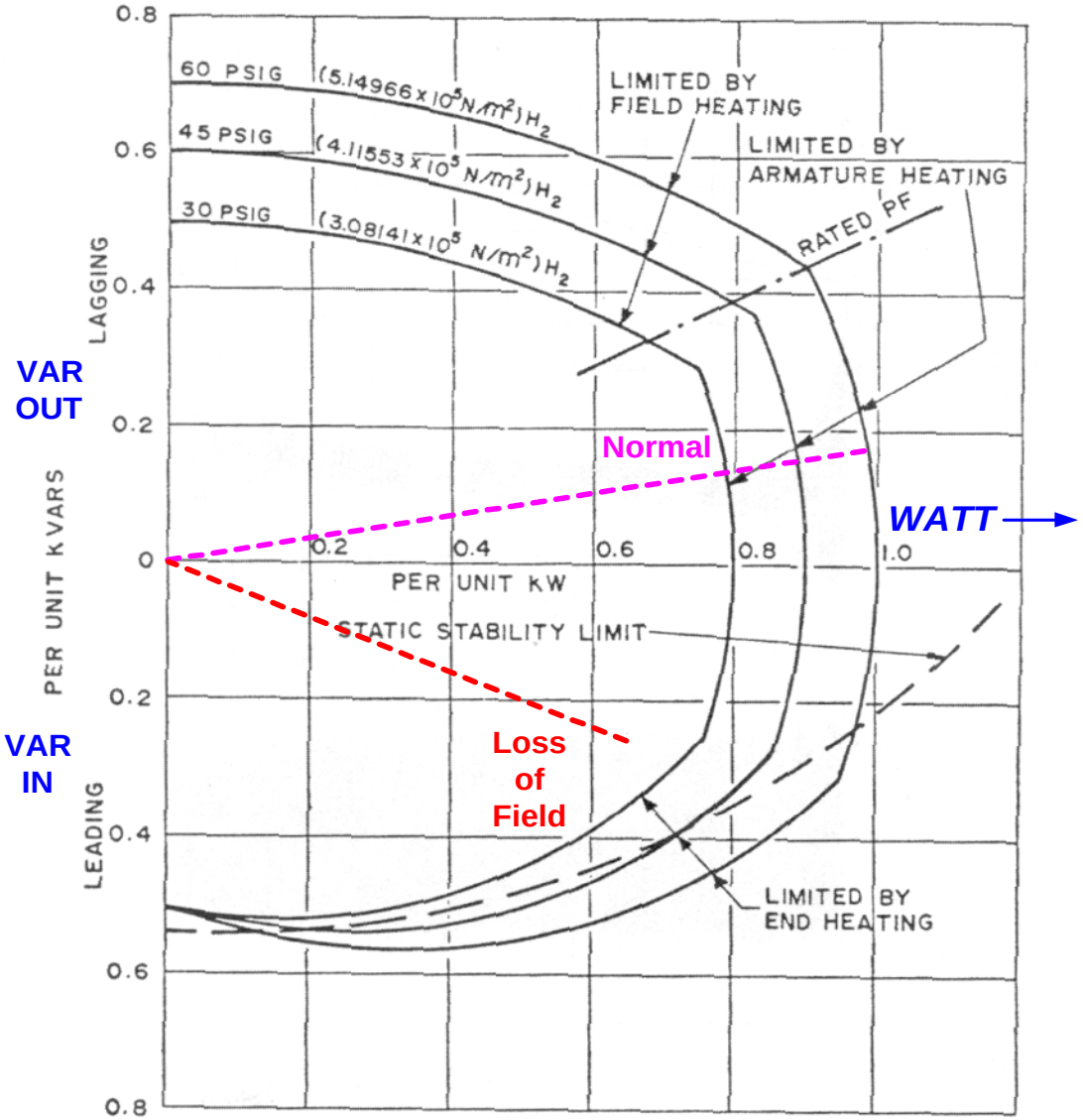
- Occurs when the DC source connected to the generator field is interrupted, or, system voltage increases

- Caused by:
  - Open field circuits
  - Field short circuits
  - Accidental tripping of the field breaker
  - Voltage regulator control systems
  - Loss of field to the main exciter
  - Loss of AC source to a *dc generator-commutator exciter* or *alternator rectifier exciter*
  - High voltage on system with generator absorbing VArs

40: Loss of Field

Can adversely effect the generator and the system!!

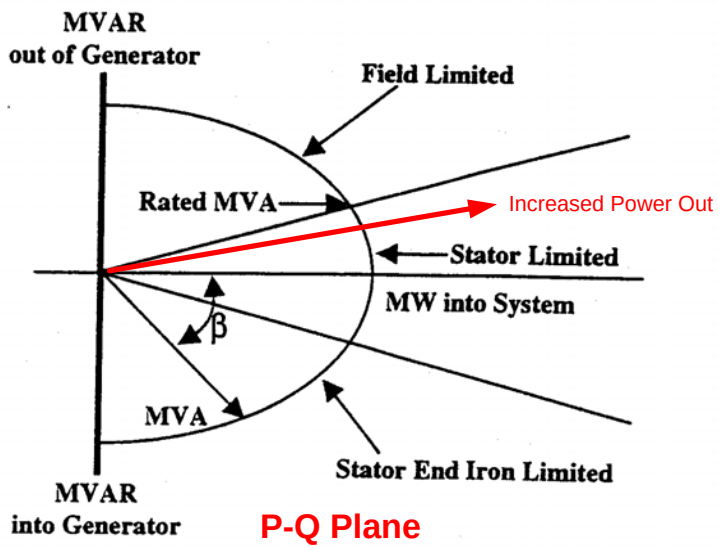
- Generator effects
  - Synchronous generator becomes induction
  - Slip induced eddy currents heat rotor surface
  - High reactive current drawn by generator overloads stator
- Power system effects
  - Loss of reactive support
  - Creates a reactive drain
  - Can trigger system/area voltage collapse



TYPICAL GENERATOR CAPABILITY CURVE

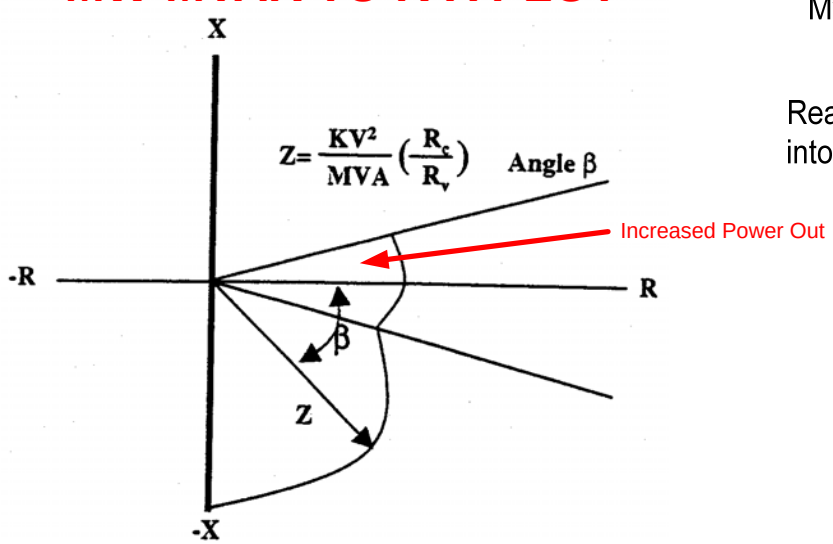
Generator capability curve viewed on the P-Q plane.

This info must be converted to the R-X plane.

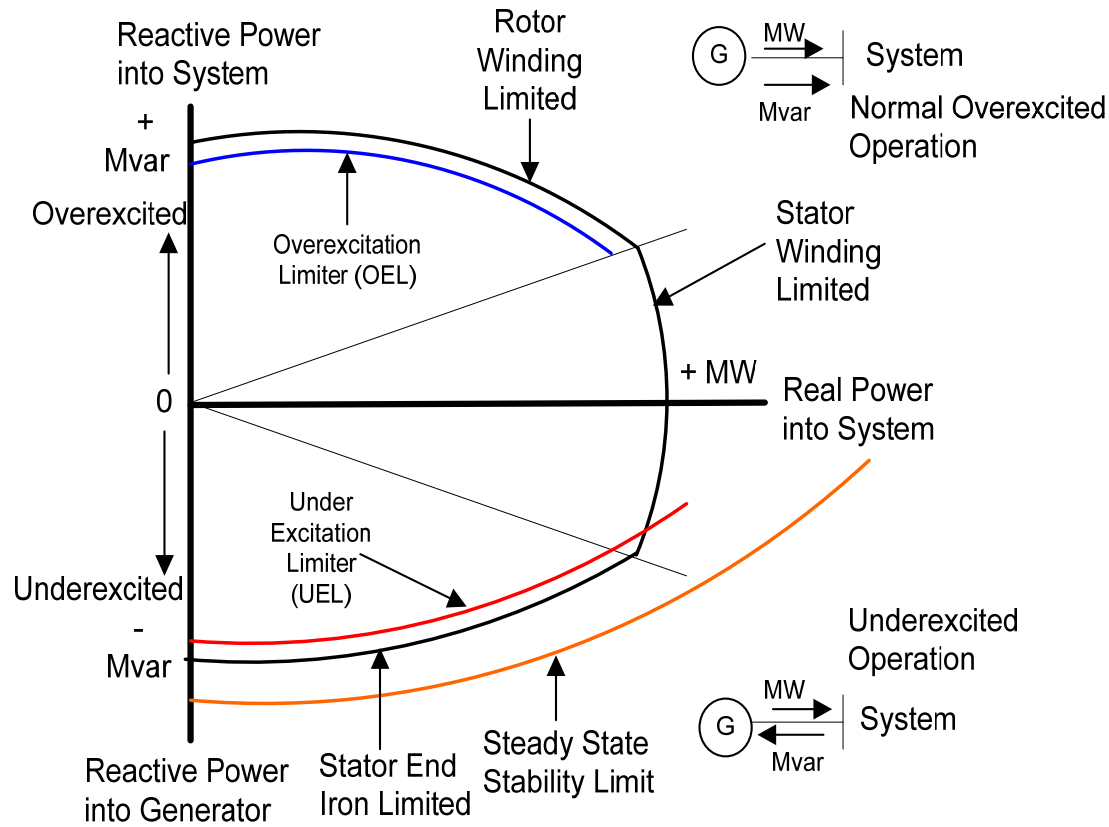


P-Q Plane

TRANSFORMATION FROM MW-MVAR TO R-X PLOT



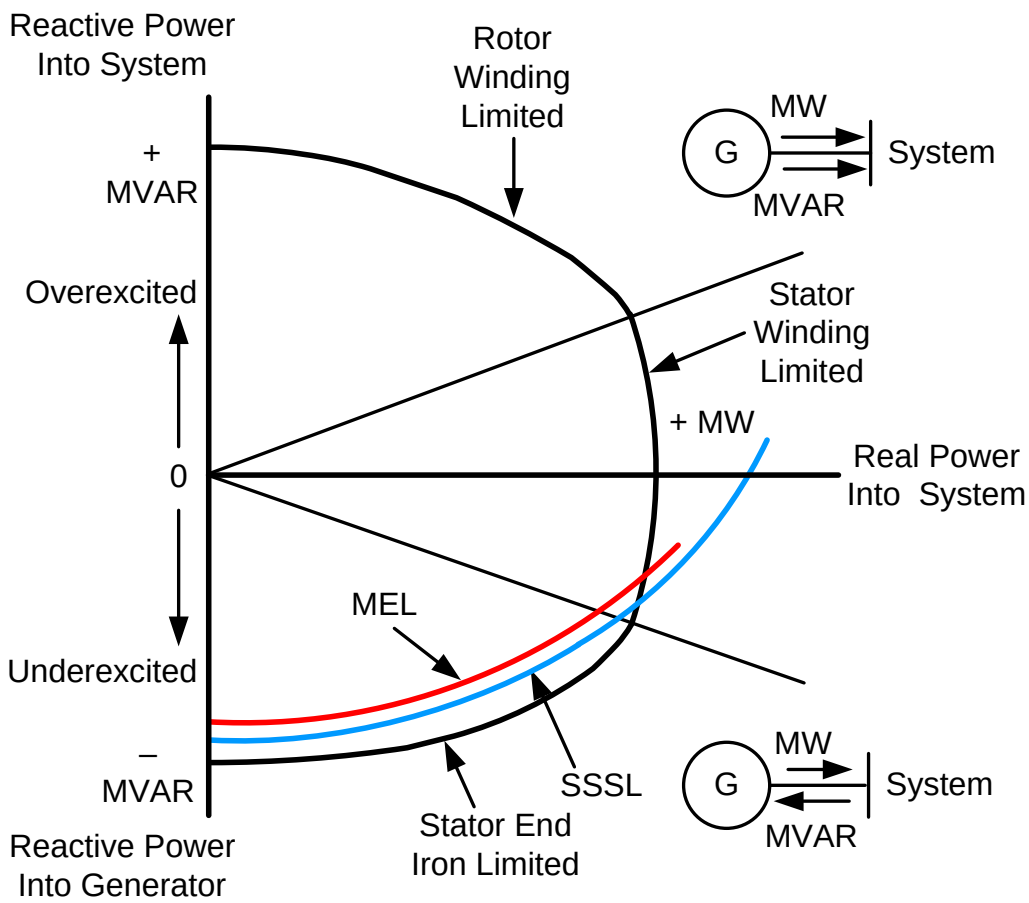
R-X Plane



TYPICAL GENERATOR CAPABILITY CURVE Excitation Limiters and Steady State Stability

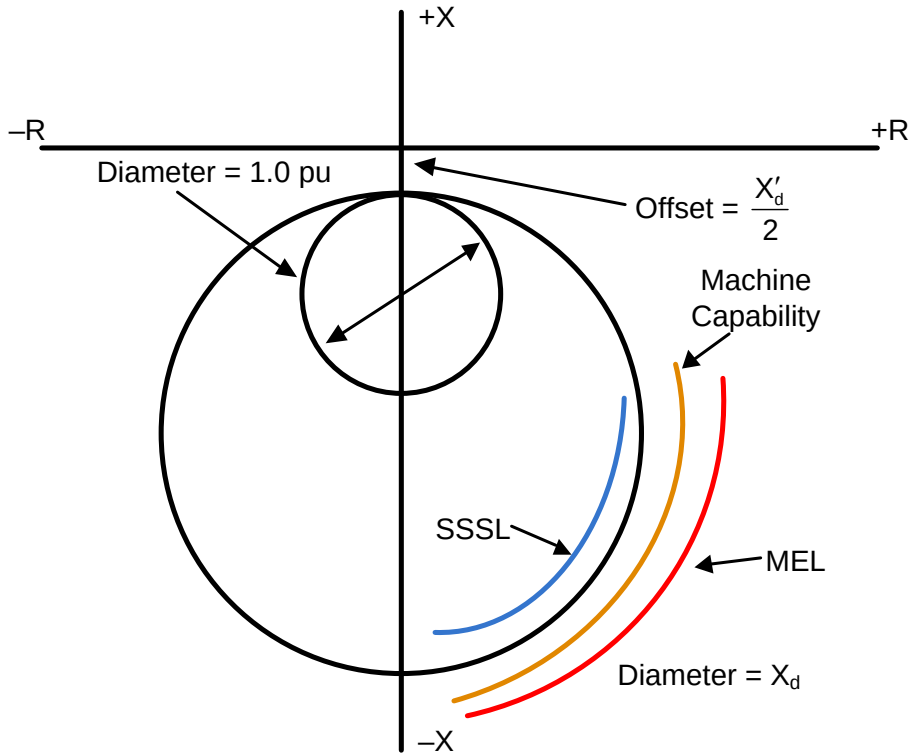
Generator Capability Curve

- Limiting factors are rotor and stator thermal limits
- Underexcited limiting factor is stator end iron heat
- Excitation control setting control is coordinated with steady-state stability limit (SSSL)
- Minimum excitation limiter (MEL) prevents exciter from reducing the field below SSSL

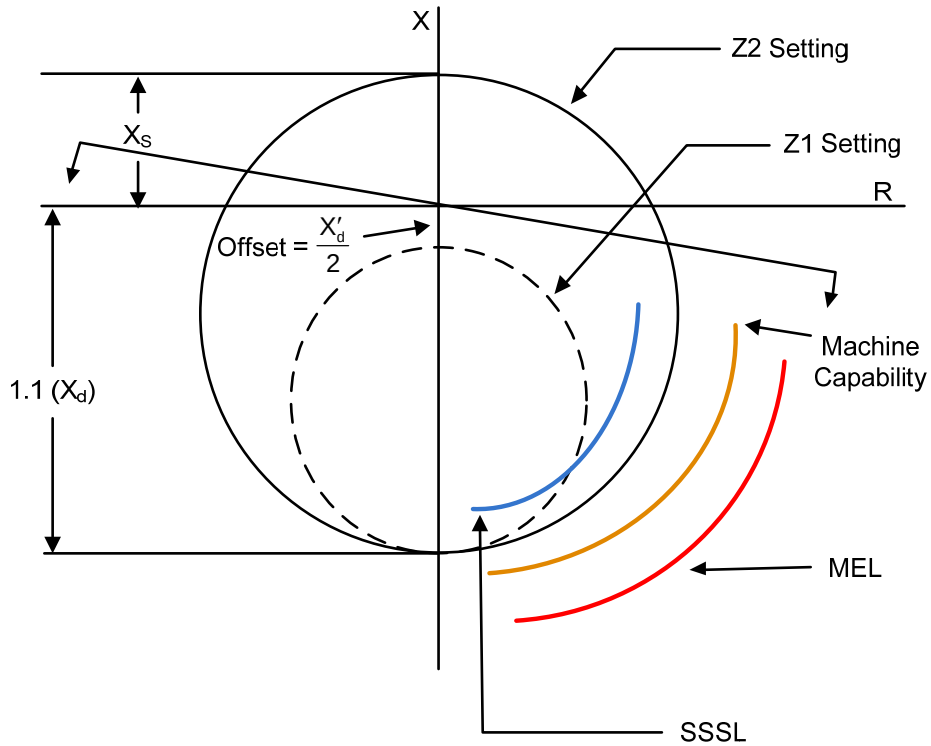


Loss of Field

GE and Westinghouse Methods



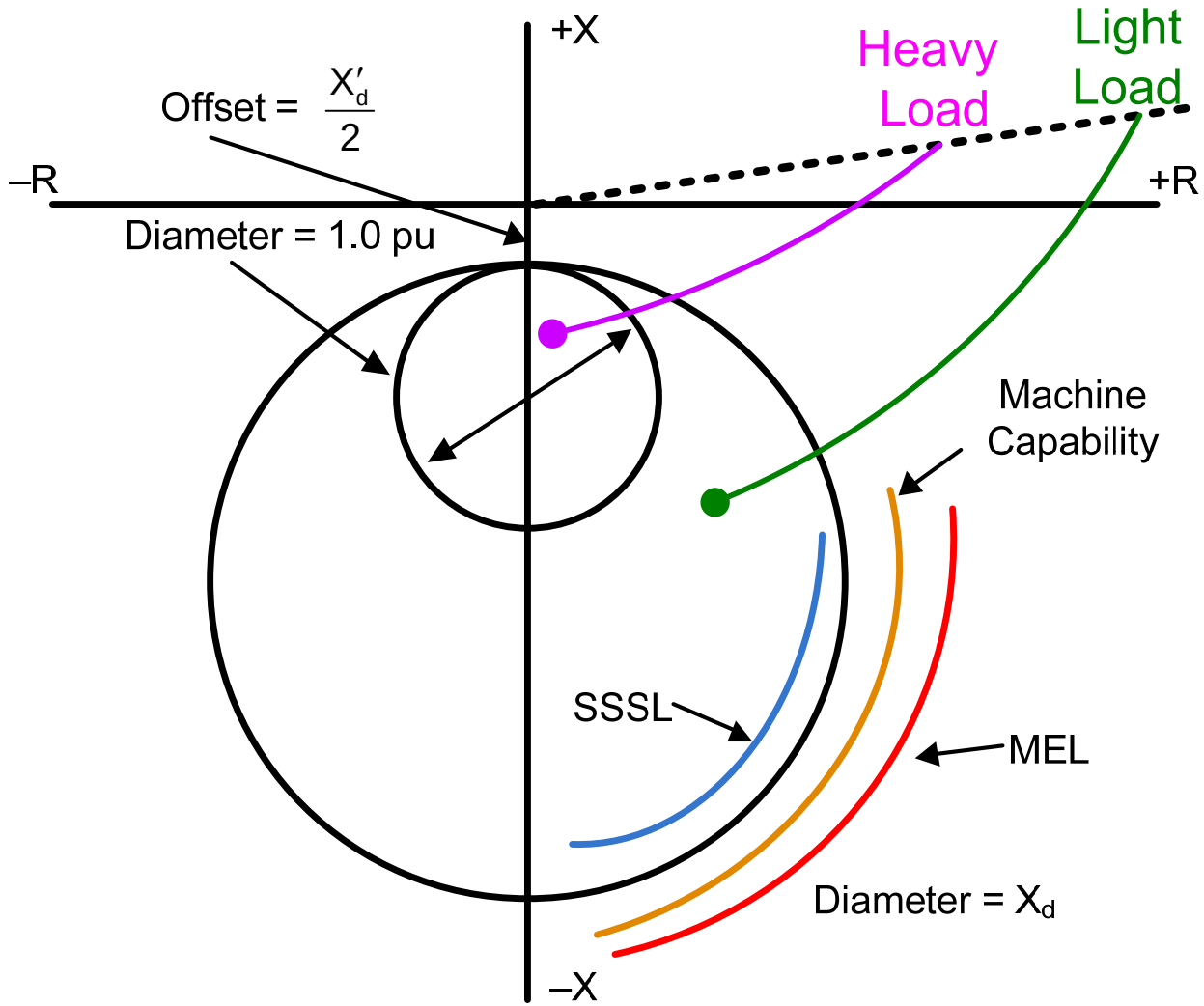
Two Zone Offset Mho
GE
CEH



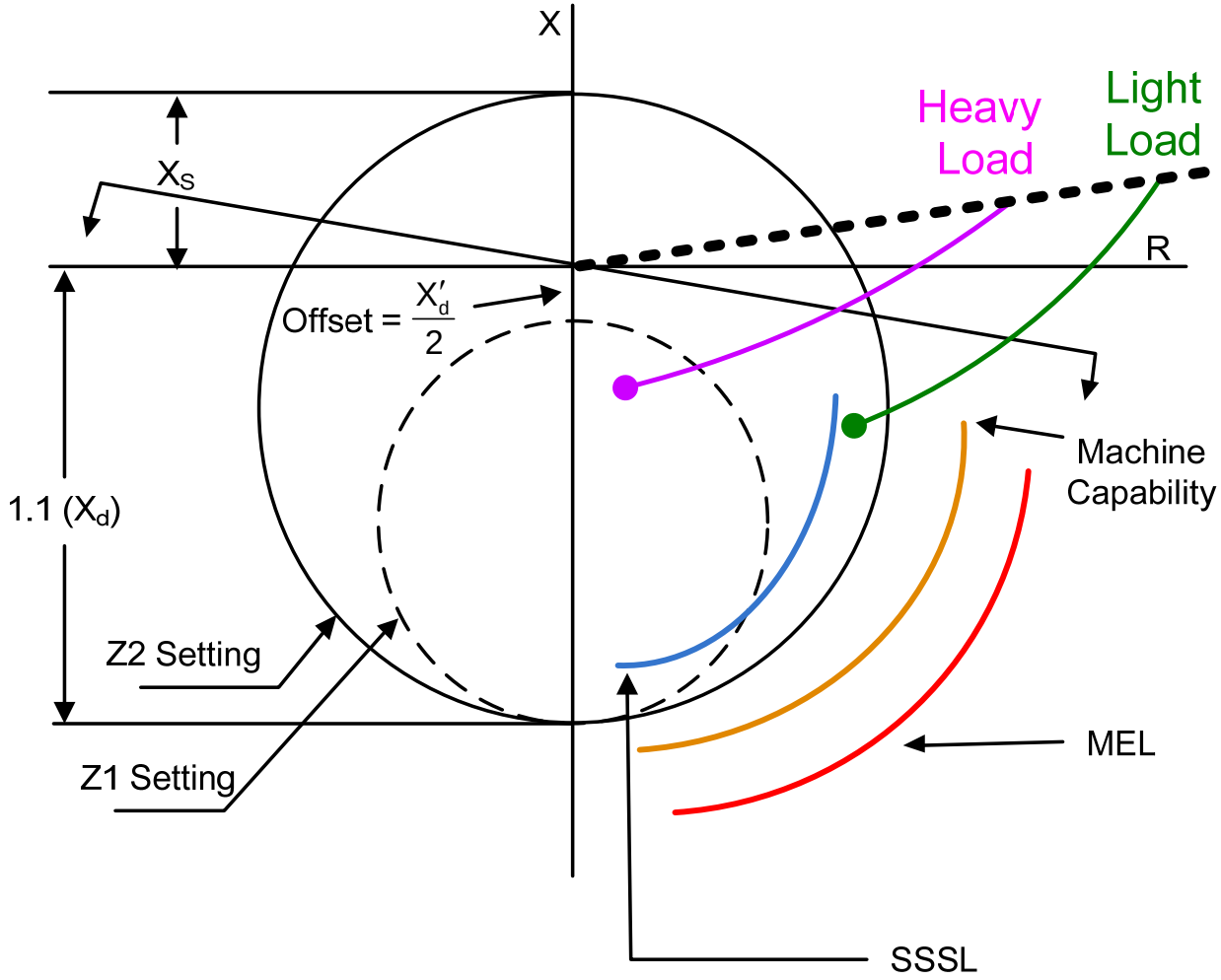
Impedance w/Directional Unit
Westinghouse
KLF

Loss of Field

Two Zone Offset Mho

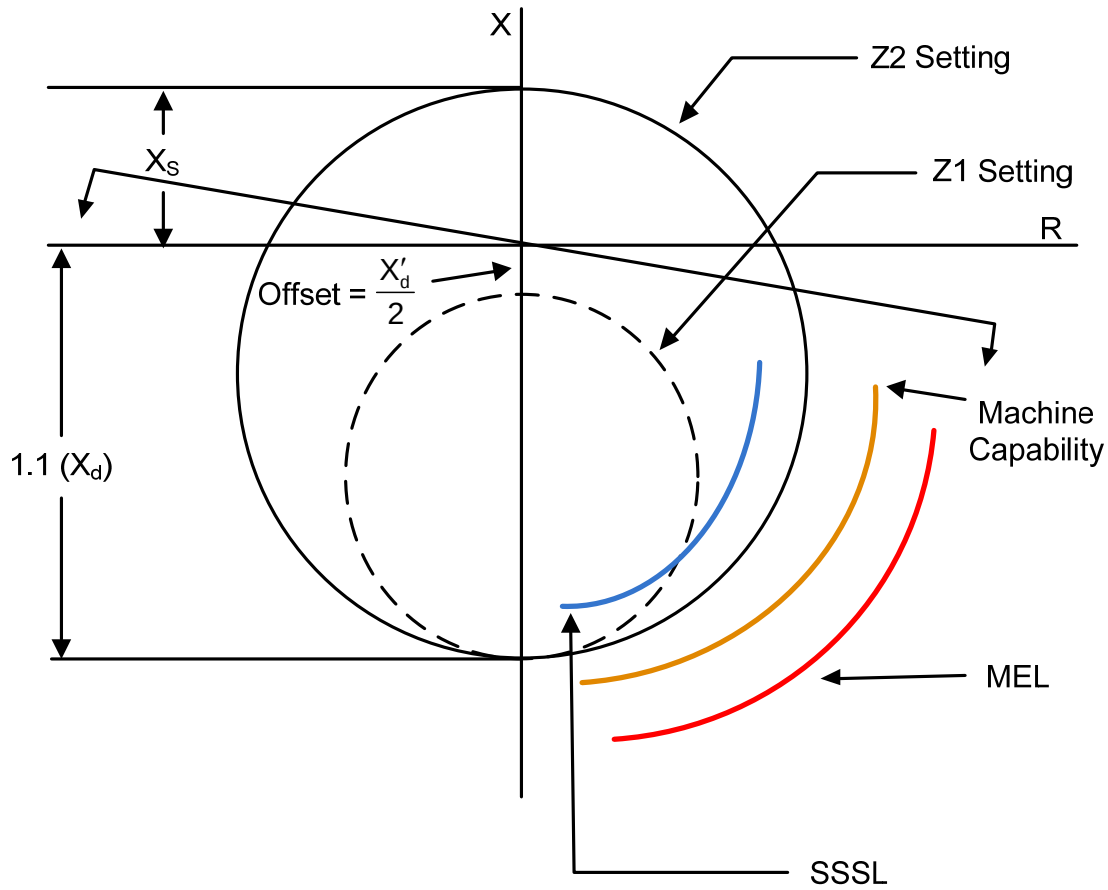


Loss of Field
Impedance w/Direction Unit



40: Multiple Mho Implementations

Better Fit Reactive Capability Curves



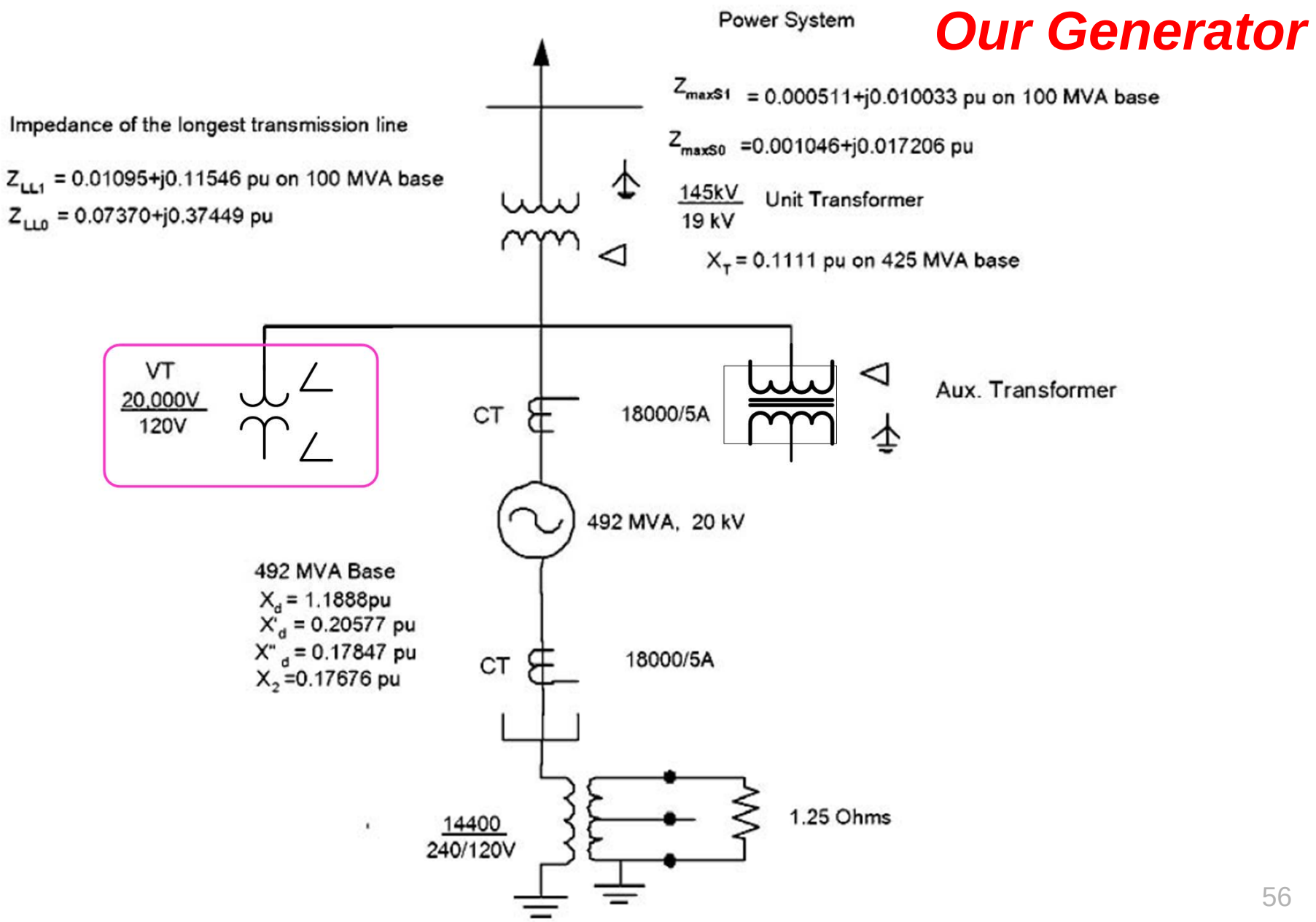
Two Zone Offset Mho Impedance w/Directional Unit

Better ability to match capability curves after conversion from P-Q to R-X plane

40: Loss of Field

- **Positive sequence quantities used to maintain security and accuracy over a wide frequency range.**
- **Must work properly from 50 to 70 Hz (60 Hz systems) Required to operate correctly (and not misoperate) with wide frequency variations possible during power swing conditions.**
- **May employ best of both methods to optimize coordination.**
  - Provide maximum coordination between machine limits, limiters and protection
  - Offset mho for Z1. Fast time for true Loss of Field event.
  - Impedance with directional unit and slower time for Z2. Better match of machine capability curve. Also able to ride through stable swing.
  - May employ voltage supervision for accelerated tripping of Z2 (slower zone) in cases of voltage collapse where machine is part of the problem, importing VArs.

Our Generator



40: Calculations for Our Generator (Offset Mho Method)

Z_{base} = (GEN kV^2 / GEN MVA) / (1.73*kV_{base})
Z_{base} = (20 kV^2 / 492 MVA) / (1.73*20 kV_{base})
Z_{base} = 0.813 Ω_{pri}

I_{base} = (MVA * 1000) / (1.73 * kV_{Base})
I_{base} = (492 MVA * 1000) / (1.73 * 20_{Base})
I_{base} = 14,219A $_{pri}$

VTR = 20,000V / 120V = 166.7
CTR = 18,000A / 5A = 3,600
CTR/VTR = 21.5996

$I_{base\ sec}$ = I $_{pri}$ / CTR
$I_{base\ sec}$ = 14,219 $_{pri}$ / 3,600
$I_{base\ sec}$ = 3.945 A $_{sec}$

$V_{LL\ sec}$ = 120V
$V_{LG\ sec}$ = $V_{LL\ sec}$ / 1.73
$V_{LL\ sec}$ = 69.28V sec

$Z_{Base\ sec}$ = $Z_{Base\ pri}$ * (CTR / VTR)
$Z_{Base\ sec}$ = 0.813 Ω_{pri} * (3,600 / 166.7)
$Z_{Base\ sec}$ = 17.55 Ω_{sec} (1pu)

<u>Reactances per unit (492 MVA Base)</u>
Xd = 1.1888 pu
X'd = 0.20577 pu

<u>Z2: Bigger Circle</u>
Diameter sec = $Z_{Base\ sec}$ / Xd
Diameter sec = 17.55Ω_{sec} / 1.188 pu
Diameter sec = 20.88Ω_{sec}

Offset sec: (X'd / 2) * $Z_{Base\ sec}$
Offset sec: (0.20577pu / 2) * 17.55 Ω_{sec}
Offset sec: -1.81Ω_{sec}

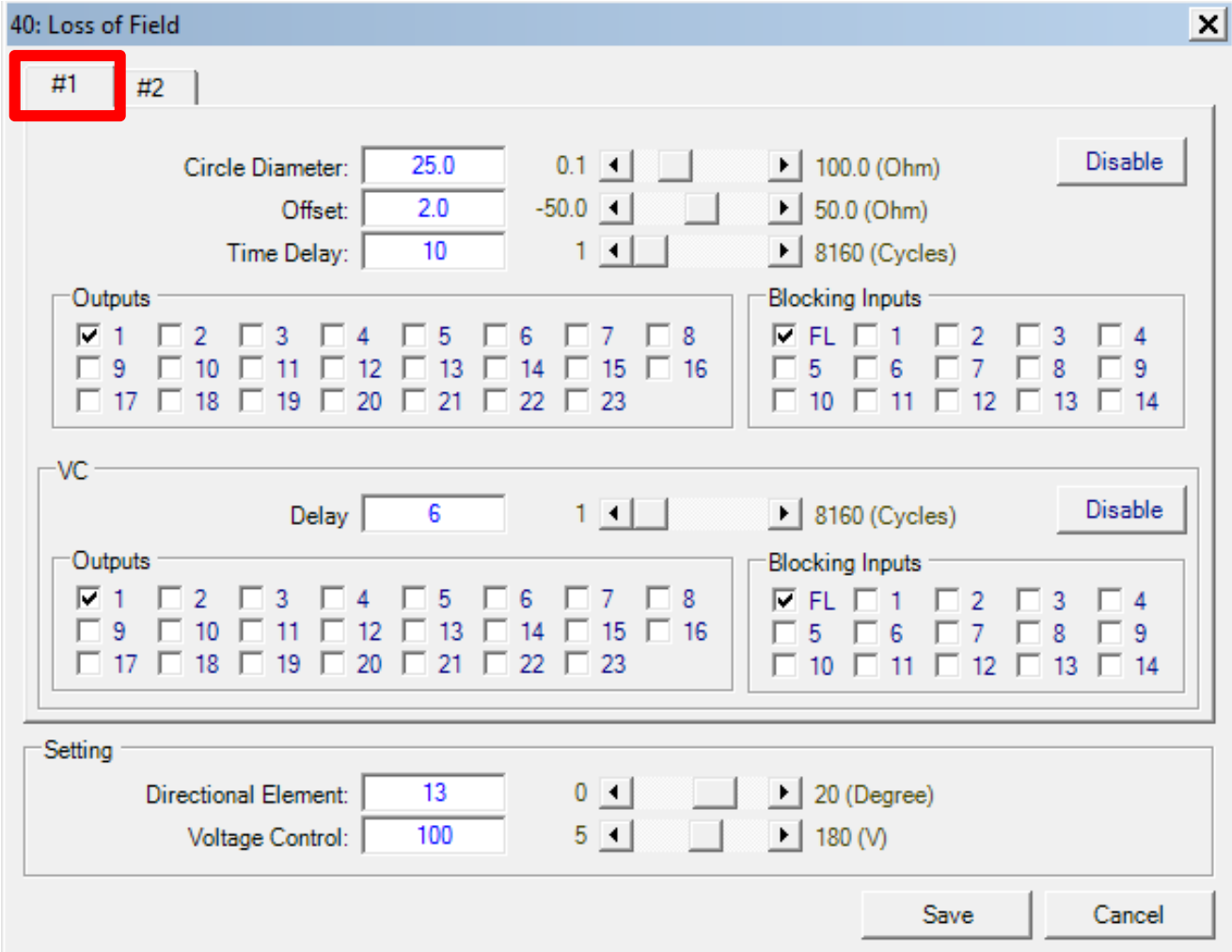
Time Delay = 1 sec.

<u>Z1: Small Circle</u>
Diameter = 1 pu sec = 17.55Ω_{sec}

Offset sec: (X'd / 2) * $Z_{Base\ sec}$
Offset sec: (0.20577pu / 2) * 17.55 Ω_{sec}
Offset sec: -1.81Ω_{sec}

Time Delay = 0.5 sec.

40: “Westinghouse” Method”; 2 Offset Mho

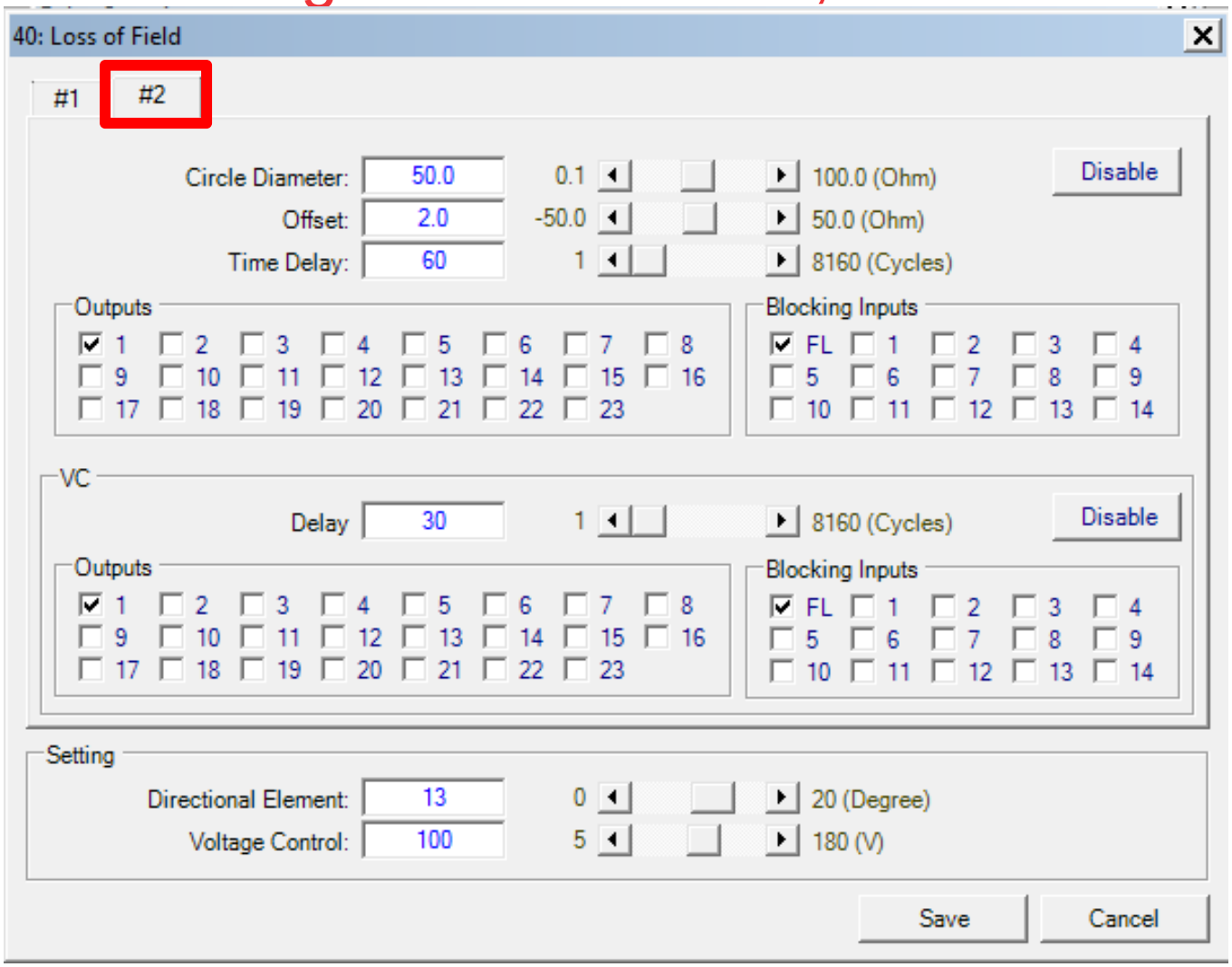


Two Zone Offset Mho Elements,

with optional Directional Control and Voltage Control

Note: Settings for example; these do not support our generator

40: “Westinghouse” Method”; 2 Offset Mho

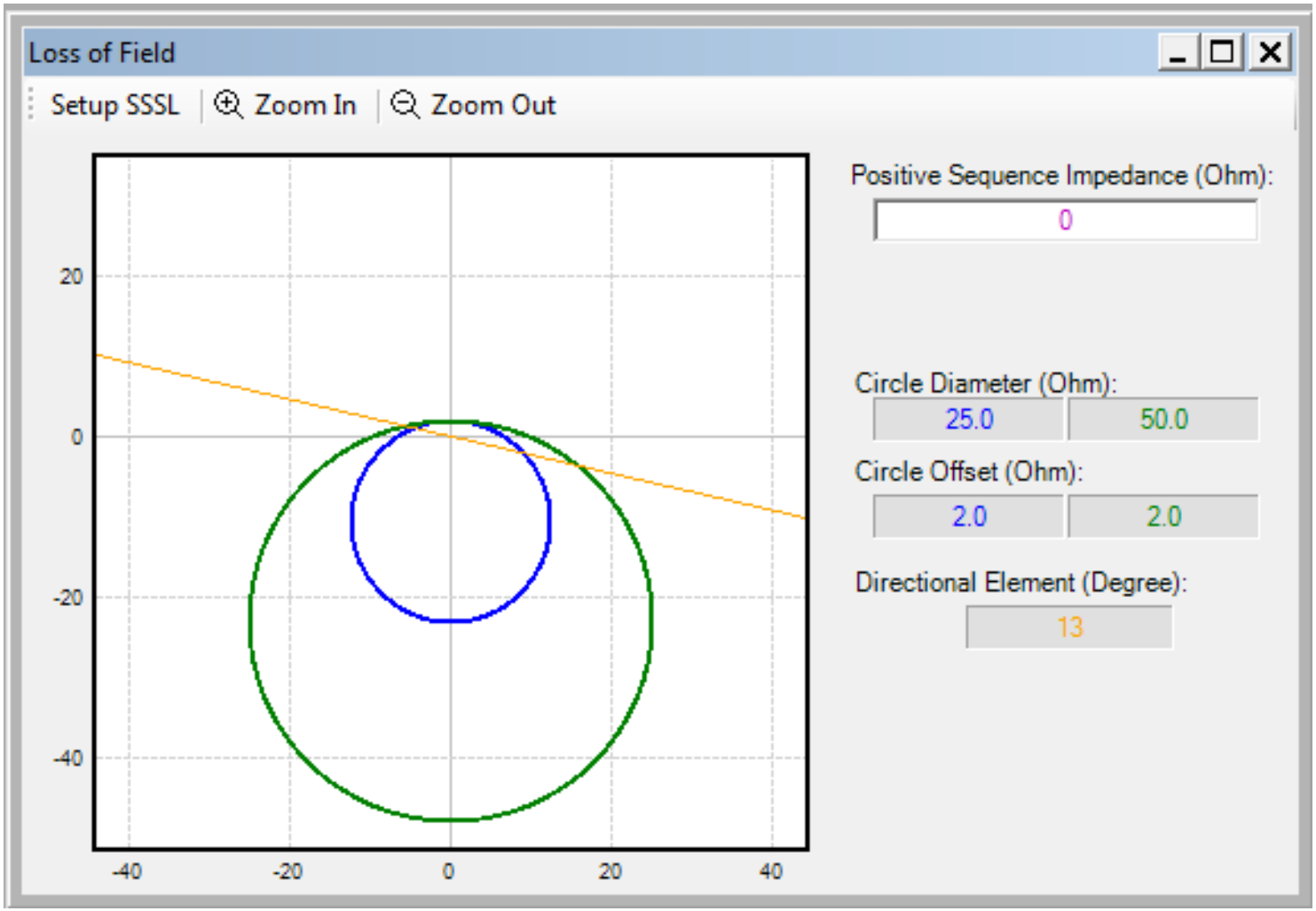


Two Zone Offset Mho Elements,

with optional Directional Control and Voltage Control

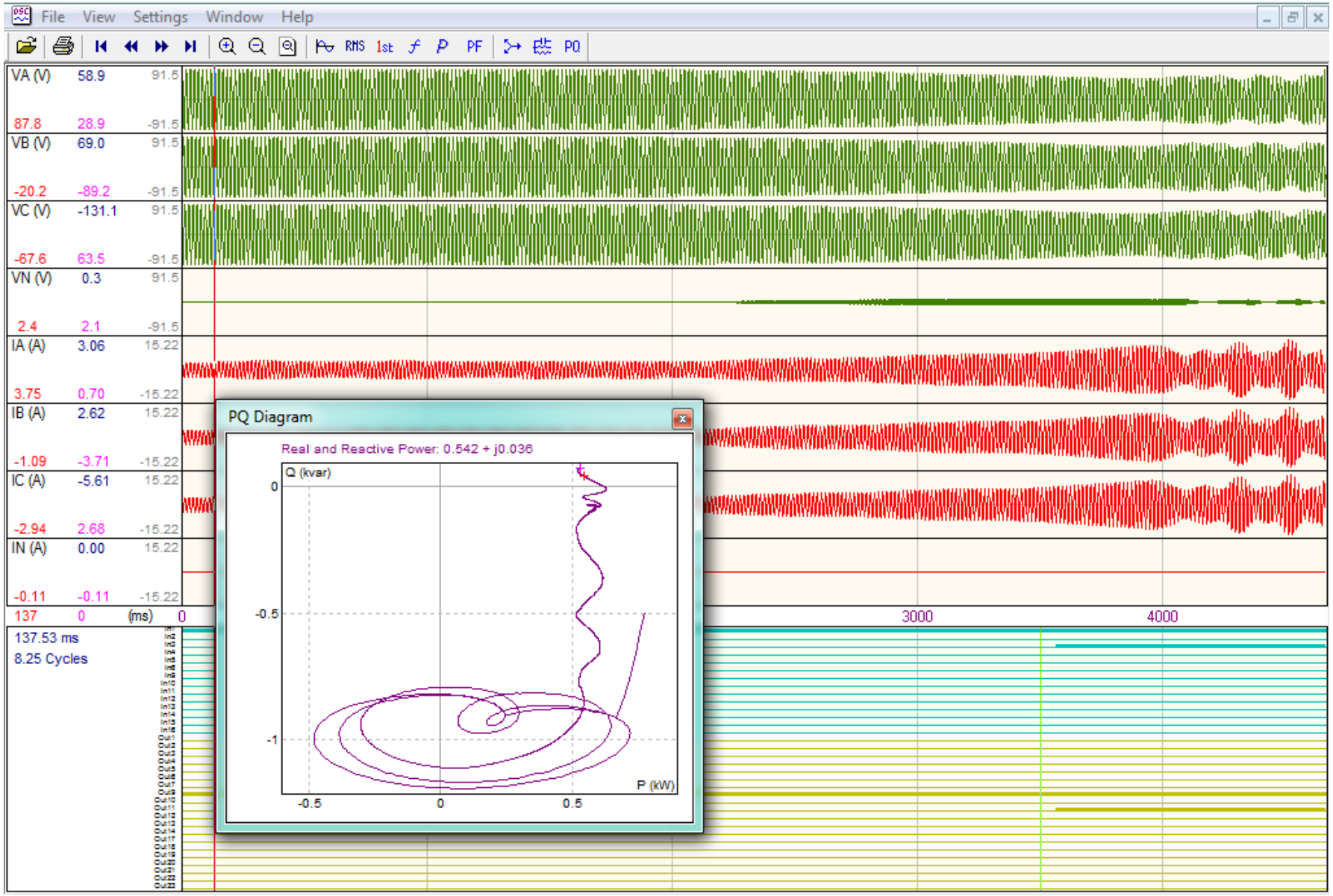
Note: Settings for example; these do not support our generator

40: “Westinghouse” Method”; 2 Offset Mho

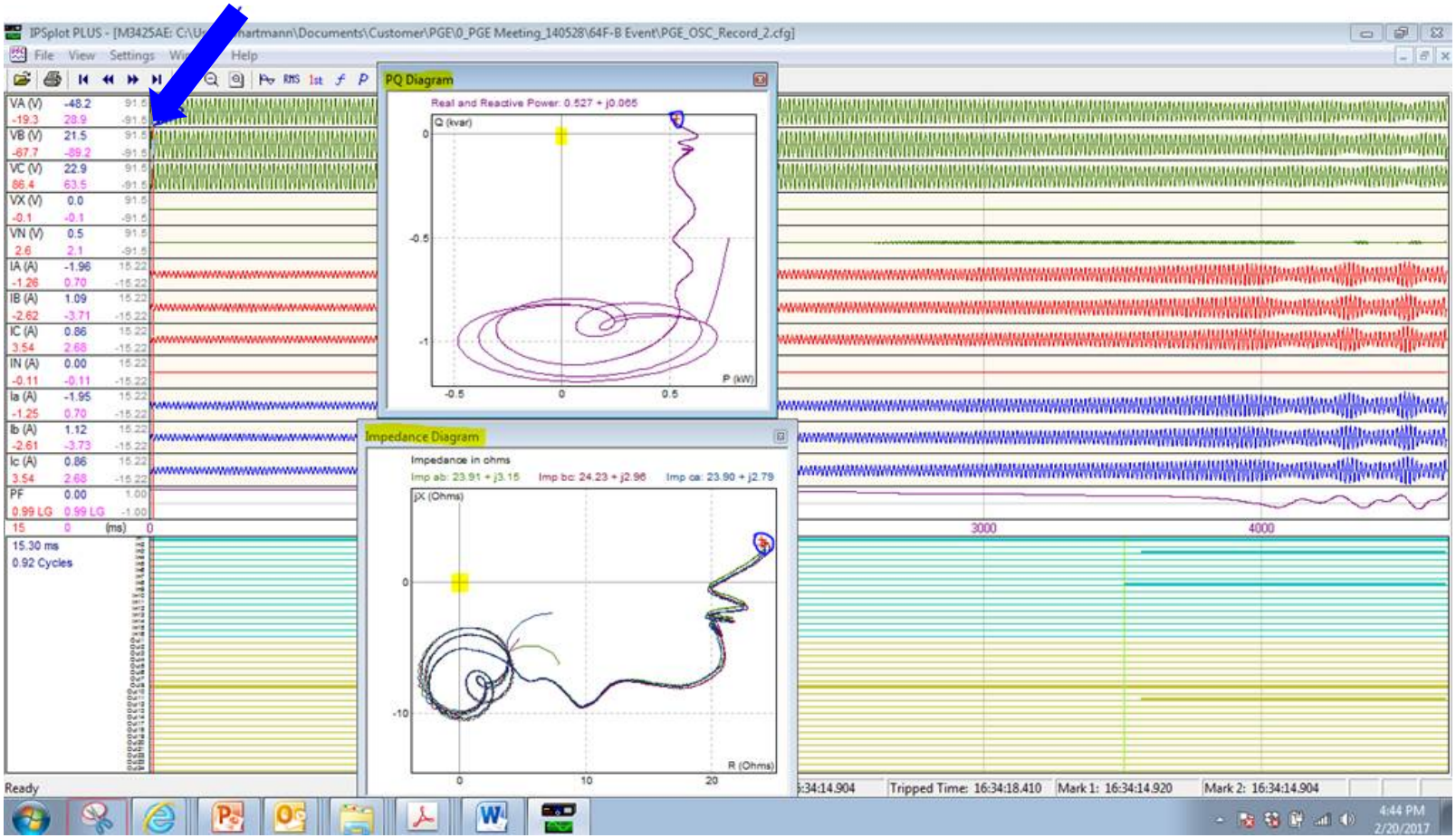


Two Zone Offset Mho Elements,
with optional Directional Control and Voltage Control

Loss of Field Event

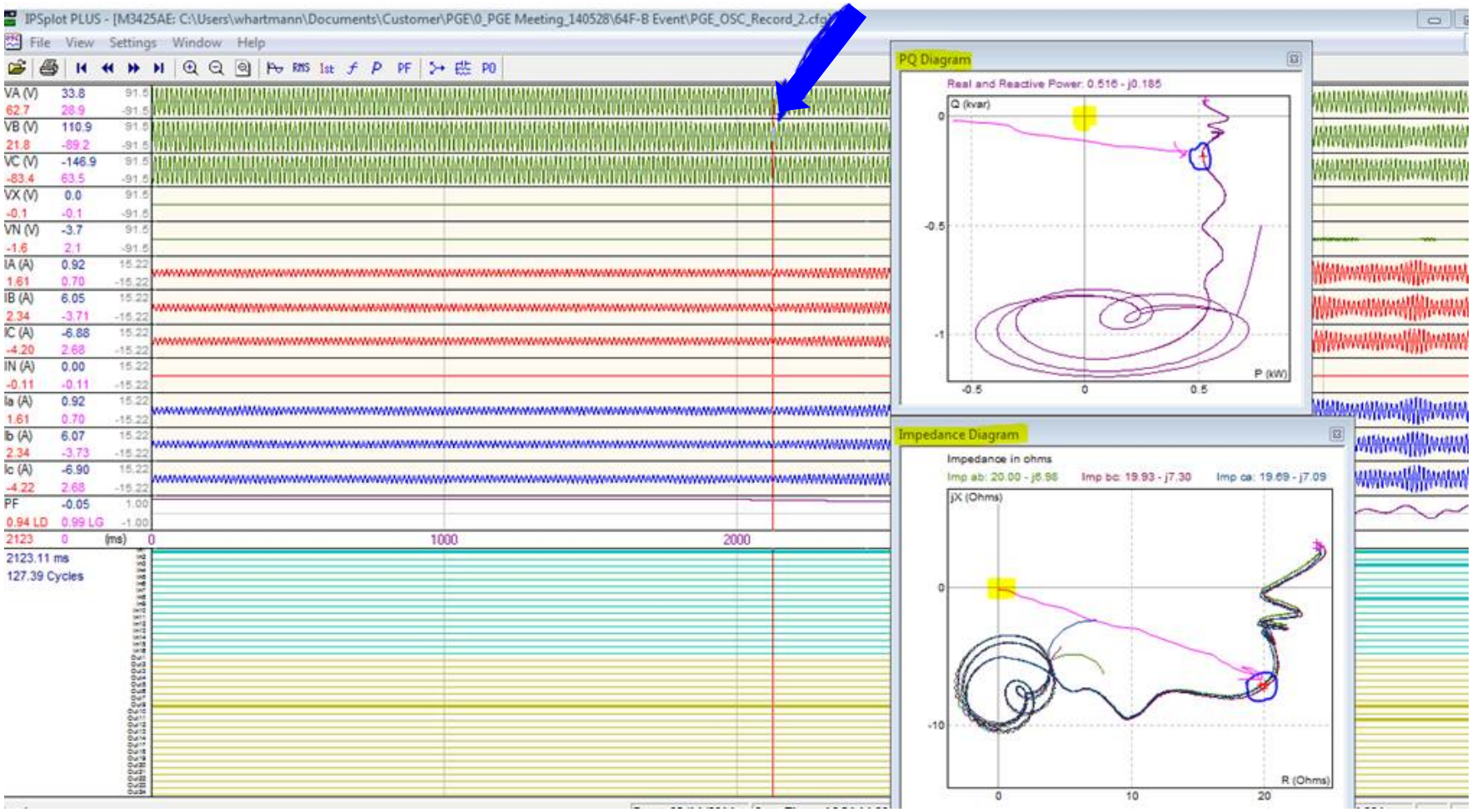


Loss of Field Event (1 of 6)



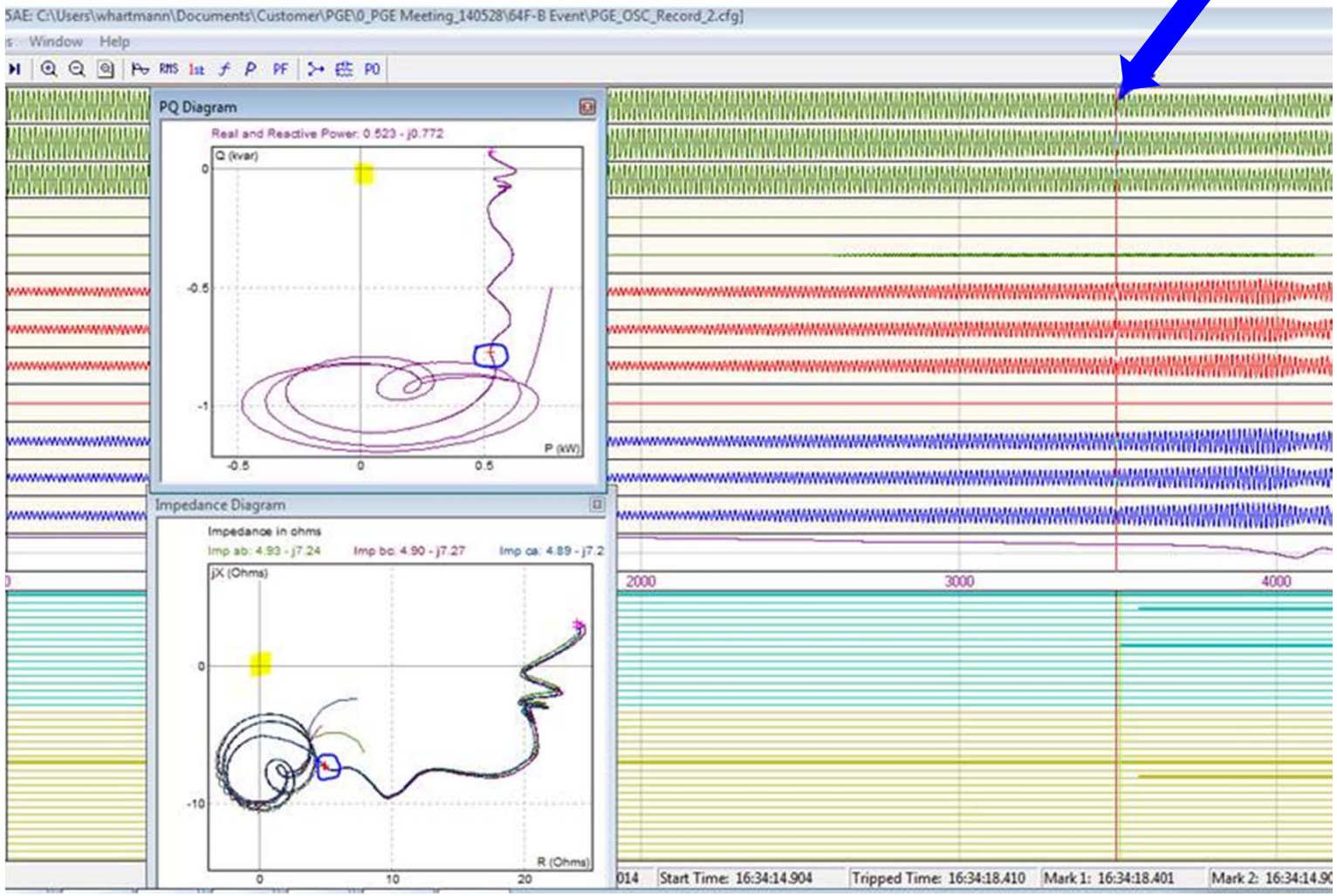
- Blue arrow shows where we are in the record
- On R-X and P-Q diagrams, yellow square on axis shows where “0, 0” is.
- On R-X and P-Q diagrams, blue circles show where the R-X and P-Q characteristics are respectively
- We have normal power output; lots of watts and a little VAr. All is good.

Loss of Field Event (2 of 6)



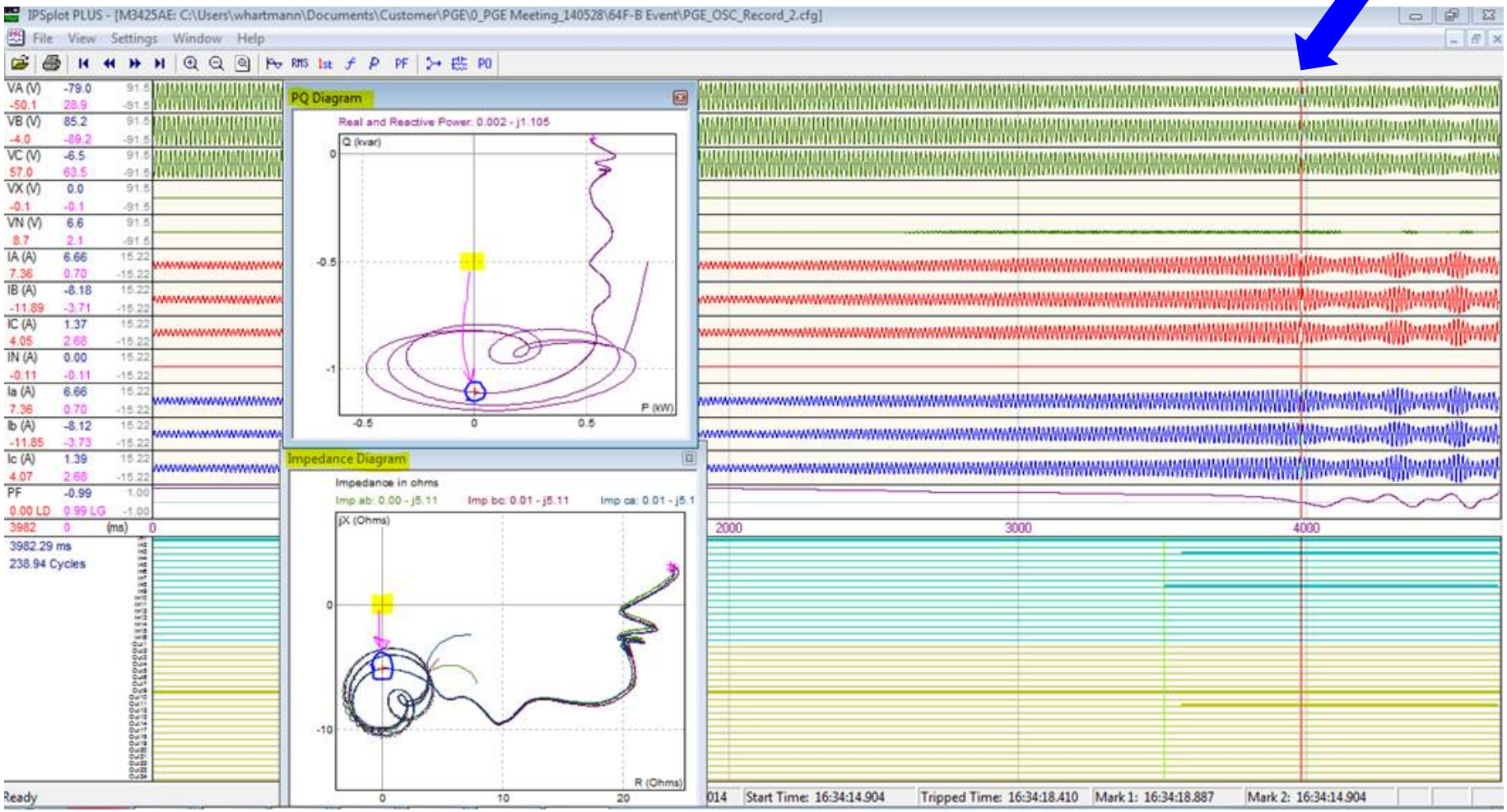
- We have lost field, and the impedance/power diagrams show we are still outputting watts but are sinking VAr
- This is before the machine goes into *asynchronous* operation with a resulting slip frequency

Loss of Field Event (3 of 6)



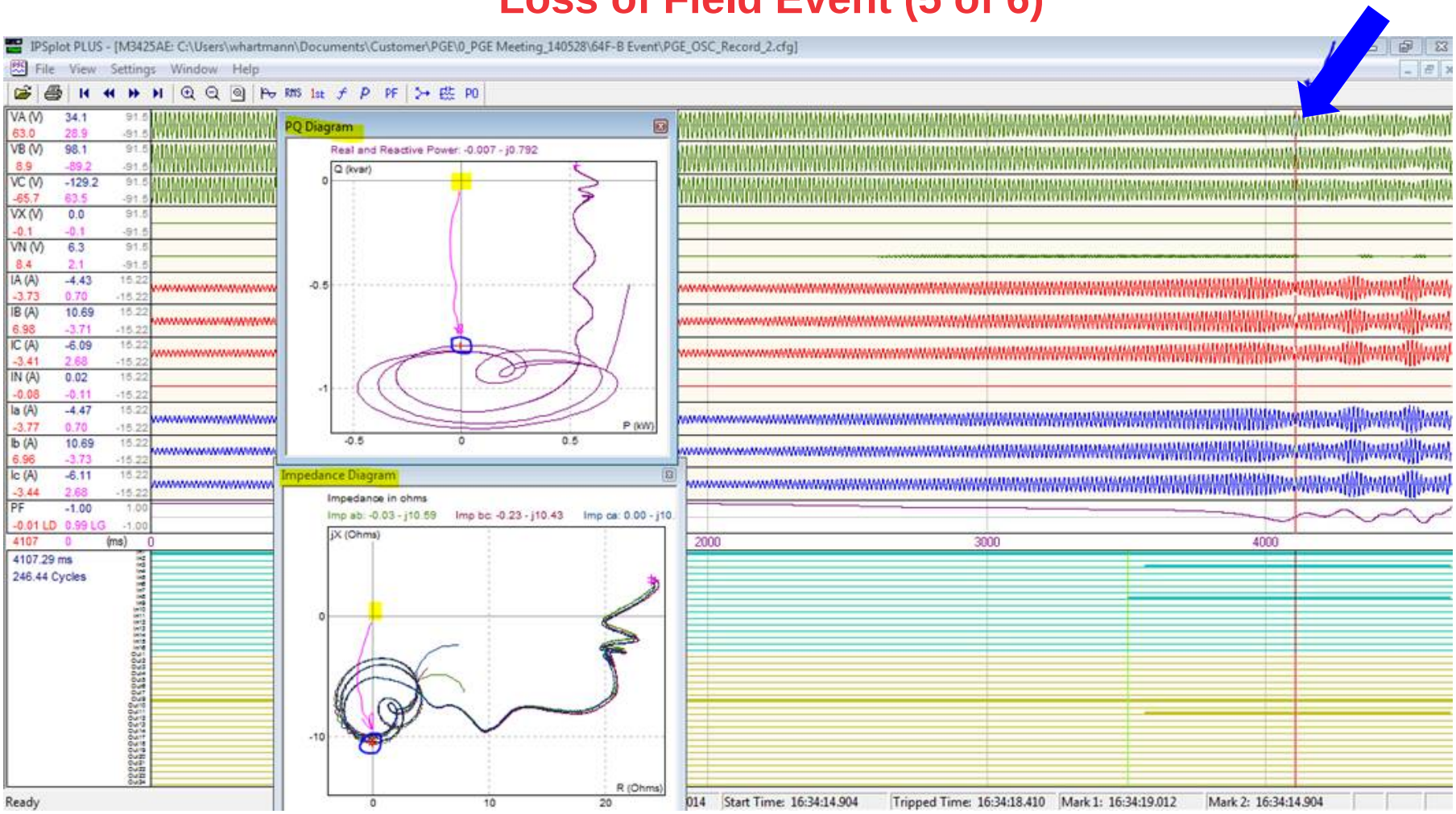
- We have lost field, and the impedance/power plan plots show we are still outputting watts but are sinking lots of VAr
- This is JUST before the machine goes into asynchronous operation with a slip

Loss of Field Event (4 of 6)



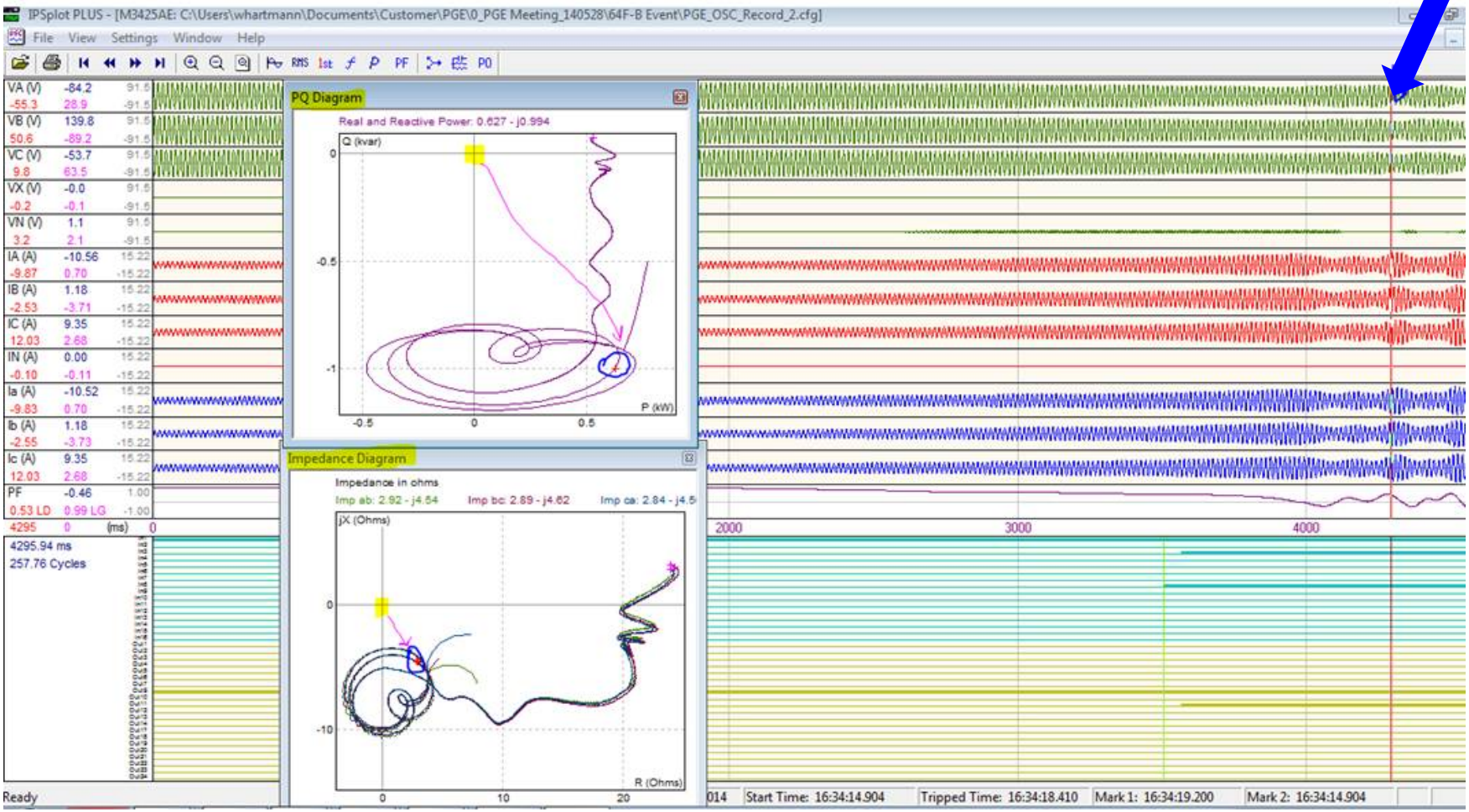
- We have lost field, and the impedance/power plan plots show we are NOT putting out ANY watts and sucking a lot of VAr. The machine is slipping a pole.
- At the instant shown, all the current into the machine is reactive (VAr sink).

Loss of Field Event (5 of 6)



- The machine is slipping a pole. We are into the first slip cycle.

Loss of Field Event (6 of 6)



- The machine is slipping a pole. We are into the first slip cycle.

40: Calculations for Our Generator (Offset Mho Method)

Z_{base} = (GEN kV^2 / GEN MVA) / (1.73*kV_{base})
Z_{base} = (20 kV^2 / 492 MVA) / (1.73*20 kV_{base})
Z_{base} = 0.813 Ω_{pri}

I_{base} = (MVA * 1000) / (1.73 * kV_{Base})
I_{base} = (492 MVA * 1000) / (1.73 * 20_{Base})
I_{base} = 14,219A $_{pri}$

VTR = 20,000V / 120V = 166.7
CTR = 18,000A / 5A = 3,600
CTR/VTR = 21.5996

$I_{base\ sec}$ = I $_{pri}$ / CTR
$I_{base\ sec}$ = 14,219 $_{pri}$ / 3,600
$I_{base\ sec}$ = 3.945 A $_{sec}$

$V_{LL\ sec}$ = 120V
$V_{LG\ sec}$ = $V_{LL\ sec}$ / 1.73
$V_{LL\ sec}$ = 69.28V sec

$Z_{Base\ sec}$ = $Z_{Base\ pri}$ * (CTR / VTR)
$Z_{Base\ sec}$ = 0.813 Ω_{pri} * (3,600 / 166.7)
$Z_{Base\ sec}$ = 17.55 Ω_{sec} (1pu)

⇒D

<u>Reactances per unit (492 MVA Base)</u>
Xd = 1.1888 pu
X'd = 0.20577 pu

<u>Z2: Bigger Circle</u>
Diameter sec = $Z_{Base\ sec}$ / Xd
Diameter sec = 17.55Ω_{sec} / 1.188 pu
Diameter sec = 20.88Ω_{sec}

Offset sec: (X'd / 2) * $Z_{Base\ sec}$
Offset sec: (0.20577pu / 2) * 17.55 Ω_{sec}
Offset sec: -1.81Ω_{sec}

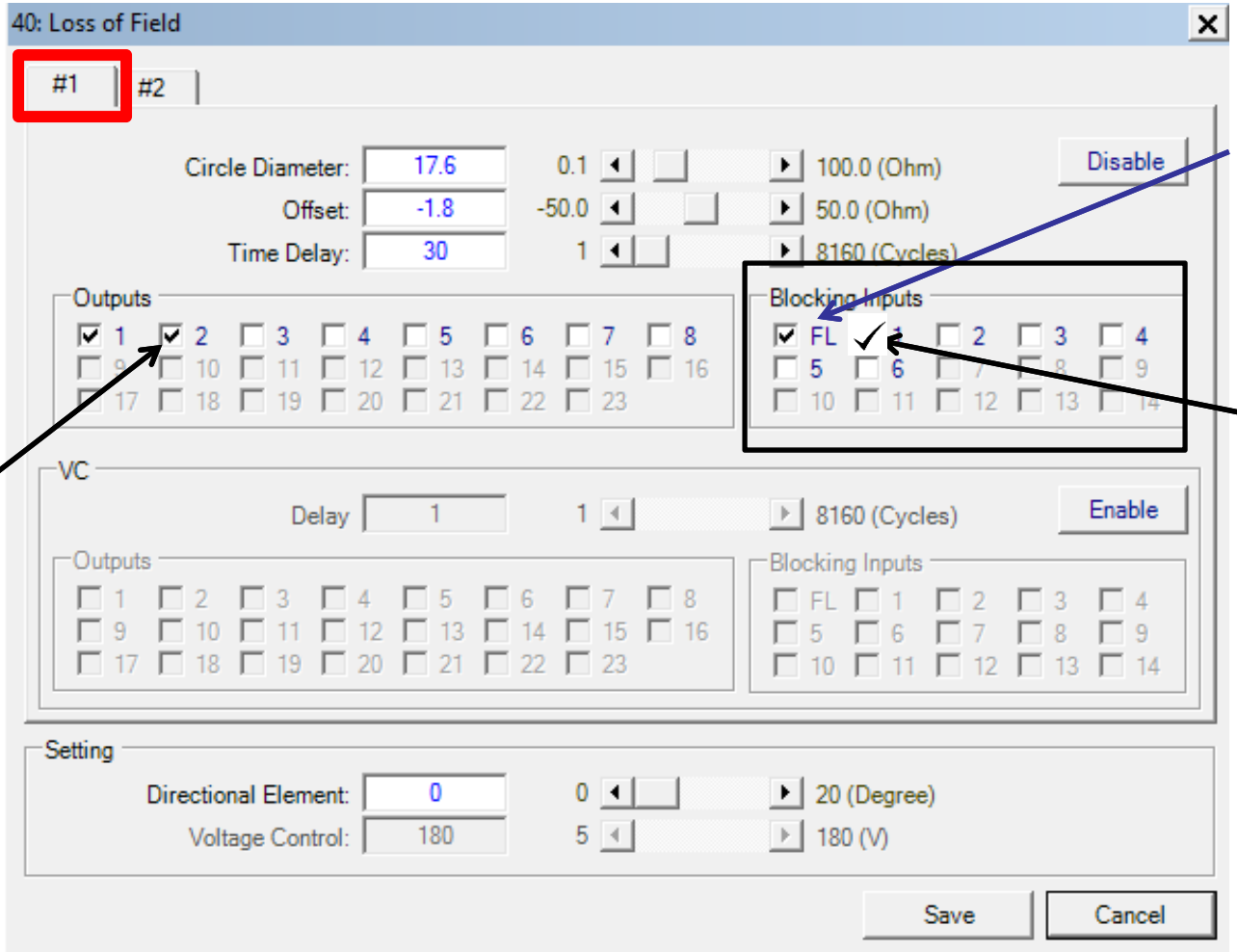
Time Delay = 1 sec.

<u>Z1: Small Circle</u>
Diameter = 1 pu sec = 17.55Ω_{sec}

Offset sec: (X'd / 2) * $Z_{Base\ sec}$
Offset sec: (0.20577pu / 2) * 17.55 Ω_{sec}
Offset sec: -1.81Ω_{sec}

Time Delay = 0.5 sec.

40: “GE” Method”; 2 Offset Mho



VT Fuse Loss

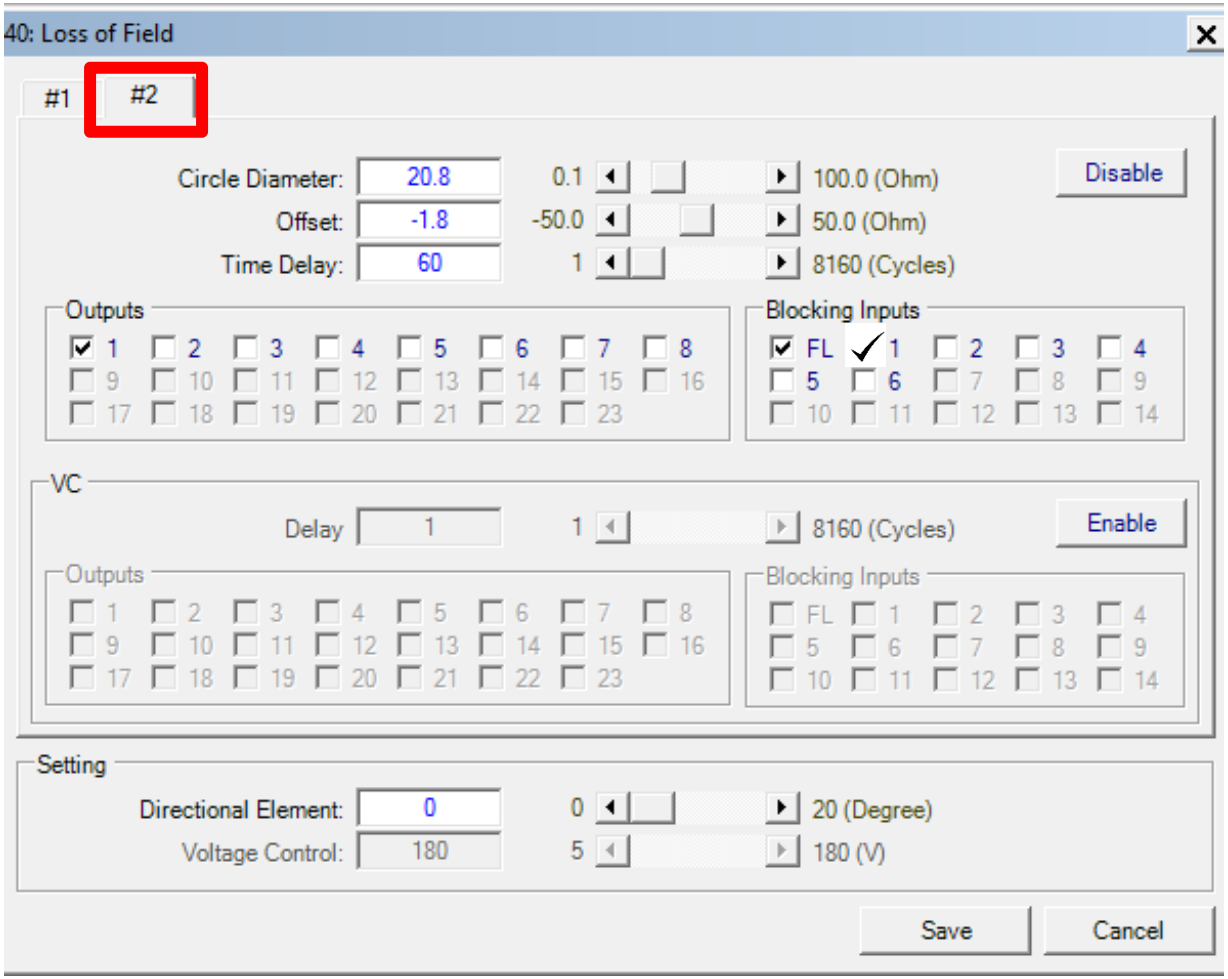
What’s missing?

52B Supervision

Additional output to isolate the test

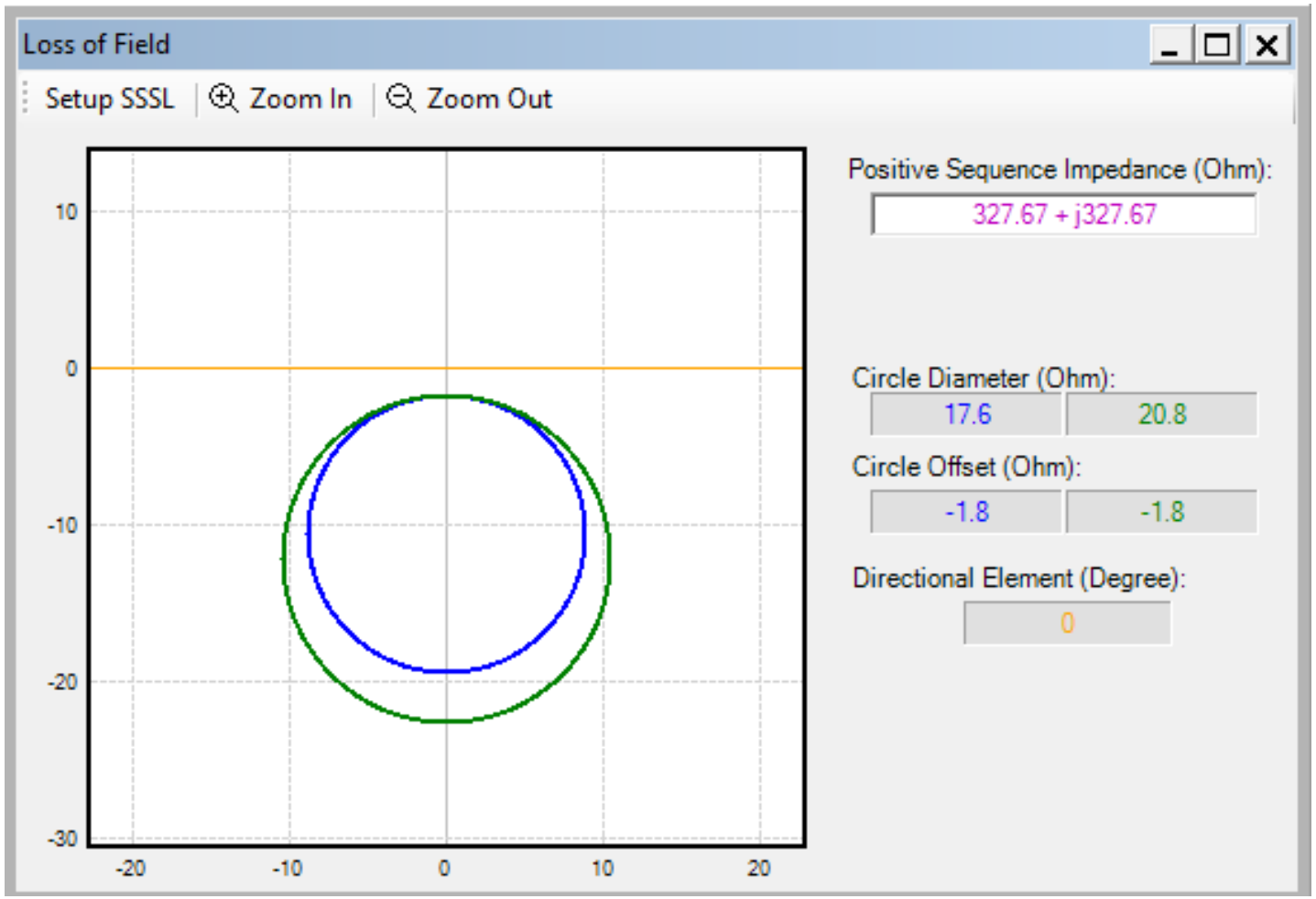
Two Zone Offset Mho Elements

40: “GE” Method”; 2 Offset Mho



Two Zone Offset Mho Elements

IPSCom Metering Screen



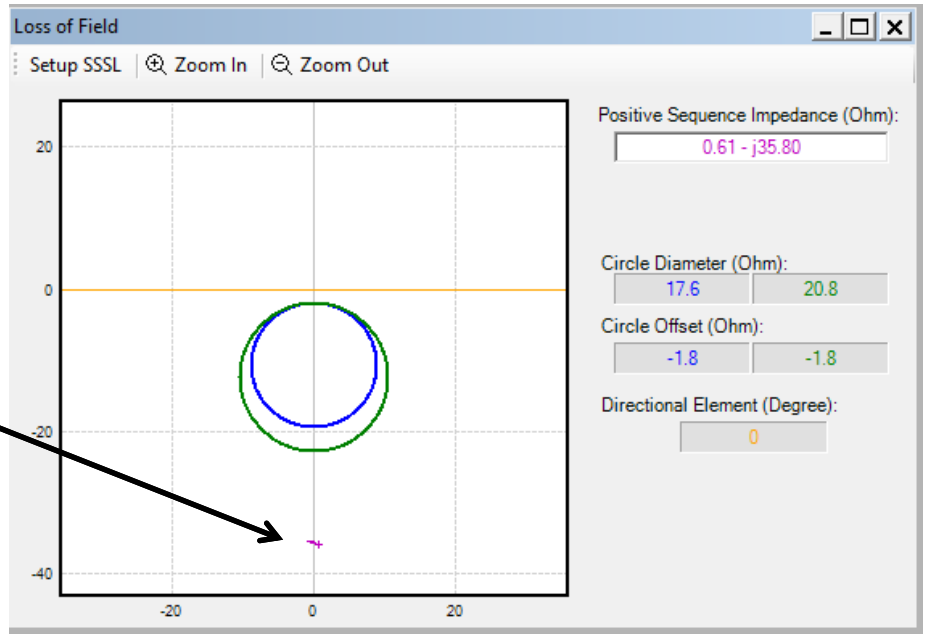
Reach = Circle Diameter + Offset

Pre-Fault Condition:

Analog Outputs			
Set Mode	Direct		
V A-N	69.28 V	0.00 °	60.000 Hz
V B-N	69.28 V	-120.00 °	60.000 Hz
V C-N	69.28 V	120.00 °	60.000 Hz
I A	2.000 A	90.00 °	60.000 Hz
I B	2.000 A	-30.00 °	60.000 Hz
I C	2.000 A	210.00 °	60.000 Hz
I Sec A	2.000 A	90.00 °	60.000 Hz
I Sec B	2.000 A	-30.00 °	60.000 Hz
I Sec C	2.000 A	210.00 °	60.000 Hz

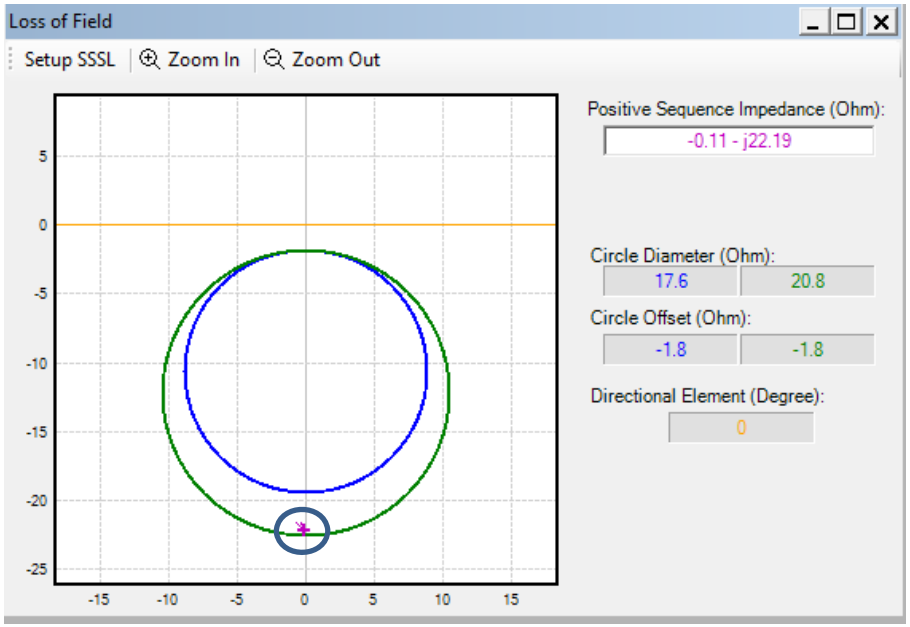
Mirrored currents, Why?

Loss of Field Monitor



Test Zone 2 Perimeter:

Analog Outputs			
Set Mode	Direct		
V A-N	45.20 V	0.00 °	60.000 Hz
V B-N	45.20 V	-120.00 °	60.000 Hz
V C-N	45.20 V	120.00 °	60.000 Hz
I A	2.000 A	90.00 °	60.000 Hz
I B	2.000 A	-30.00 °	60.000 Hz
I C	2.000 A	210.00 °	60.000 Hz
I Sec A	2.000 A	90.00 °	60.000 Hz
I Sec B	2.000 A	-30.00 °	60.000 Hz
I Sec C	2.000 A	210.00 °	60.000 Hz



Loss of Field Monitor

20.8 + 1.8 = 22.6

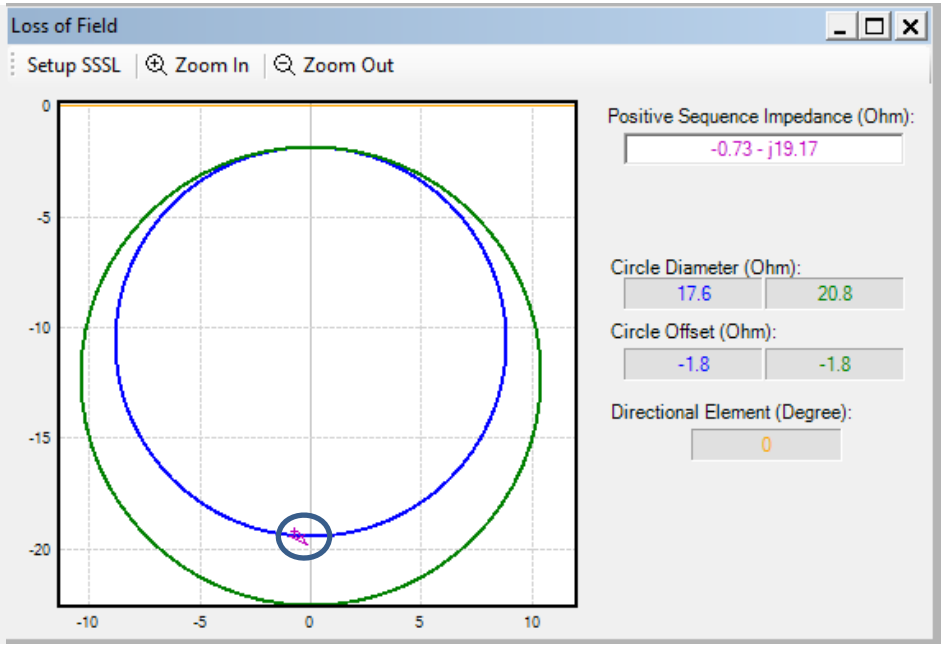
22.6 ohms X 2 Amps= 45.2 Volts

Binary Inputs / Trigger				
Trip				60.05 cy

Check Timing Trip 1

Test Zone 1Perimeter:

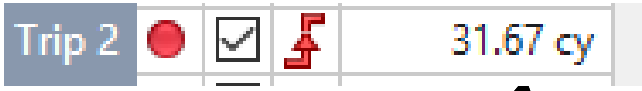
Analog Outputs			
Set Mode	Direct		
V A-N	38.80 V	0.00 °	60.000 Hz
V B-N	38.80 V	-120.00 °	60.000 Hz
V C-N	38.80 V	120.00 °	60.000 Hz
I A	2.000 A	90.00 °	60.000 Hz
I B	2.000 A	-30.00 °	60.000 Hz
I C	2.000 A	210.00 °	60.000 Hz
I Sec A	2.000 A	90.00 °	60.000 Hz
I Sec B	2.000 A	-30.00 °	60.000 Hz
I Sec C	2.000 A	210.00 °	60.000 Hz



Loss of Field Monitor

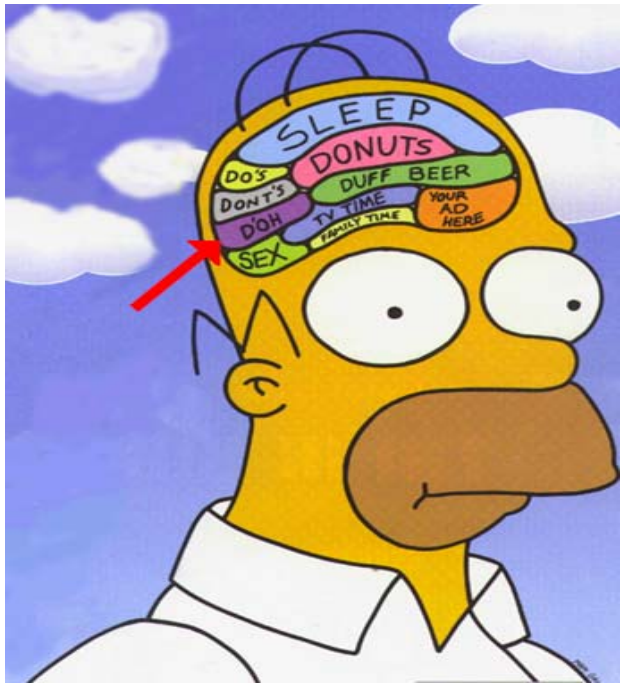
17.6 + 1.8 = 19.4

19.4 ohms X 2 Amps= 38.8 Volts



Check Timing Trip 2

Back to our "DOH" moment



"Thinking logically as to how a relay responds in a faulted condition helps to visualize a proper test sequence"

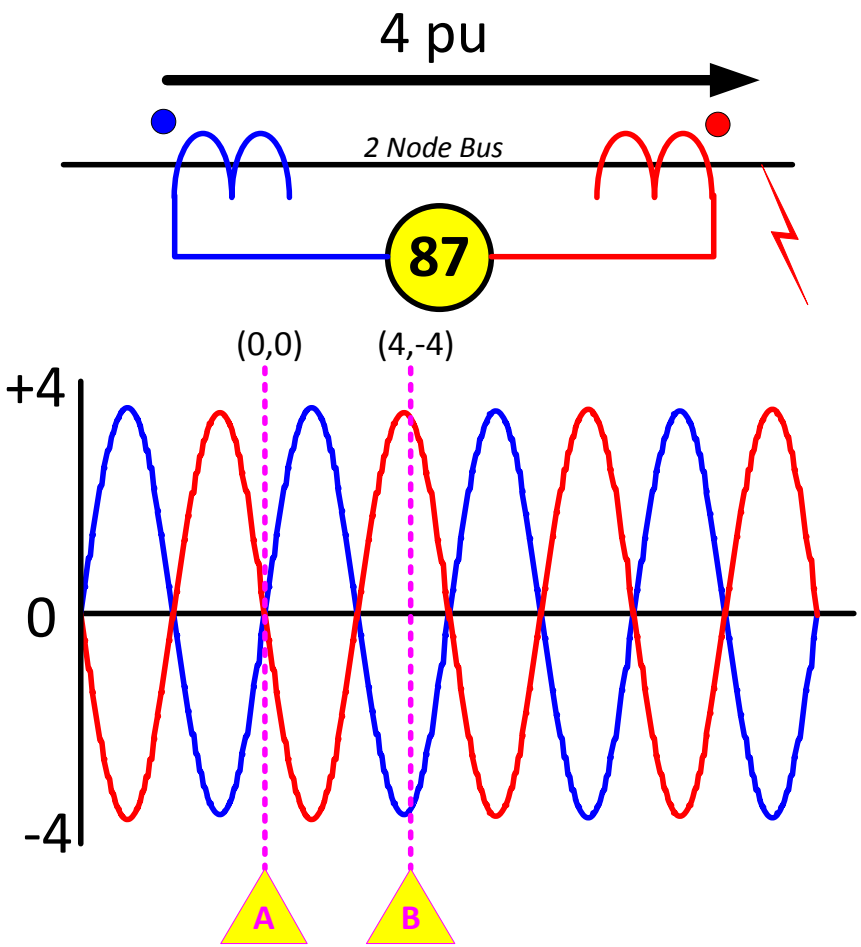
- Input 1 of the M-3425A is open, which means?
- If I put a jumper across it what will this indicate?
- How will the voltage elements respond with the jumper in place?
- Should we test this?

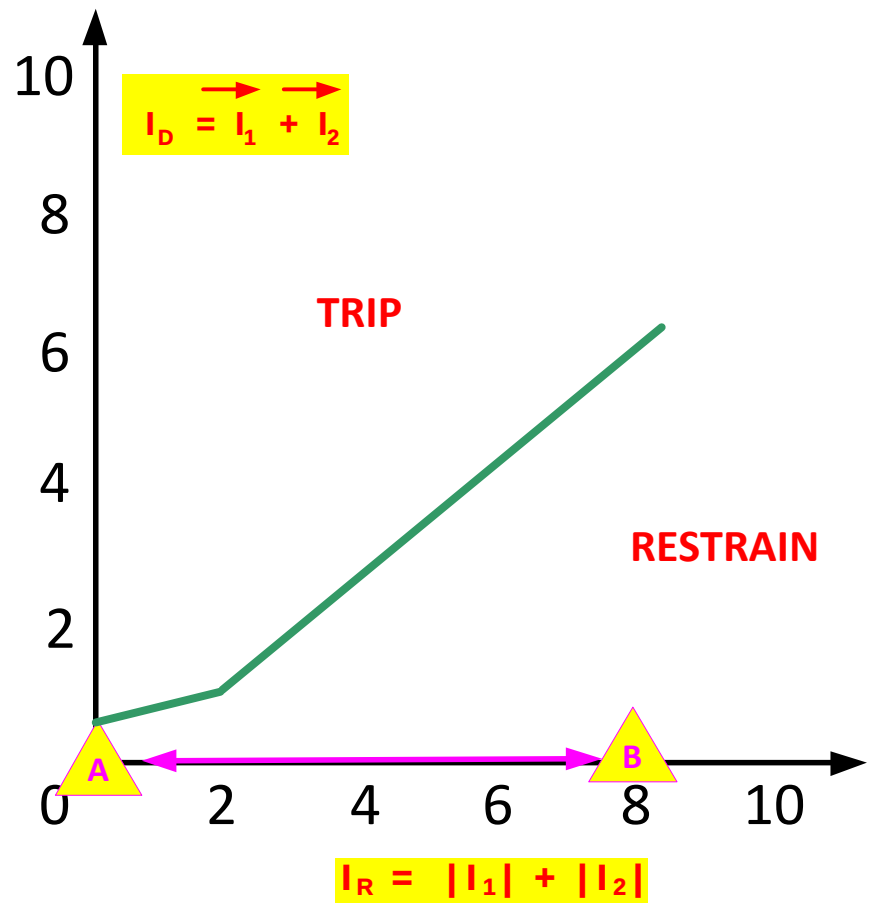
Phase Differential Current (87)

Stator Phase Faults

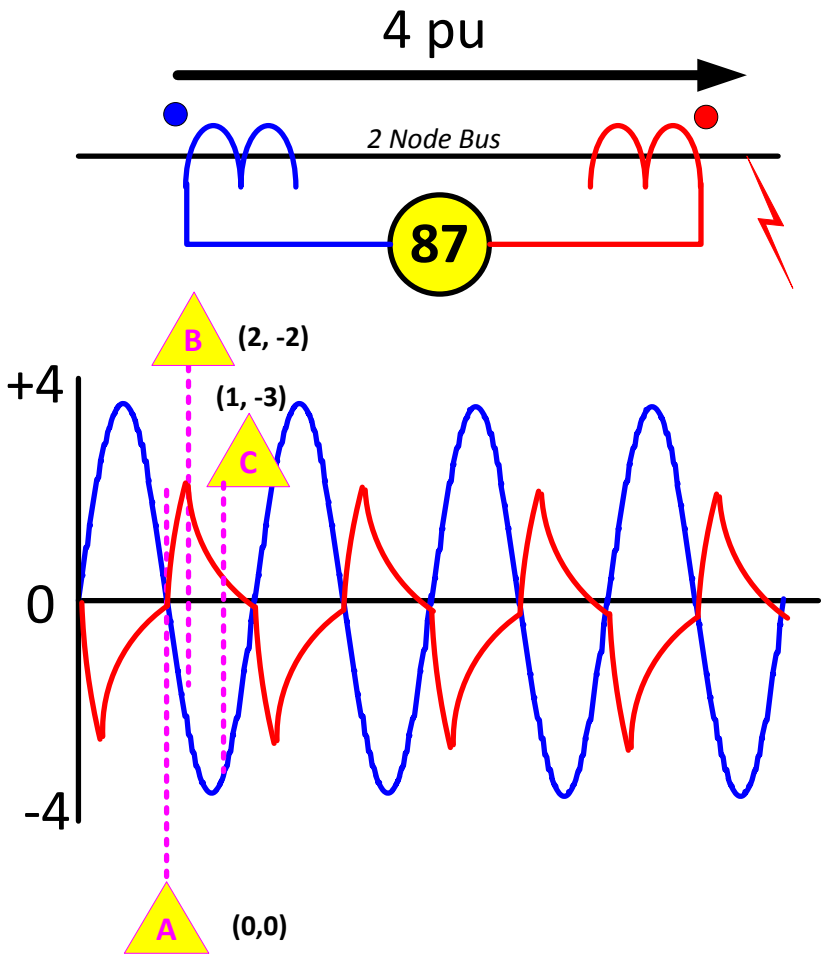
- 87G – Phase Differential (primary for in-zone faults)
  - What goes into zone must come out (Kirchoff's Law)
  - Challenges to Differential
    - CT replication issues: Remnant flux causing saturation
    - DC offset desensitization for energizing transformers and large load pick up
    - Must work properly from 10 Hz to 80Hz so it operates correctly at off-nominal frequencies from internal faults during startup
    - May require multiple elements for CGT static start
  - Tactics:
    - Use variable percentage slope
    - Operate over wide frequency range
    - Uses I_{RMS}/I_{FUND} to adaptively desensitize element when challenged by DC offset for security
      - DC offset can occur from black starting and close-in faults

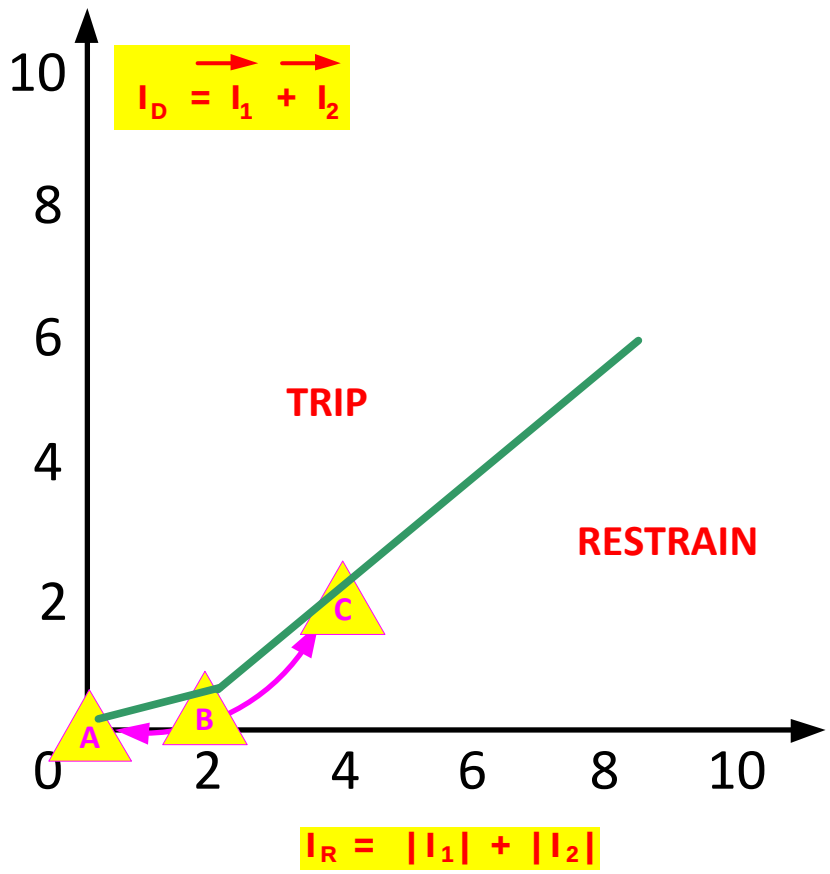
Through Current: Perfect Replication



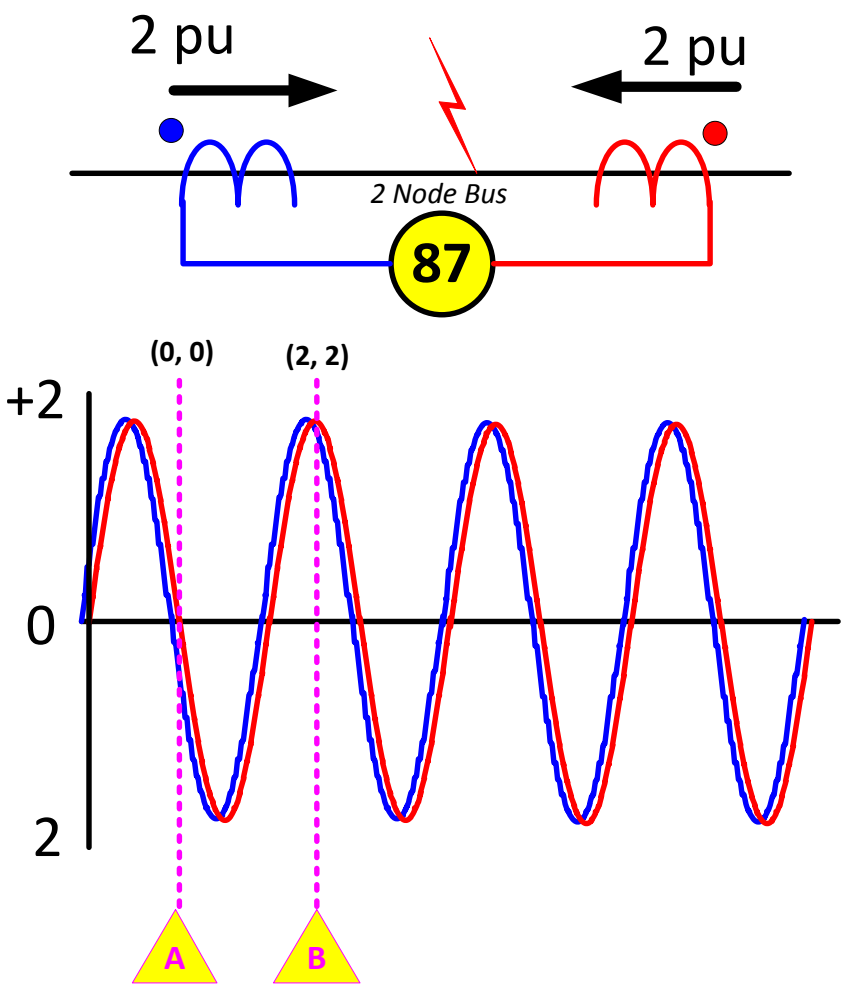


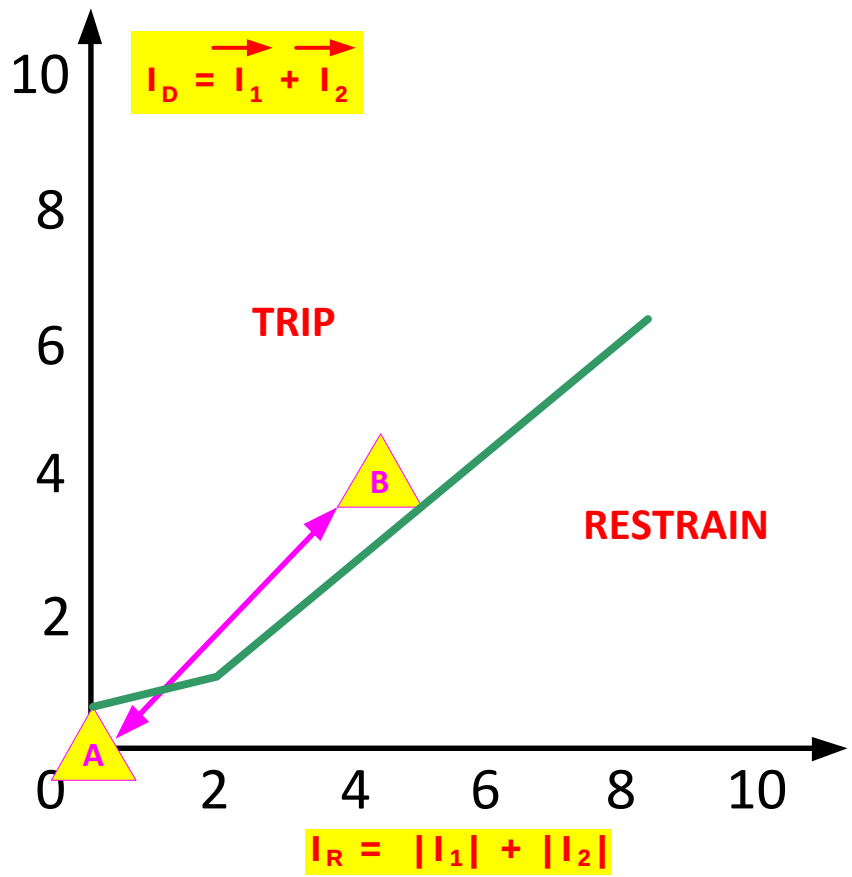
Through Current: Imperfect Replication



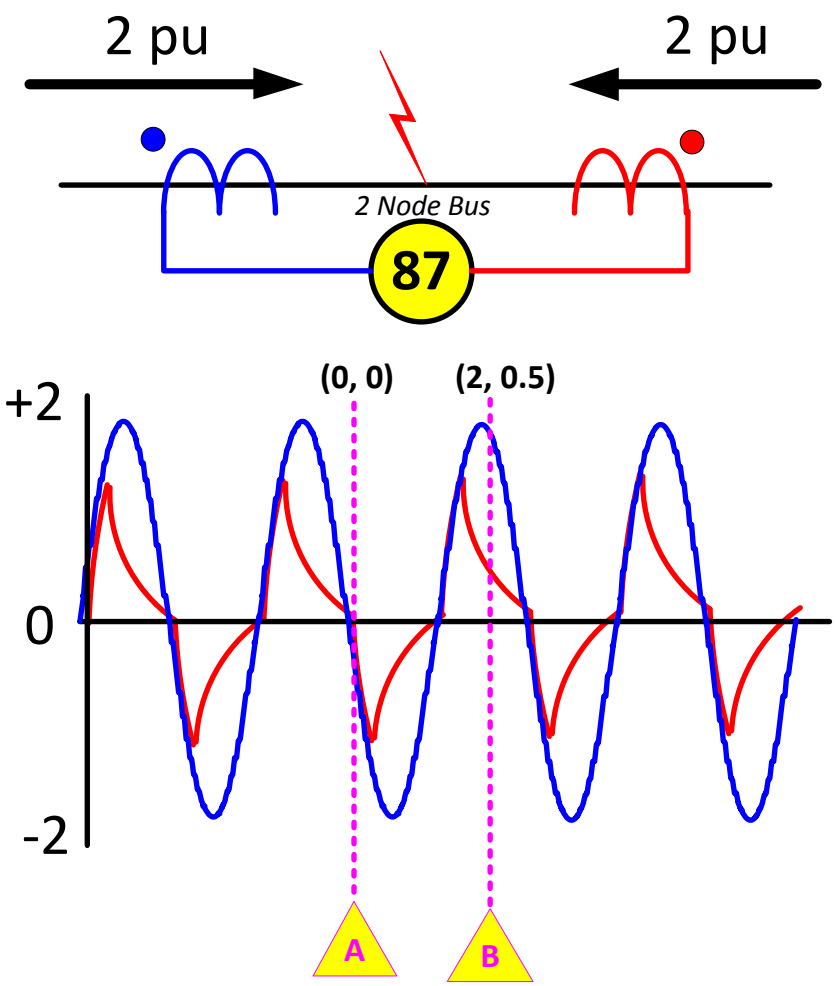


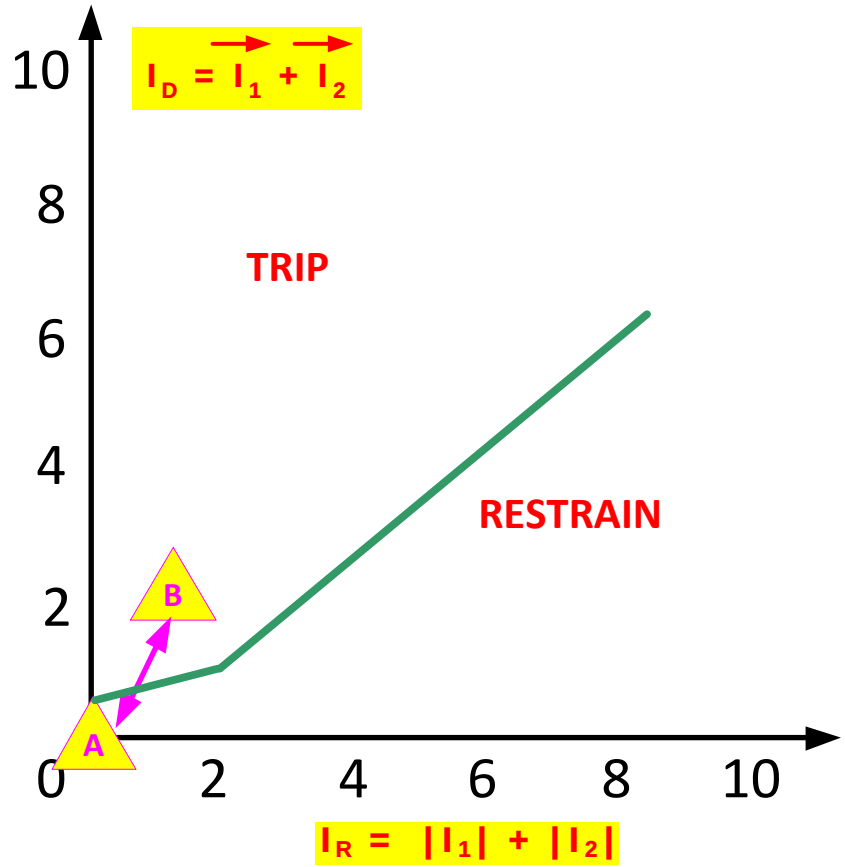
Internal Fault: Perfect Replication





Internal Fault: Imperfect Replication





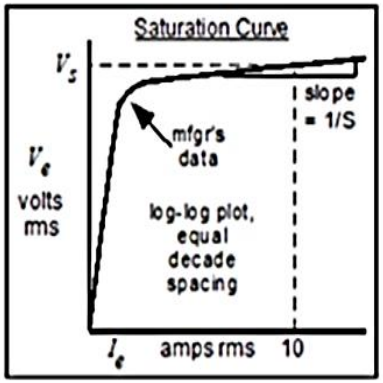
CT Remanence and Performance

- Magnetization left behind in CT iron after an external magnetic field is removed
- Caused by current interruption with DC offset
- CT saturation is increased by other factors working alone or in combination:
  - High system X/R ratio which increases time constant of the CT saturation period
  - CT secondary circuit burden which causes high CT secondary voltage
  - High primary fault or through-fault current which causes high secondary CT voltage

CT Saturation [1]

INPUT PARAMETERS:

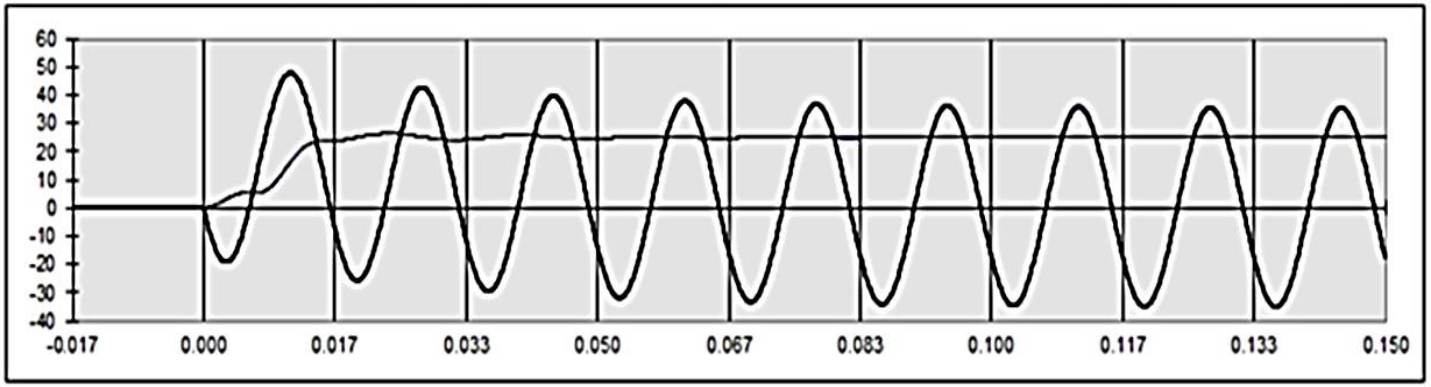
		ENTER:	
Inverse of sat. curve slope =	S =	22	---
RMS voltage at 10A exc. current =	Vs =	400	volts rms
Turns ratio = n2/1 =	N =	80	---
Winding resistance =	Rw =	0.300	ohms
Burden resistance =	Rb =	0.500	ohms
Burden reactance =	Xb =	0.500	ohms
System X/R ratio =	XoverR =	12.0	---
Per unit offset in primary current =	Off =	0.50	-1<Off<1
Per unit remanence (based on Vs) =	λrem	0.50	---
Symmetrical primary fault current =	Ip =	2,000	amps rms



CALCULATED:

Rt = Total burden resistance = Rw + Rb =	0.800	ohms
pf = Total burden power factor =	0.848	---
Zb = Total burden impedance =	0.943	ohms
Tau1 = System time constant =	0.032	seconds
Lamsat = Peak flux-linkages corresponding to Vs	1.501	Wb-turns
ω = Radian freq =	376.99	rad/s
RP = Rms-to-peak ratio =	0.34584	
A = Coefficient in instantaneous ie versus lambda curve: ie = A * l^S :	3.83E-03	---
dt = Time step =	0.000083	seconds
Lb = Burden inductance =	0.00133	henries

Thick lines: **Ideal (blue)** and **actual (black)** secondary current in amps vs time in seconds.
Thin lines: **Ideal (blue)** and **actual (black)** secondary current extracted fundamental rms value, using a simple DFT with a one-cycle window.

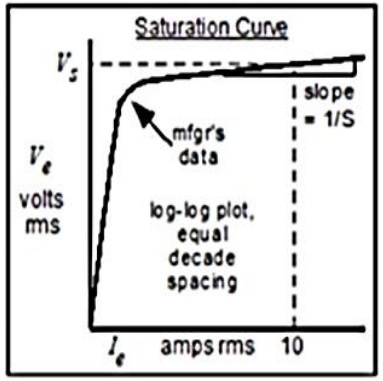


400:5, C400, R=0.5, Offset = 0.5, 2000A

CT Saturation [2]

INPUT PARAMETERS:

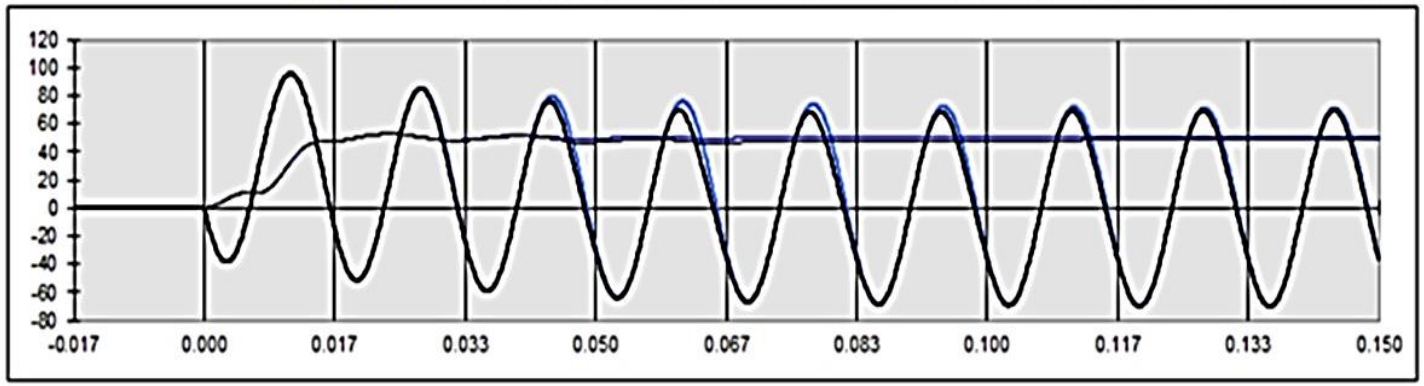
		ENTER:	
Inverse of sat. curve slope =	S =	22	---
RMS voltage at 10A exc. current =	Vs =	400	volts rms
Turns ratio = n2/1 =	N =	80	---
Winding resistance =	Rw =	0.300	ohms
Burden resistance =	Rb =	0.500	ohms
Burden reactance =	Xb =	0.500	ohms
System X/R ratio =	XoverR =	12.0	---
Per unit offset in primary current =	Off =	0.50	-1<Off<1
Per unit remanence (based on Vs) =	λrem	0.50	---
Symmetrical primary fault current =	Ip =	4,000	amps rms



CALCULATED:

Rt = Total burden resistance = Rw + Rb =	0.800	ohms
pf = Total burden power factor =	0.848	---
Zb = Total burden impedance =	0.943	ohms
Tau1 = System time constant =	0.032	seconds
Lamsat = Peak flux-linkages corresponding to Vs	1.501	Wb-turns
ω = Radian freq =	376.99	rad/s
RP = Rms-to-peak ratio =	0.34584	
A = Coefficient in instantaneous ie versus lambda curve: ie = A * l^S :	3.83E-03	---
dt = Time step =	0.000083	seconds
Lb = Burden inductance =	0.00133	henries

Thick lines: **Ideal (blue)** and **actual (black)** secondary current in amps vs time in seconds.
Thin lines: **Ideal (blue)** and **actual (black)** secondary current extracted fundamental rms value, using a simple DFT with a one-cycle window.

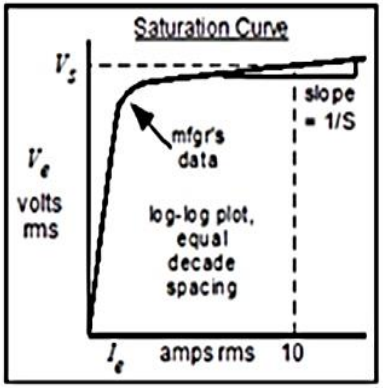


400:5, C400, R=0.5, Offset = 0.5, **4000A**

CT Saturation [3]

INPUT PARAMETERS:

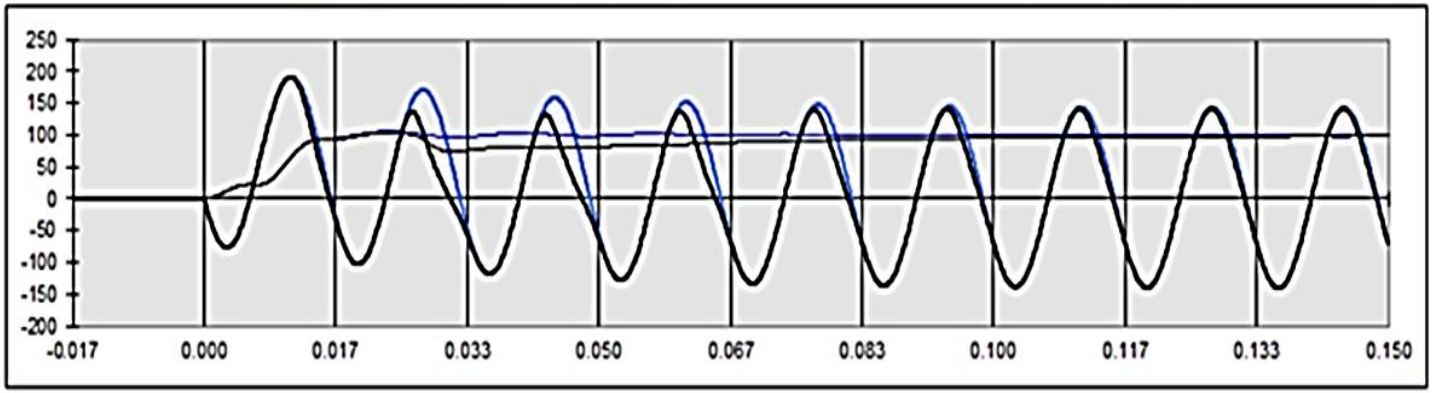
		ENTER:	
Inverse of sat. curve slope =	S =	22	---
RMS voltage at 10A exc. current =	Vs =	400	volts rms
Turns ratio = n2/1 =	N =	80	---
Winding resistance =	Rw =	0.300	ohms
Burden resistance =	Rb =	0.500	ohms
Burden reactance =	Xb =	0.500	ohms
System X/R ratio =	XoverR =	12.0	---
Per unit offset in primary current =	Off =	0.50	-1<Off<1
Per unit remanence (based on Vs) =	λrem	0.50	---
Symmetrical primary fault current =	Ip =	8,000	amps rms



CALCULATED:

Rt =	Total burden resistance = Rw + Rb =	0.800	ohms
pf =	Total burden power factor =	0.848	---
Zb =	Total burden impedance =	0.943	ohms
Tau1 =	System time constant =	0.032	seconds
Lamsat =	Peak flux-linkages corresponding to Vs	1.501	Wb-turns
ω =	Radian freq =	376.99	rad/s
RP =	Rms-to-peak ratio =	0.34584	
A =	Coefficient in instantaneous ie versus lambda curve: ie = A * l^S :	3.83E-03	---
dt =	Time step =	0.000083	seconds
Lb =	Burden inductance =	0.00133	henries

Thick lines: **Ideal (blue)** and **actual (black)** secondary current in amps vs time in seconds.
Thin lines: **Ideal (blue)** and **actual (black)** secondary current extracted fundamental rms value, using a simple DFT with a one-cycle window.

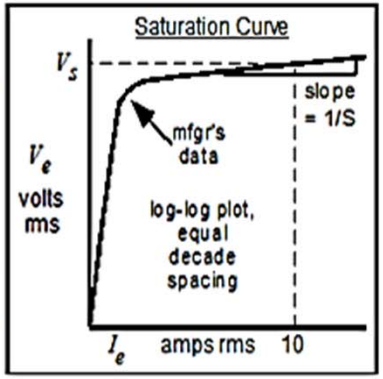


400:5, C400, R=0.5, Offset = 0.5, **8000A**

CT Saturation [4]

INPUT PARAMETERS:

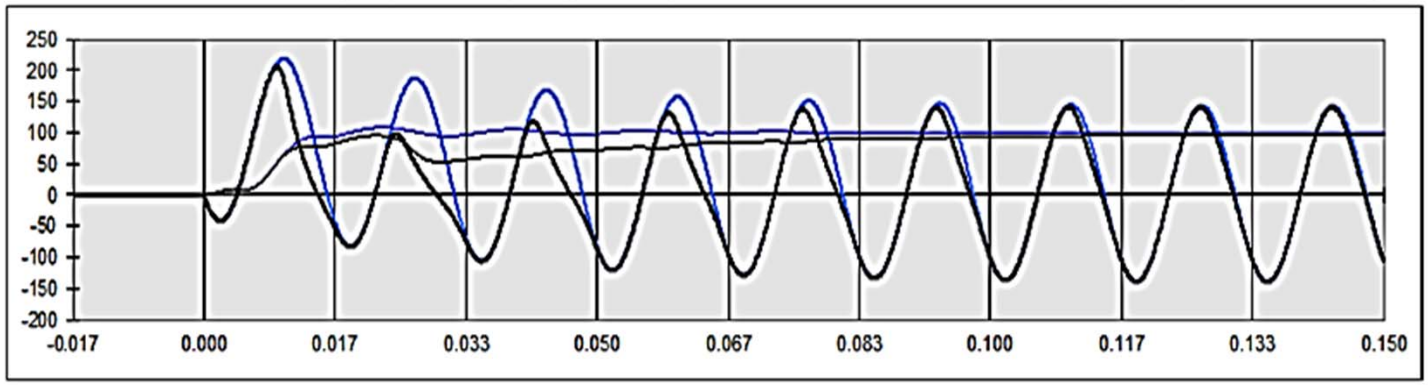
		ENTER:	
Inverse of sat. curve slope =	S =	22	---
RMS voltage at 10A exc. current =	Vs =	400	volts rms
Turns ratio = n2/1=	N =	80	---
Winding resistance =	Rw =	0.300	ohms
Burden resistance =	Rb =	0.500	ohms
Burden reactance =	Xb =	0.500	ohms
System X/R ratio =	XoverR =	12.0	---
Per unit offset in primary current =	Off =	0.75	-1<Off<1
Per unit remanence (based on Vs) =	λrem	0.50	---
Symmetrical primary fault current =	Ip =	8,000	amps rms



CALCULATED:

Rt = Total burden resistance = Rw + Rb =	0.800	ohms
pf = Total burden power factor =	0.848	---
Zb = Total burden impedance =	0.943	ohms
Tau1 = System time constant =	0.032	seconds
Lamsat = Peak flux-linkages corresponding to Vs	1.501	Wb-turns
ω = Radian freq =	376.99	rad/s
RP = Rms-to-peak ratio =	0.34584	
A = Coefficient in instantaneous ie versus lambda curve: ie = A * l^S :	3.83E-03	---
dt = Time step =	0.000083	seconds
Lb = Burden inductance =	0.00133	henries

Thick lines: Ideal (blue) and actual (black) secondary current in amps vs time in seconds.
Thin lines: Ideal (blue) and actual (black) secondary current extracted fundamental rms value, using a simple DFT with a one-cycle window.

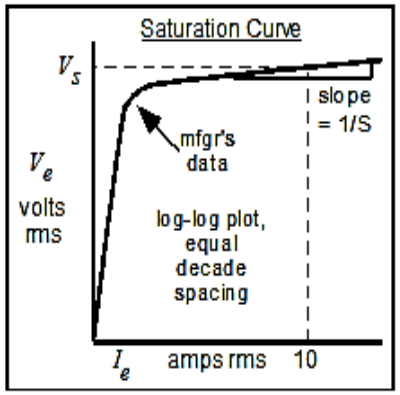


400:5, C400, R=0.5, **Offset = 0.75**, 8000A

CT Saturation [5]

INPUT PARAMETERS:

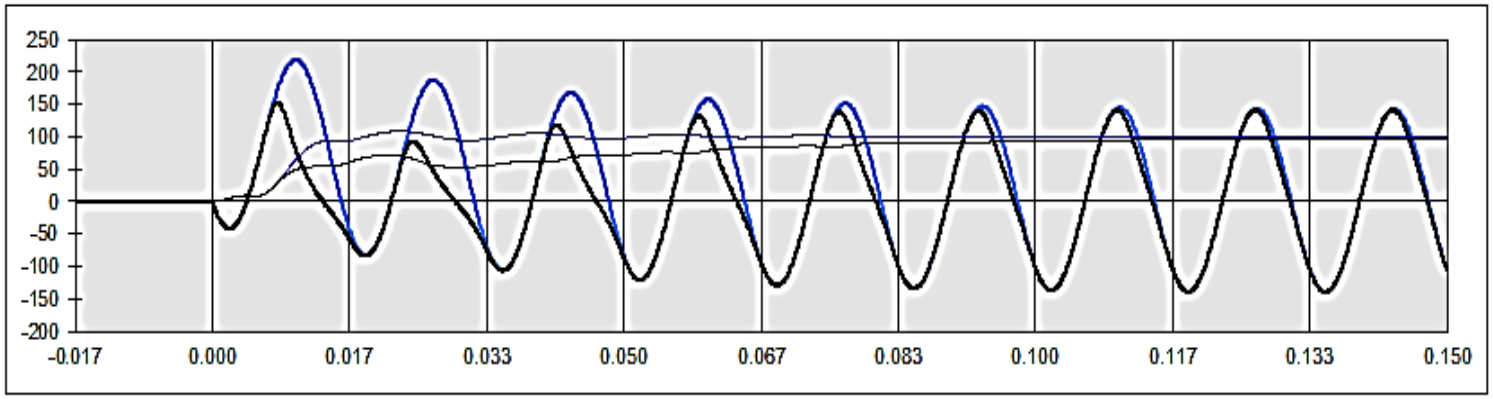
		ENTER:	
Inverse of sat. curve slope =	S =	22	—
RMS voltage at 10A exc. current =	Vs =	400	volts rms
Turns ratio = n2/1=	N =	80	—
Winding resistance =	Rw =	0.300	ohms
Burden resistance =	Rb =	0.500	ohms
Burden reactance =	Xb =	0.500	ohms
System X/R ratio =	XoverR =	12.0	—
Per unit offset in primary current =	Off =	0.75	-1<Off<1
Per unit remanence (based on Vs) =	λrem	0.75	—
Symmetrical primary fault current =	Ip =	8,000	amps rms



CALCULATED:

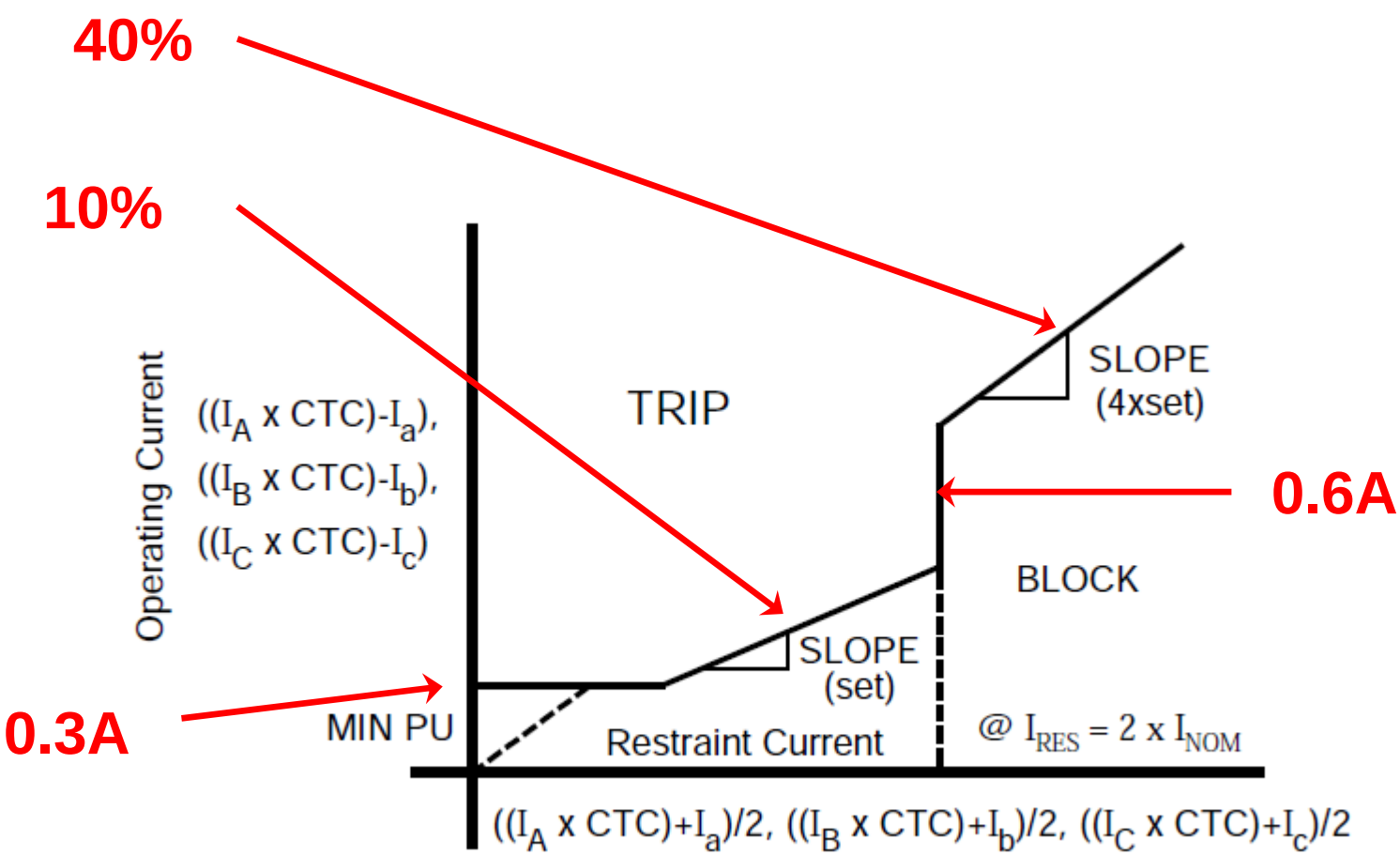
Rt =	Total burden resistance = Rw + Rb =	0.800	ohms
pf =	Total burden power factor =	0.848	—
Zb =	Total burden impedance =	0.943	ohms
Tau1 =	System time constant =	0.032	seconds
Lamsat =	Peak flux-linkages corresponding to Vs	1.501	Wb-turns
ω =	Radian freq =	376.99	rad/s
RP =	Rms-to-peak ratio =	0.34584	
A =	Coefficient in instantaneous ie versus lambda curve: ie = A * l^S :	3.83E-03	—
dt =	Time step =	0.000083	seconds
Lb =	Burden inductance =	0.00133	henries

Thick lines: **Ideal (blue)** and **actual (black)** secondary current in amps vs time in seconds.
Thin lines: **Ideal (blue)** and **actual (black)** secondary current extracted fundamental rms value, using a simple DFT with a one-cycle window.



400:5, C400, **R=0.75**, Offset = 0.75, 8000A

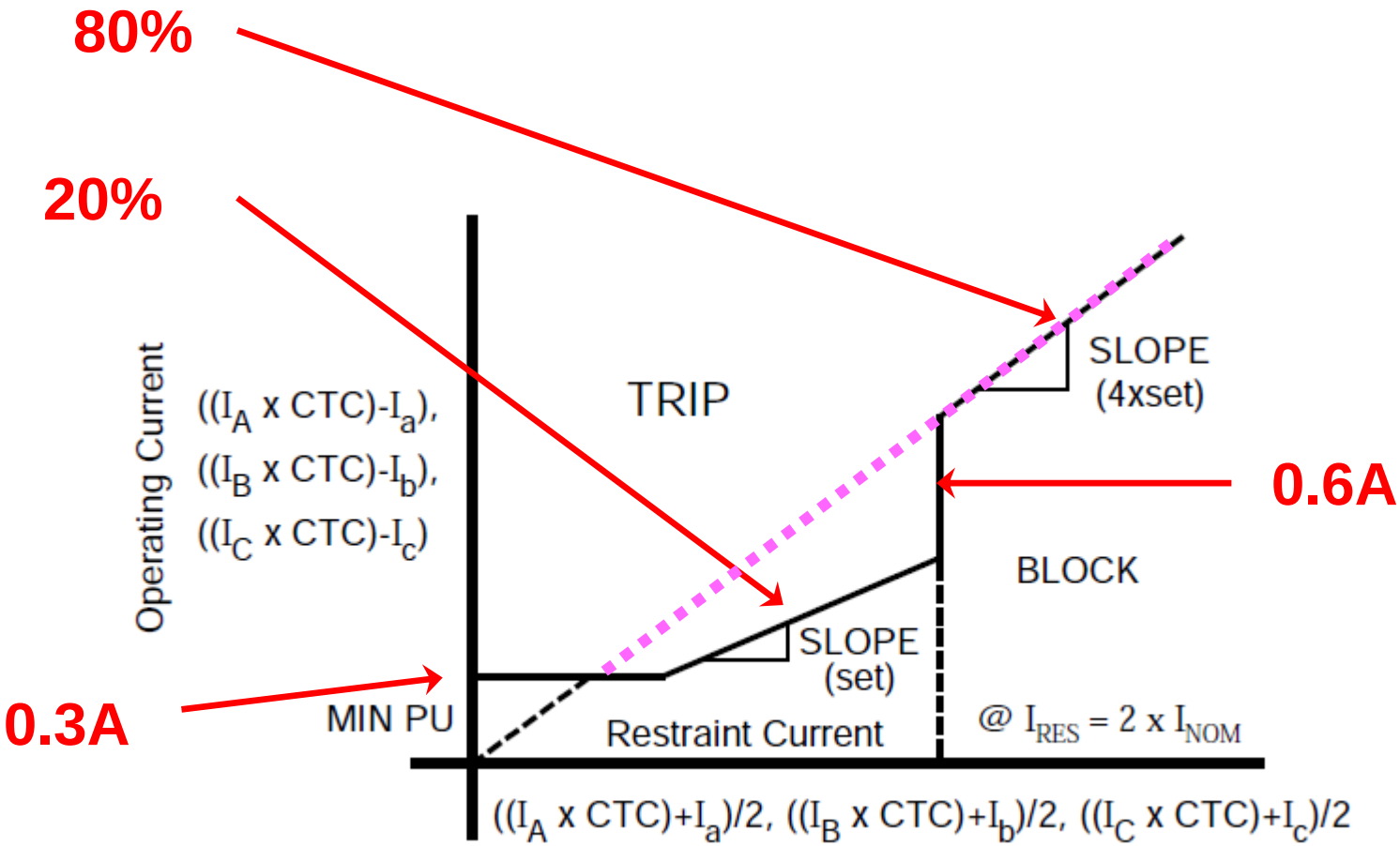
87 Characteristic



CTC = CT Correction Ratio = Line CTR/Neutral CTR
Used when Line and Neutral CTs have different ratios

87 Characteristic

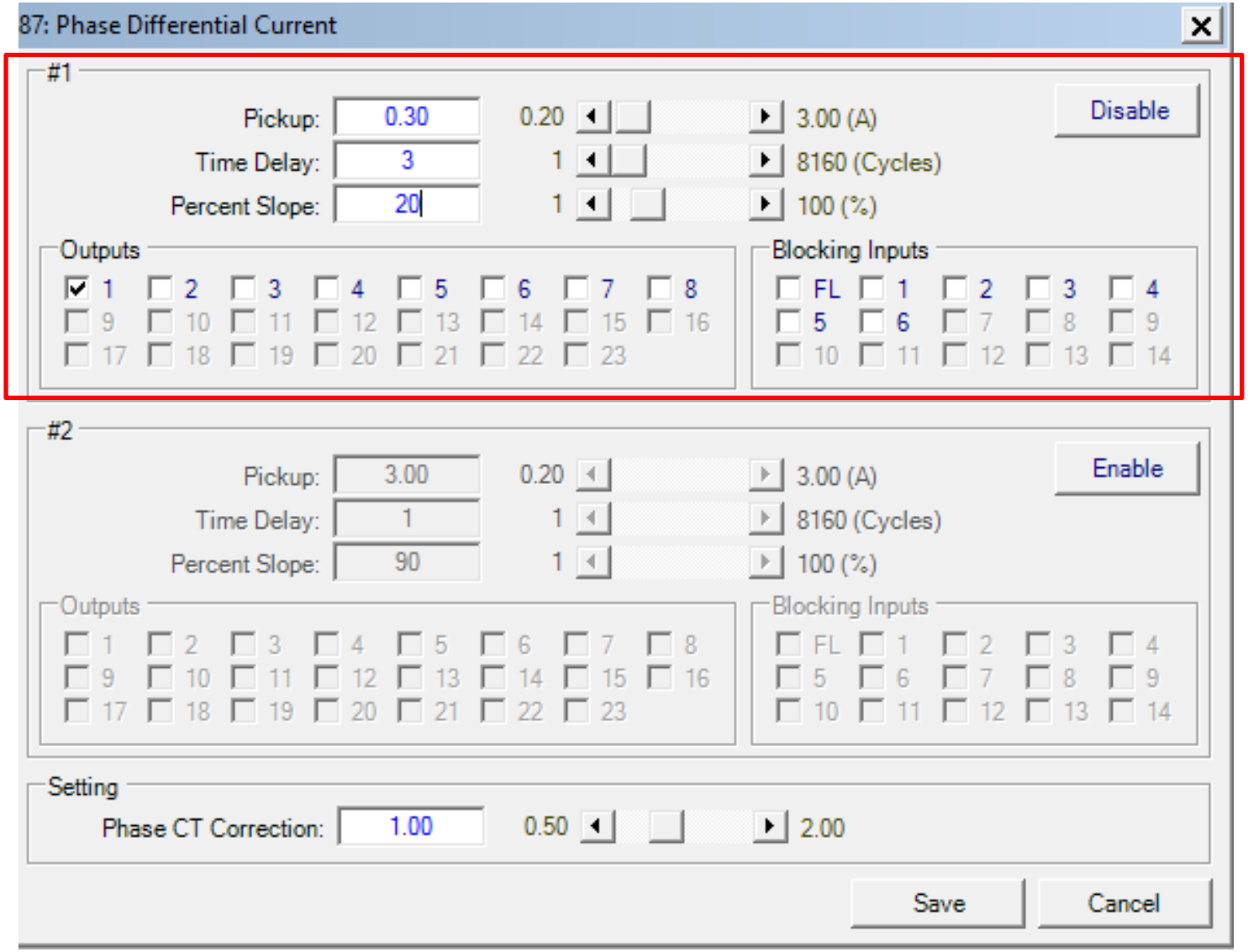
I_{RSM}/I_{FUND} > Pickup



⇒D

CTC = CT Correction Ratio = Line CTR/Neutral CTR
Used when Line and Neutral CTs have different ratios

87 Setting Screen

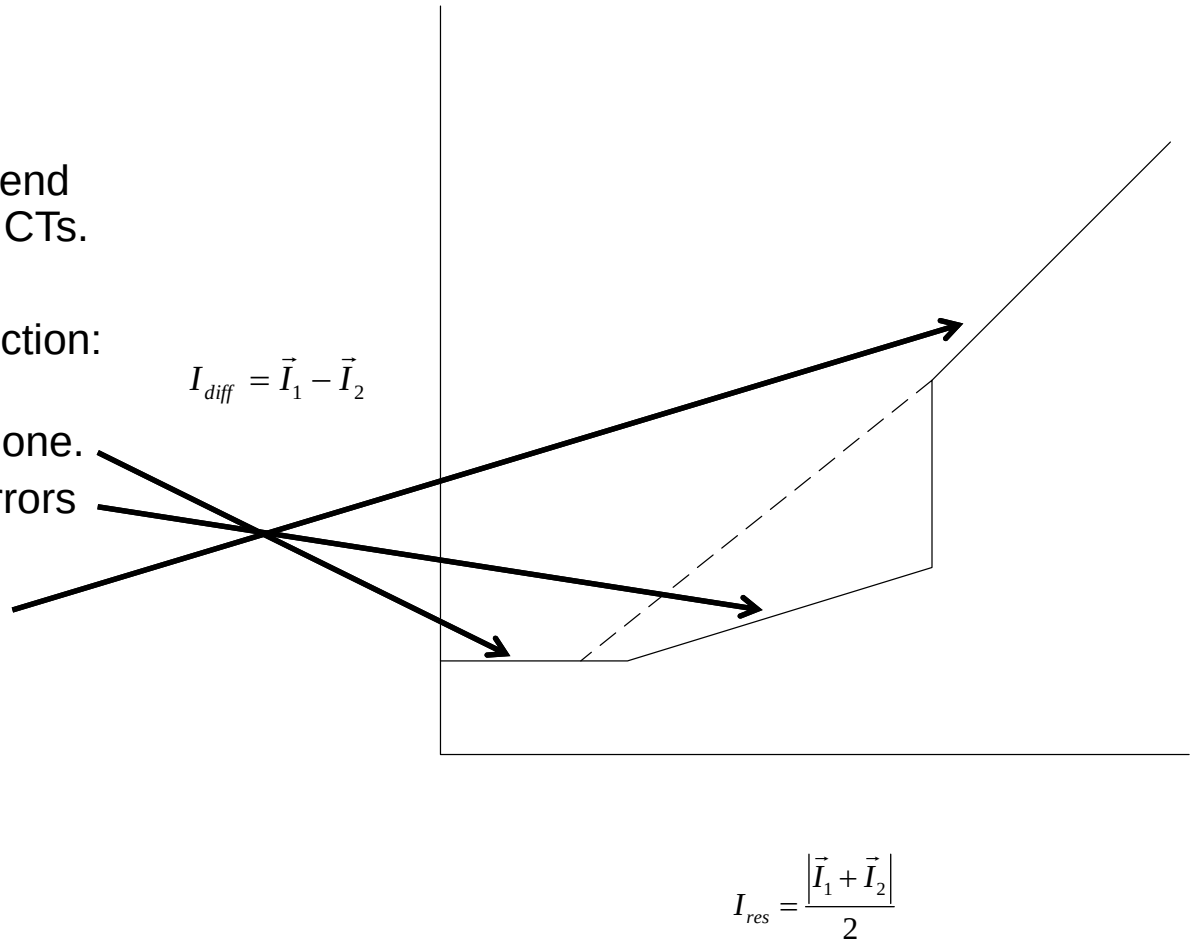


Functional Tests
Phase to Phase Fault (87)

Compares currents at the terminal end CTs with current at the neutral end CTs.

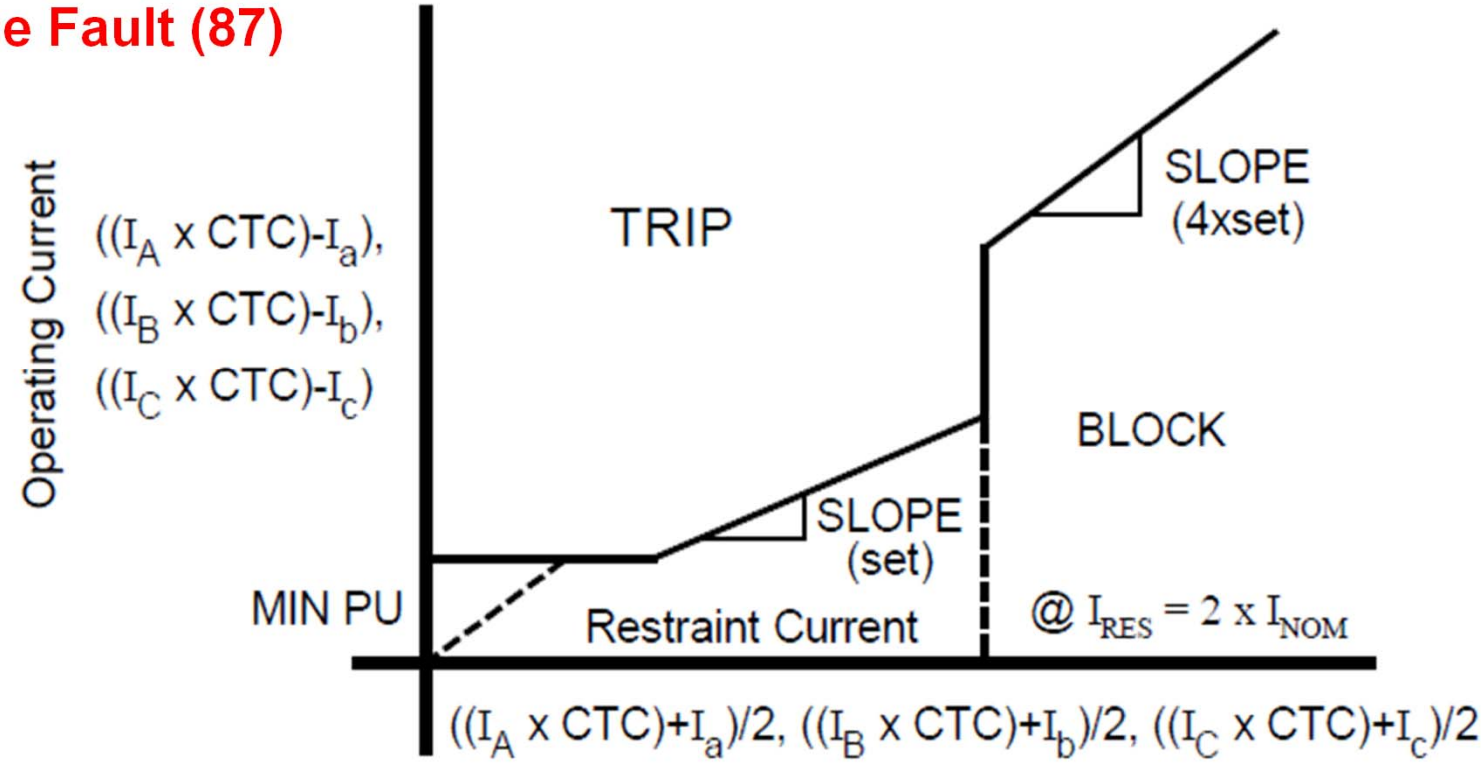
Normally provides 3 zones of protection:

1. Minimum Pickup for maximum sensitivity for faults inside the zone.
2. Slope 1 compensates for CT errors
3. Slope 2 is less sensitive for saturation during through fault conditions



$$Slope(\%) = \frac{Idiff}{Ires} x100$$

Functional Tests
Phase to Phase Fault (87)



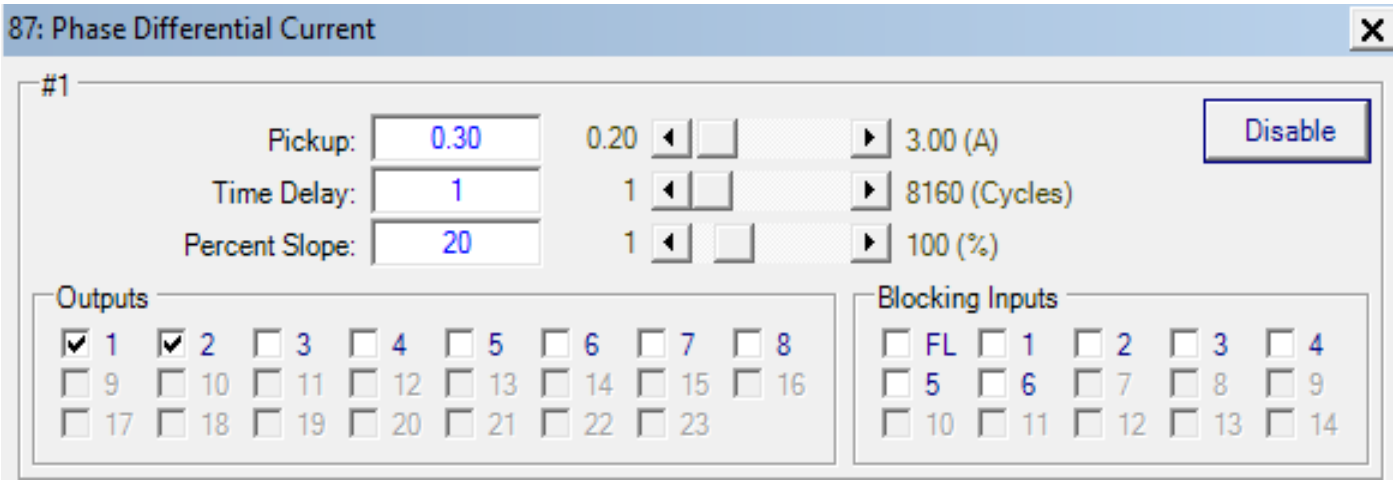
- To accommodate different CT ratios on neutral and terminal end CTs, a compensation factor "CTC" may be applied
- CTC = Line CTR / Neutral CTR
- CTC applied to <u>terminal</u> Side currents

$$Slope(\%) = \frac{Idiff}{Ires} x100$$

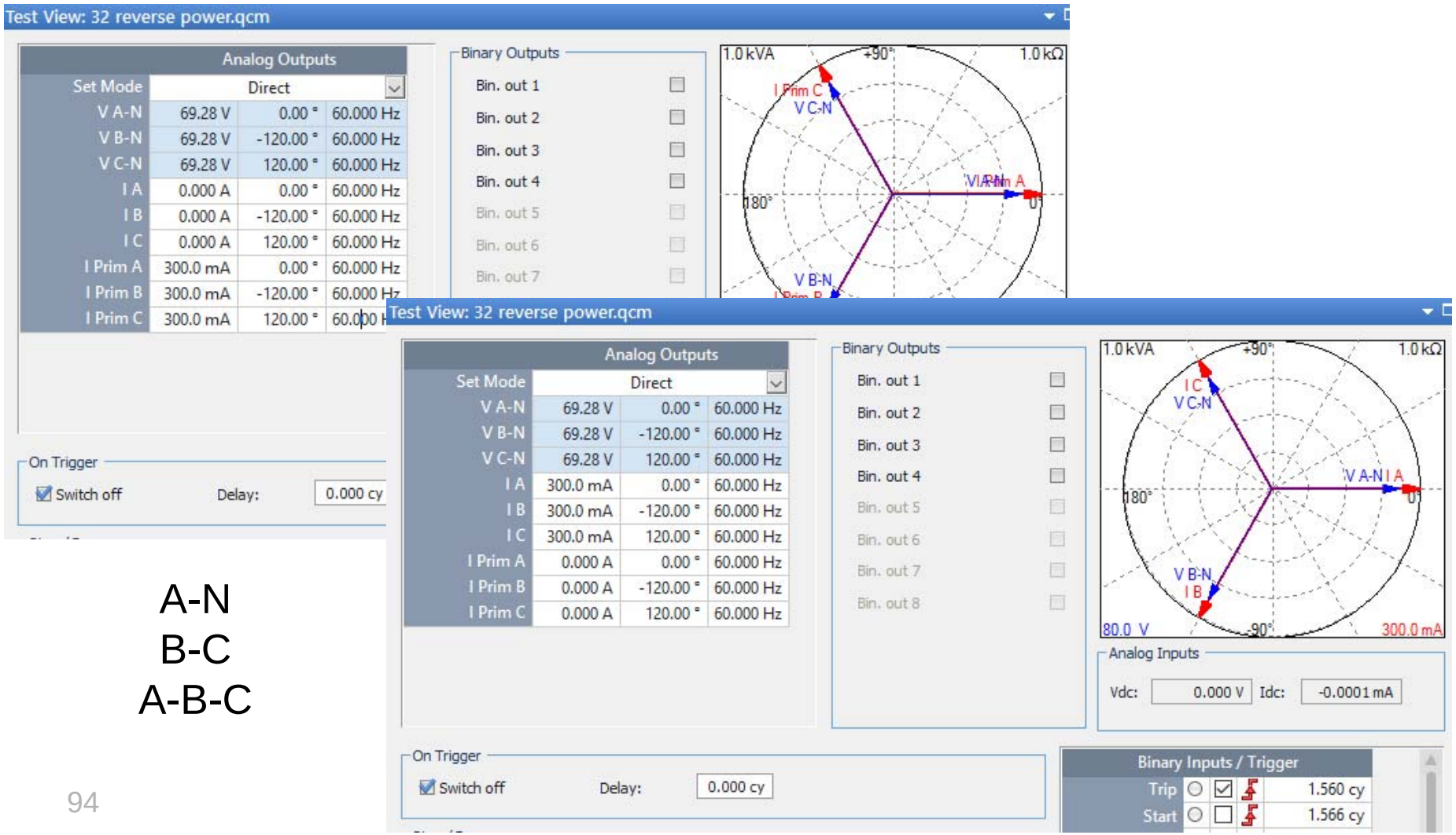
Functional Tests
Phase to Phase Fault (87)

Key Design Points

1. Sensitivity for faults inside the zone
2. Security against false trips caused by CT saturation



Test for minimum pick-up, both windings

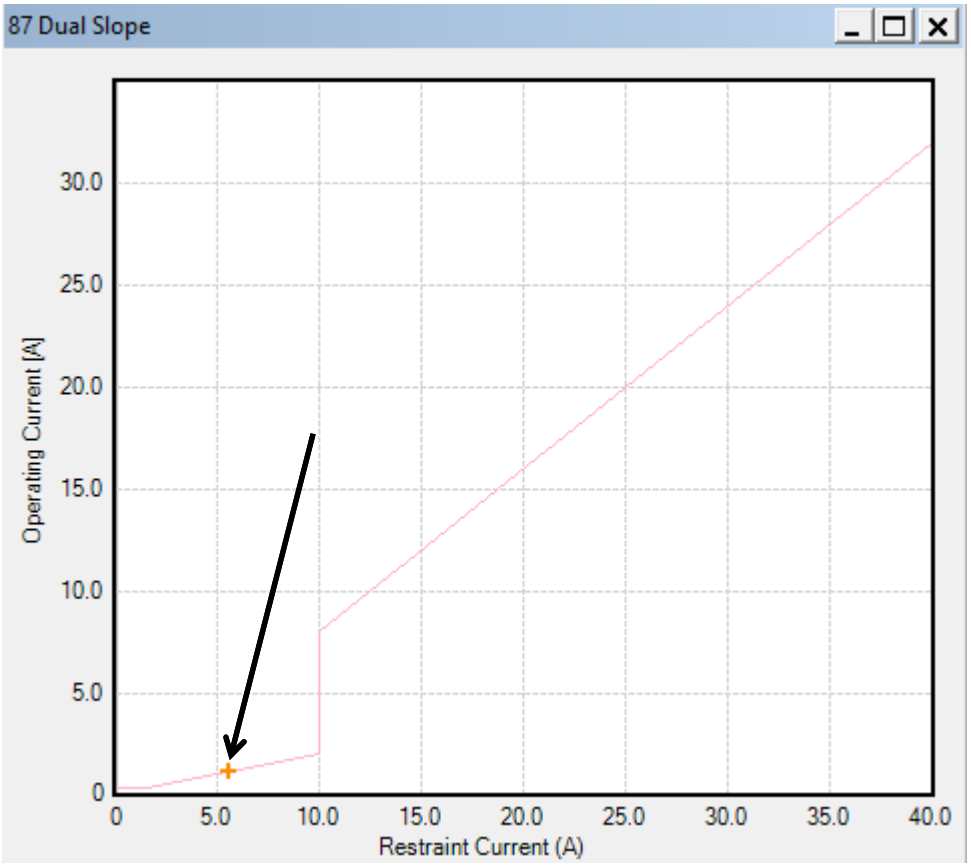


A-N
B-C
A-B-C

Slope 1 test, Math Class!!

1. 5A on all 6 phases, ramp all triples of one side until 87 trip
2. Calculate I diff (6.1-5 =1.1)
3. I restraint (6.1+5=11.1) / 2=20% slope

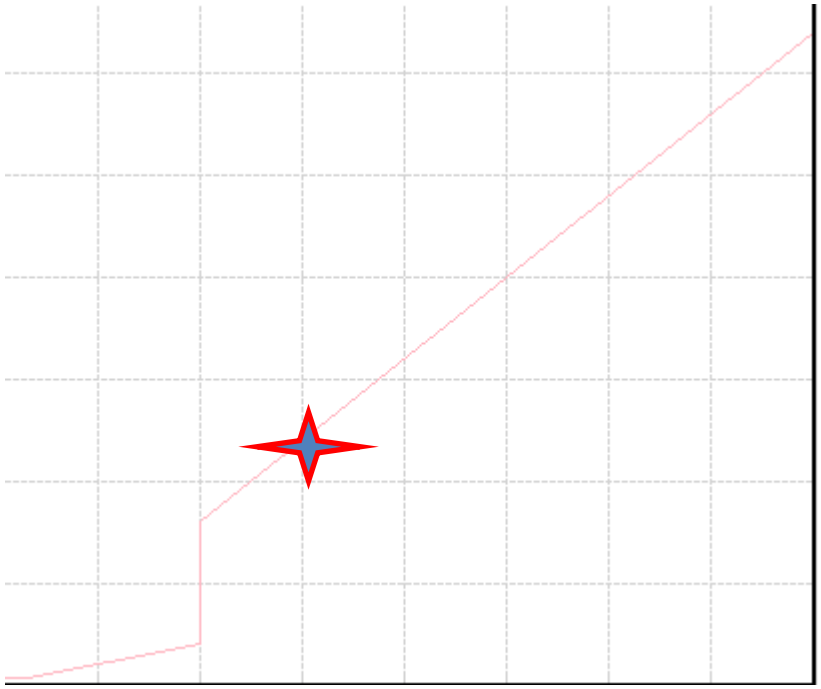
Analog Outputs			
Set Mode	Direct		
V A-N	69.28 V	0.00 °	60.000 Hz
V B-N	69.28 V	-120.00 °	60.000 Hz
V C-N	69.28 V	120.00 °	60.000 Hz
I A	5.000 A	0.00 °	60.000 Hz
I B	5.000 A	-120.00 °	60.000 Hz
I C	5.000 A	120.00 °	60.000 Hz
I Prim A	6.100 A	0.00 °	60.000 Hz
I Prim B	6.100 A	-120.00 °	60.000 Hz
I Prim C	6.100 A	120.00 °	60.000 Hz



Slope 2 test, Math Class!!

1. 12A on all 6 phases, ramp all triples of one side until 87 trip
2. Calculate I diff (28-12 =16)
3. I restraint (28+12=40) / 2=80% slope

Analog Outputs			
Set Mode	Direct		
V A-N	69.28 V	0.00 °	60.000 Hz
V B-N	69.28 V	-120.00 °	60.000 Hz
V C-N	69.28 V	120.00 °	60.000 Hz
I A	12.00 A	0.00 °	60.000 Hz
I B	12.00 A	-120.00 °	60.000 Hz
I C	12.00 A	120.00 °	60.000 Hz
I Prim A	28.00 A	0.00 °	60.000 Hz
I Prim B	28.00 A	-120.00 °	60.000 Hz
I Prim C	28.00 A	120.00 °	60.000 Hz

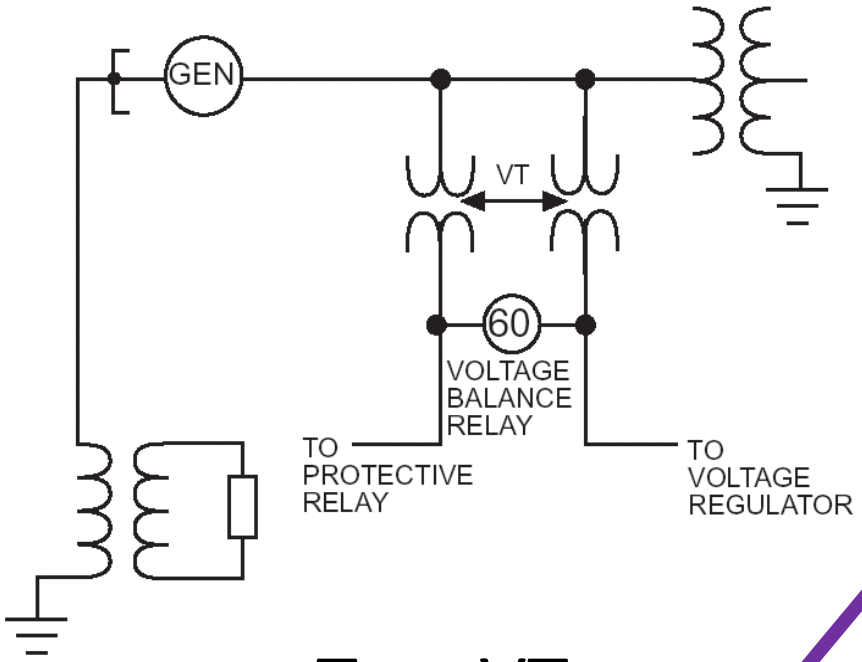


VT Circuit Failure / Fuse Loss (60FL)

Fuse Loss

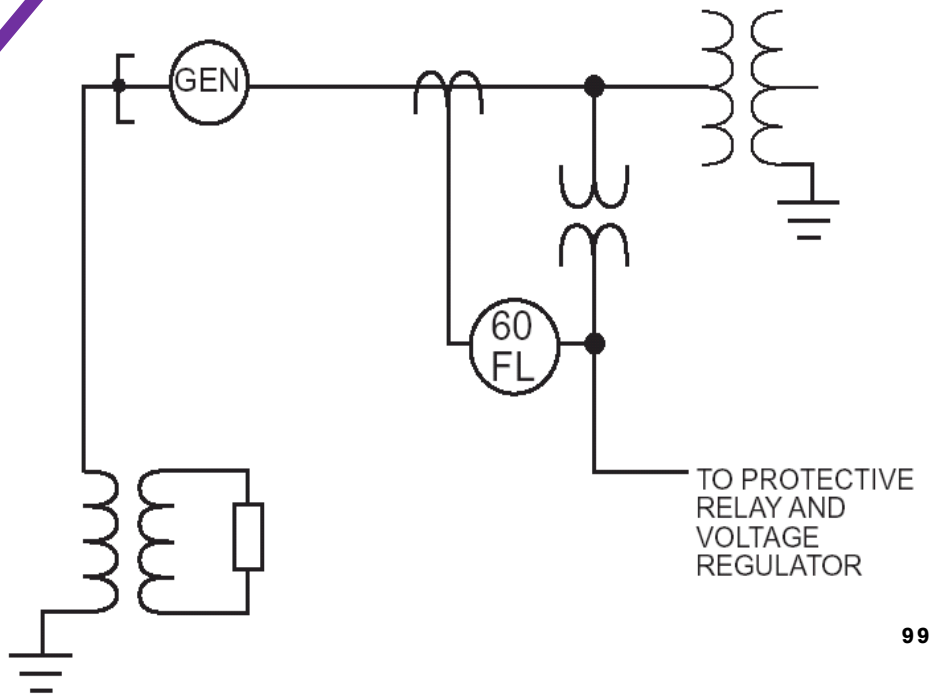
- Fuse loss (loss of voltage potential) can cause voltage sensitive elements to misoperate
  - 51V, 21, 78, 32, 67, 67N, 40
- Typically performed using two sets of VTs and a voltage balance relay
- Some small hydro installations may only have one set of VTs
- Use Symmetrical Component and 3-Phase Voltage/Current methods to provide fuse loss detection on a single VT set

Fuse Loss



Two VTs

One VT

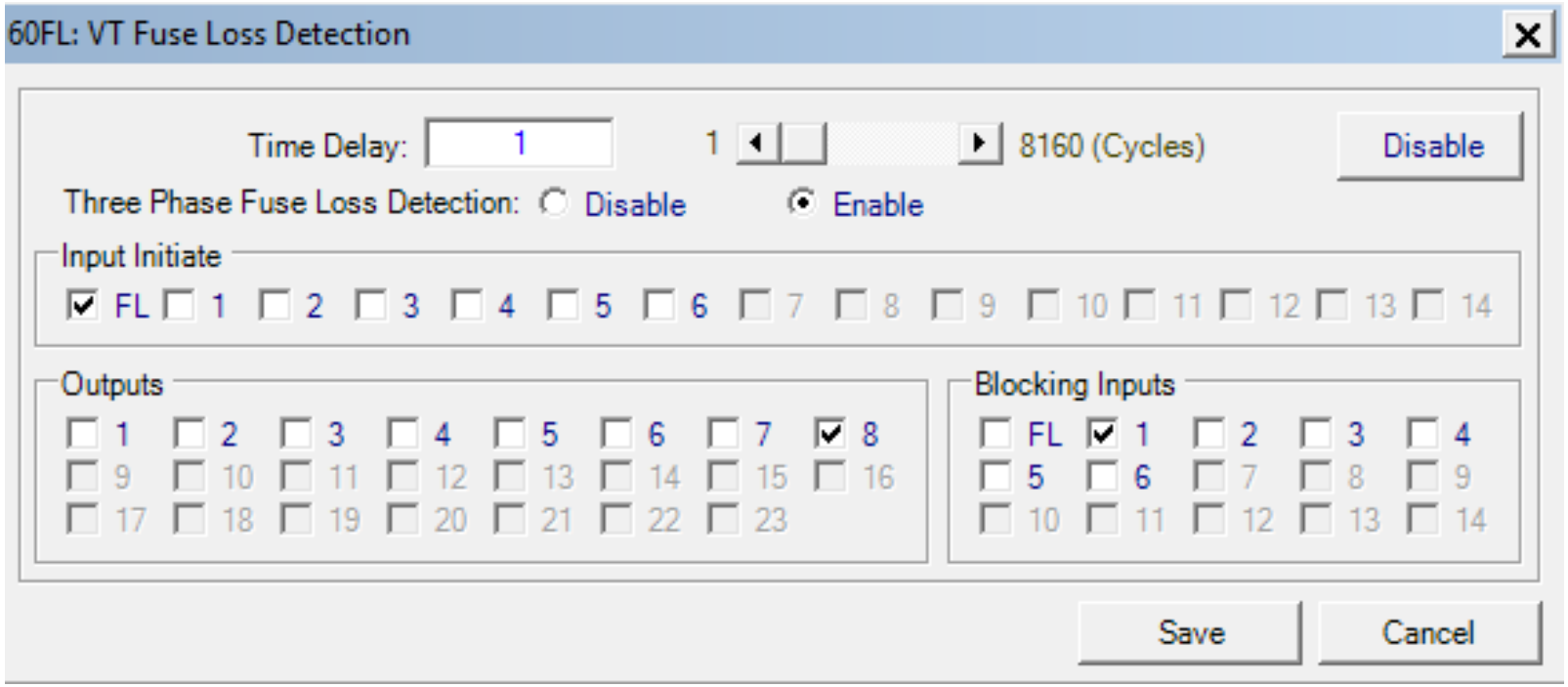


Fuse Loss (LOP) Detection:

Symmetrical Components & 3-Phase Voltage/Current Monitoring

- Use to block voltage dependent elements from misoperating and to alarm
  - Stops nuisance tripping and attendant full load rejection on LOP
- 1 and 2 phase LOP detection by symmetrical component comparison
  - Presence of Negative Sequence Voltage and Negative Sequence Current indicates a Fault
  - Presence of Negative Sequence Voltage and absence of Negative Sequence Current indicates a Fuse Loss
- 3 phase LOP detected by voltage and current monitoring
  - Low 3-Phase Voltages and High 3-Phase Currents indicates a Fault
  - Low 3-Phase Voltages and Low 3-Phase Current indicates a Fuse Loss

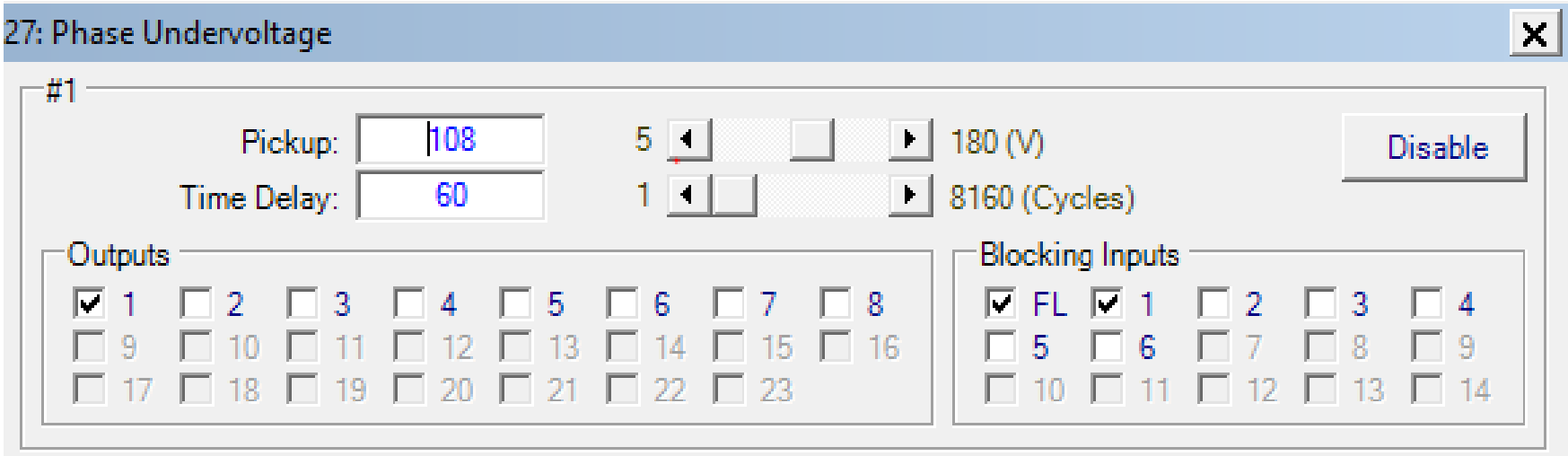
Loss of Potential Settings



Input initiate- Internal or external?
Output-To system alarm
Blocking- Only when 52B is open (closed breaker)
Three Phase Detection-Compares Voltage to Current

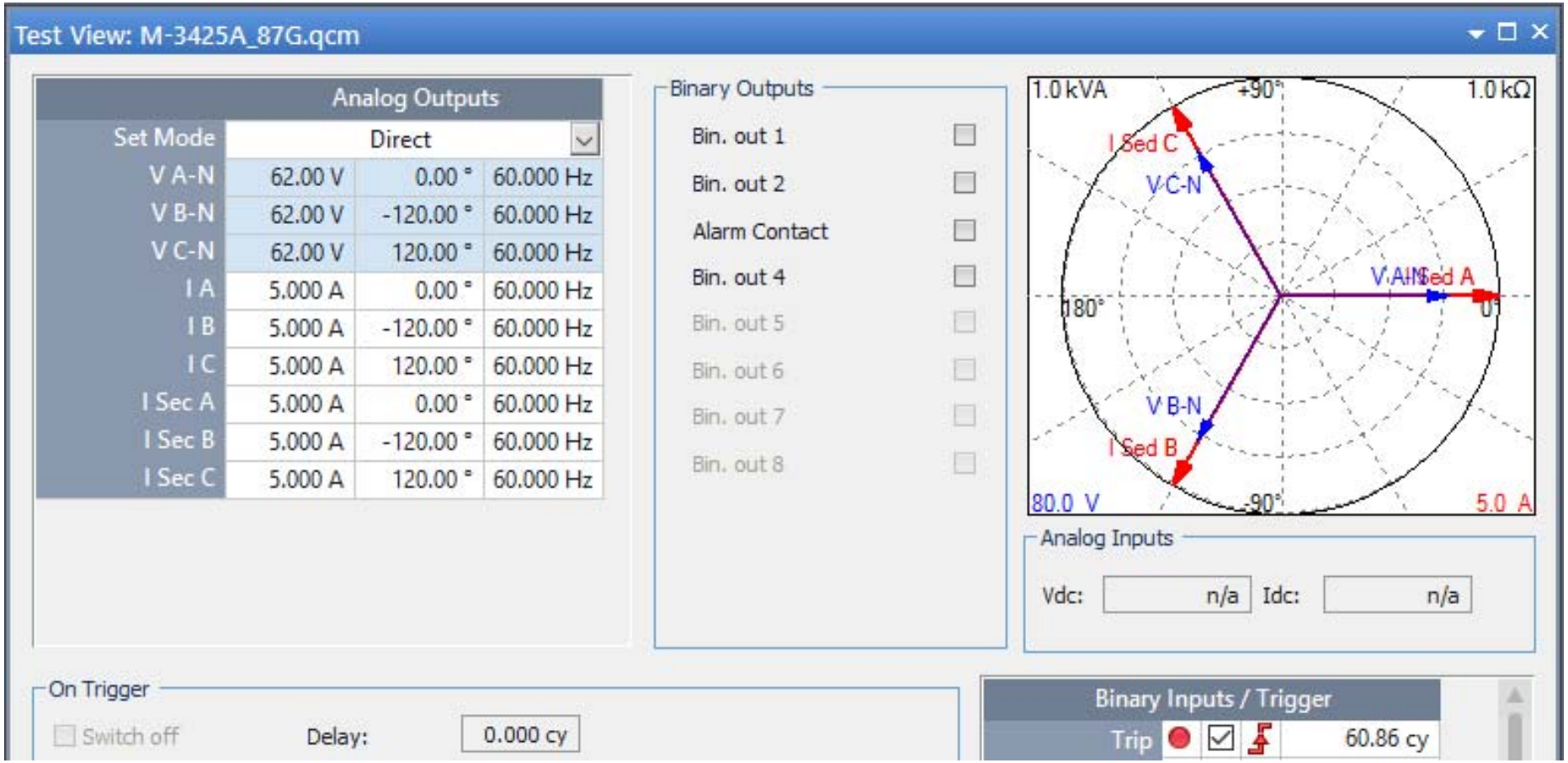
⇒D

Set Undervoltage Element (27)



FL (fuse loss to block)
52b blocks when input contact is closed (open breaker)
Time delay (exceeds delay for LOP)

Test the Undervoltage Element (27)



LOP Test

1) Single Phase
2) 2 of 3 Phases
3) 3 Phase

Analog Outputs			
Set Mode	Direct		
V A-N	69.28 V	0.00 °	60.000 Hz
V B-N	69.28 V	-120.00 °	60.000 Hz
V C-N	69.28 V	120.00 °	60.000 Hz
I A	5.000 A	0.00 °	60.000 Hz
I B	5.000 A	-120.00 °	60.000 Hz
I C	5.000 A	120.00 °	60.000 Hz
I Sec A	5.000 A	0.00 °	60.000 Hz
I Sec B	5.000 A	-120.00 °	60.000 Hz
I Sec C	5.000 A	120.00 °	60.00

Pre-fault

Analog Outputs			
Set Mode	Direct		
V A-N	0.000 V	0.00 °	60.000 Hz
V B-N	69.28 V	-120.00 °	60.000 Hz
V C-N	69.28 V	120.00 °	60.000 Hz
I A	5.000 A	0.00 °	60.000 Hz
I B	5.000 A	-120.00 °	60.000 Hz
I C	5.000 A	120.00 °	60.000 Hz
I Sec A	5.000 A	0.00 °	60.000 Hz
I Sec B	5.000 A	-120.00 °	60.000 Hz
I Sec C	5.000 A	120.00 °	60.000 Hz

Single phase-fault

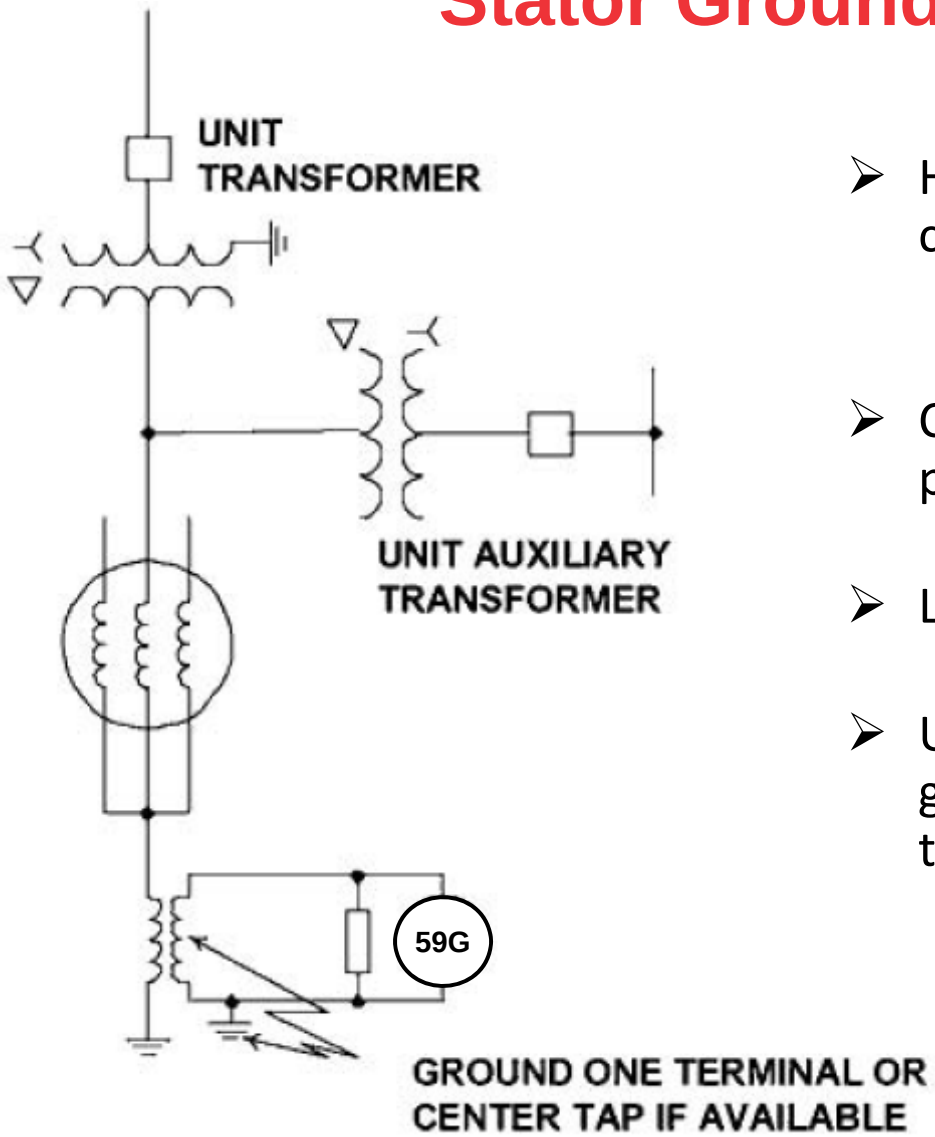
Binary Inputs / Trigger			
Trip	○	☐	n/a
Start	○	☐	n/a
Alarm	●	☐	n/a

Analog Outputs			
Set Mode	Direct		
V A-N	0.000 V	0.00 °	60.000 Hz
V B-N	0.000 V	-120.00 °	60.000 Hz
V C-N	0.000 V	120.00 °	60.000 Hz
I A	5.000 A	0.00 °	60.000 Hz
I B	5.000 A	-120.00 °	60.000 Hz
I C	5.000 A	120.00 °	60.000 Hz
I Sec A	5.000 A	0.00 °	60.000 Hz
I Sec B	5.000 A	-120.00 °	60.000 Hz
I Sec C	5.000 A	120.00 °	60.000 Hz

Three phase-fault, I must be present

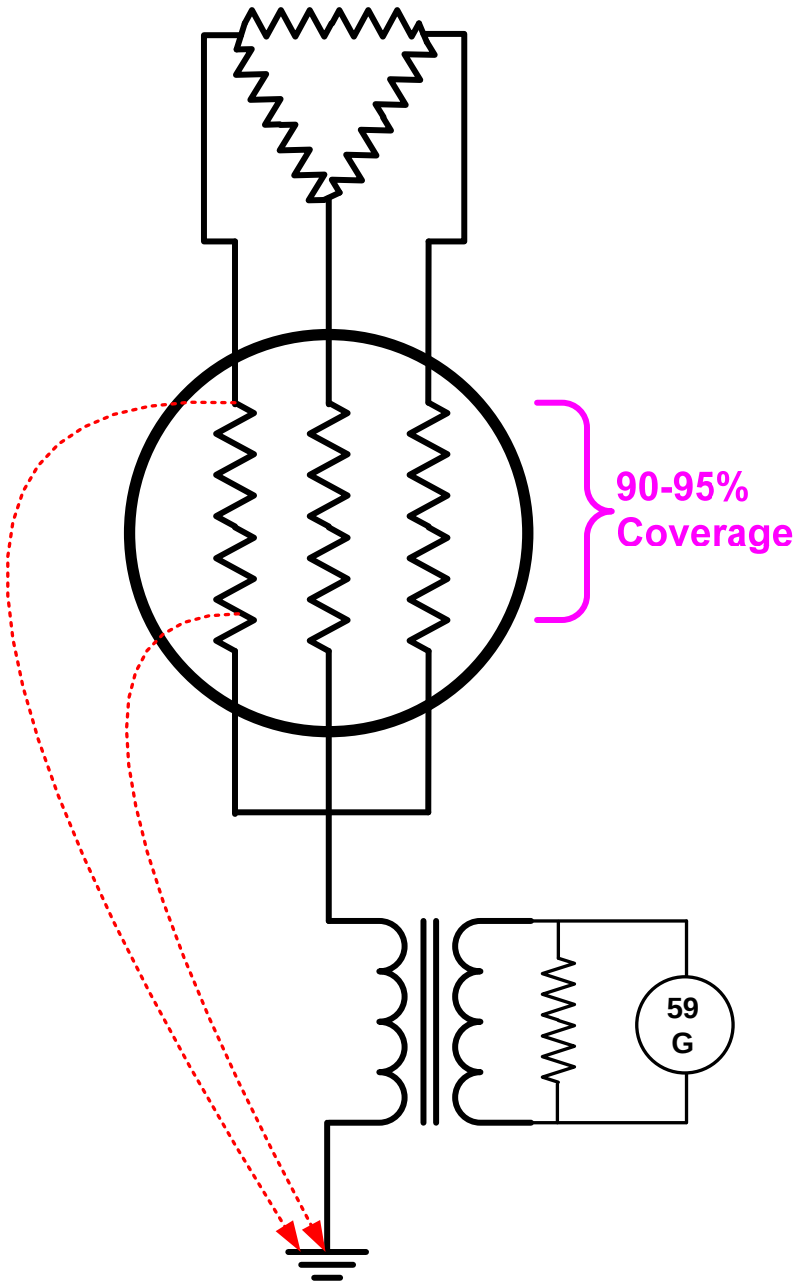
95% Stator Ground Fault (59G)

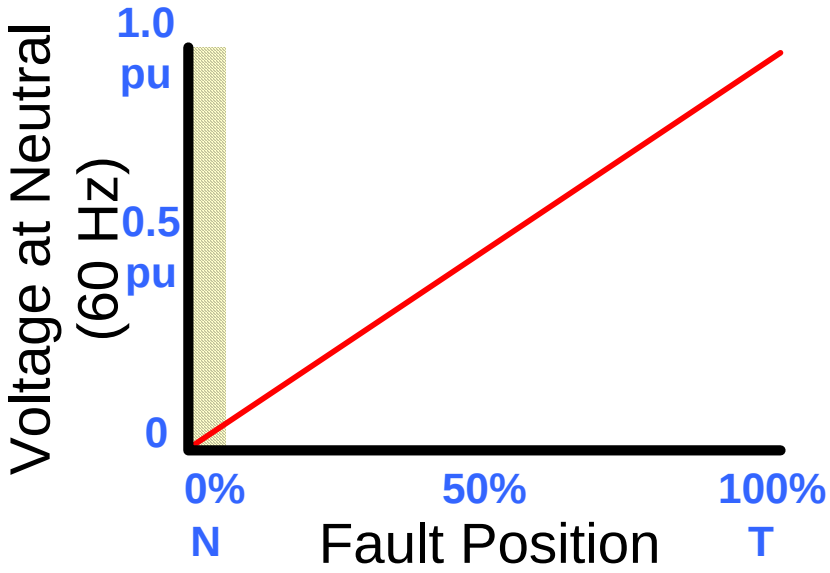
Stator Ground Fault (59G)



- High impedance ground limits ground fault current to about 10A
  - Limits damage on internal ground fault
- Conventional neutral overvoltage relay provides 90-95% stator coverage
- Last 5-10% near neutral not covered
- Undetected grounds in this region bypass grounding transformer, solidly grounding the machine!

59G Element





- **Neutral grounding transformer (NGT) ratio selected that provides 120 to 240V for ground fault at machine terminals**
  - **Max L-G volts =13.8kV / 1.73 = 7995V**
  - **Max NGT volts sec. = 7995V / 120V = 66.39 VTR**

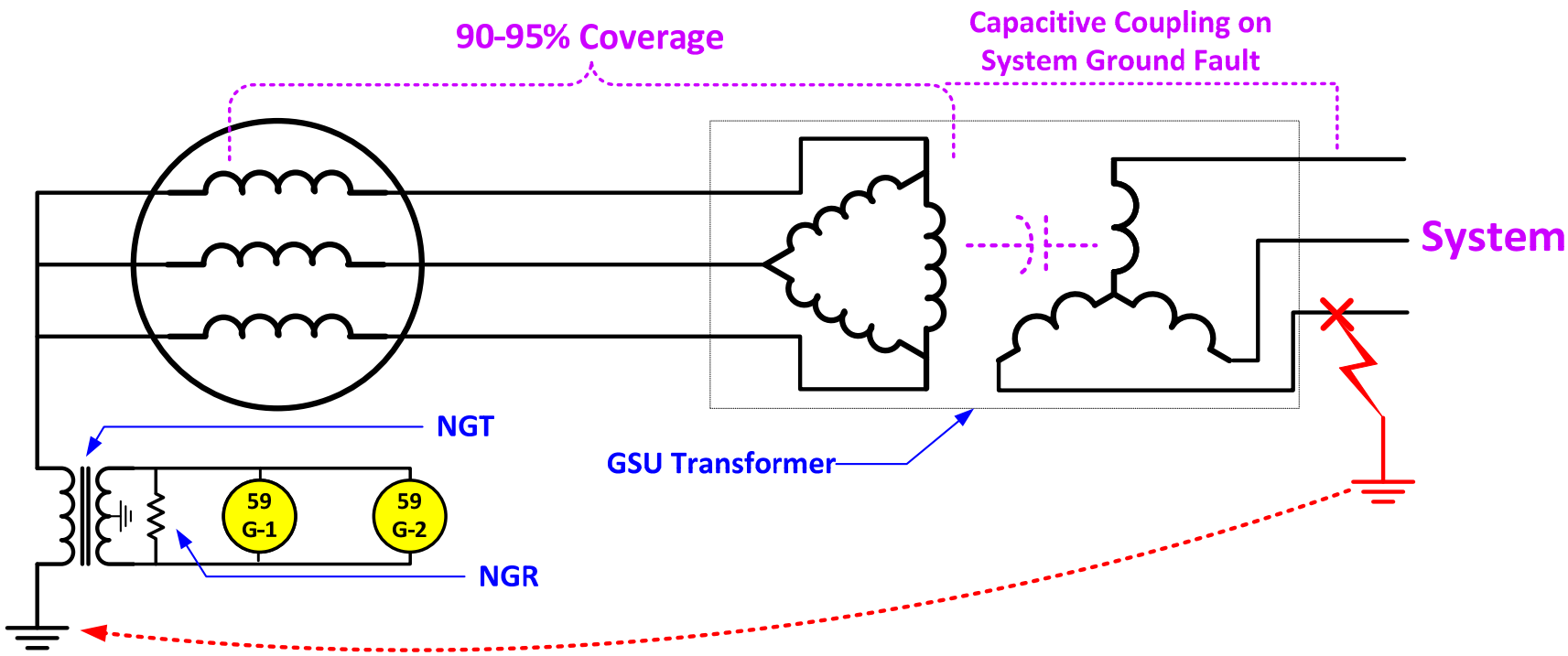
Stator Ground Fault-High Z Grounded Machines

- 95% stator ground fault provided by 59G
  Tuned to the fundamental frequency
  - Must work properly from 10 to 80 Hz to provide protection during startup

- Additional coverage near neutral (last 5%) provided by:
  - 27TN: 3rd harmonic undervoltage
  - 59D: Ratio of 3rd harmonic at terminal and neutral ends of winding

- Full 100% stator coverage by 64S
  - Use of sub-harmonic injection
  - May be used when generator is off-line
  - Immune to changes in loading (MW, MVAR)

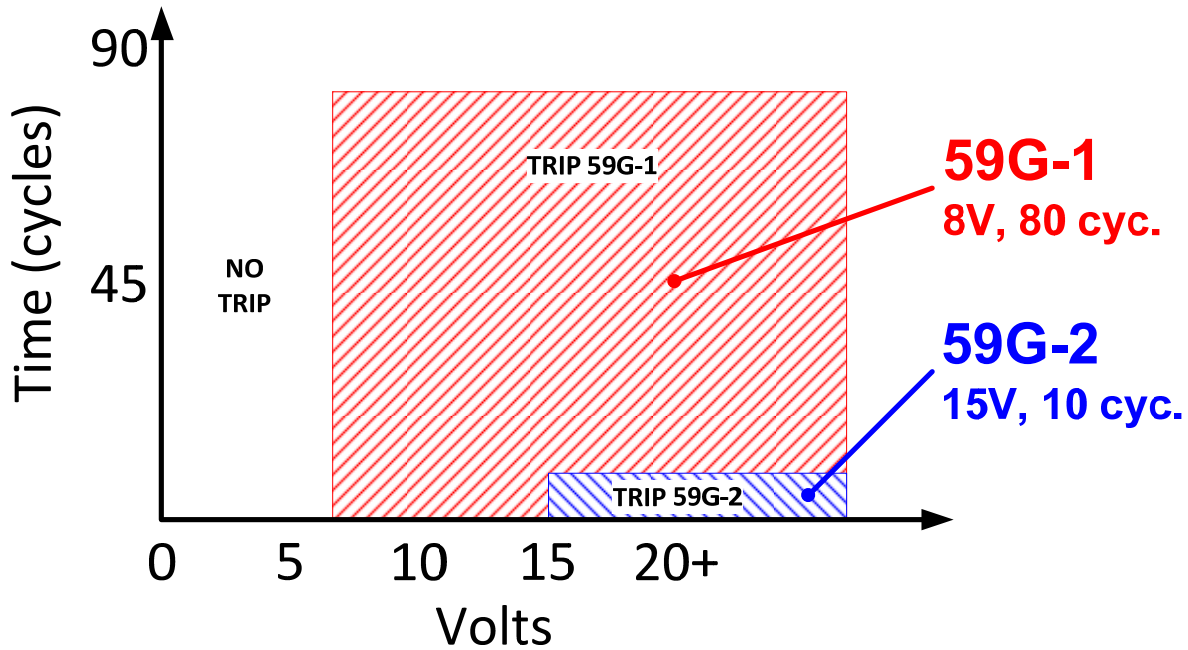
59G System Ground Fault Issue



- GSU provides capacitive coupling for system ground faults into generator zone
- Use two levels of 59G with short and long time delays for selectivity
- <u>Cannot</u> detect ground faults at/near the neutral (very important)

Multiple 59G Element Application

- **59G-1,** set in this example to 5%, may sense capacitance coupled out-of-zone ground fault
  - **Long** time delay

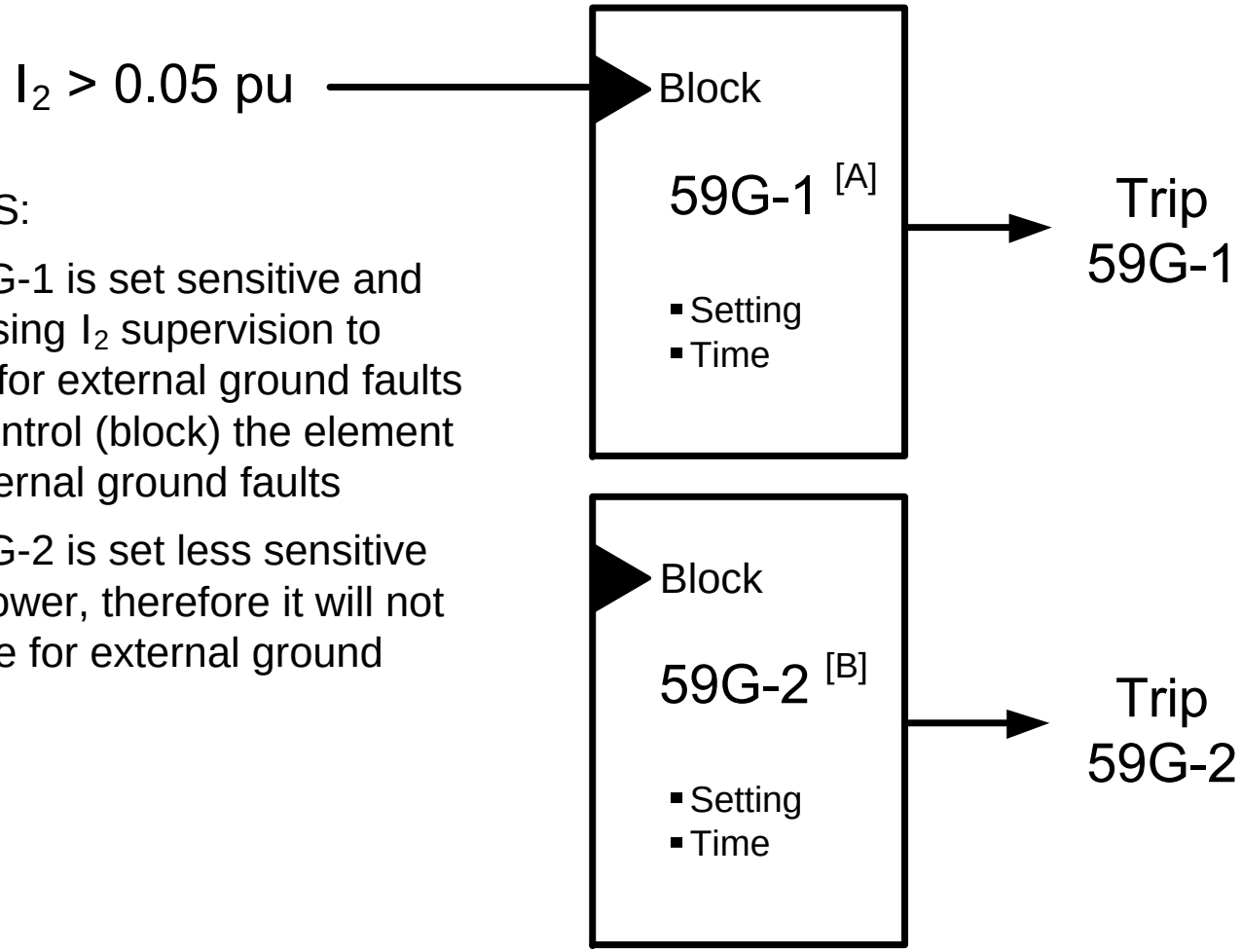


- 59G-2, set in this example to 15%, is set above capacitance coupled out-of-zone ground fault
  - Short time delay

Use of Symmetrical Component Quantities to Supervise 59G Tripping Speed

- A ground fault in the generator zone produces primarily <u>zero</u> sequence voltage
  - Negligible V_2, I_2 or I_0
- A fault in the VT secondary or system (GSU coupled) generates <u>negative</u> sequence quantities in addition to zero sequence voltage
- The I_2 method may be employed to control the 59G for system ground faults
- The V_2/V_0 method may be employed to control the 59G for system and VT secondary ground faults

Use of I_2 to Supervise 59G Tripping Speed

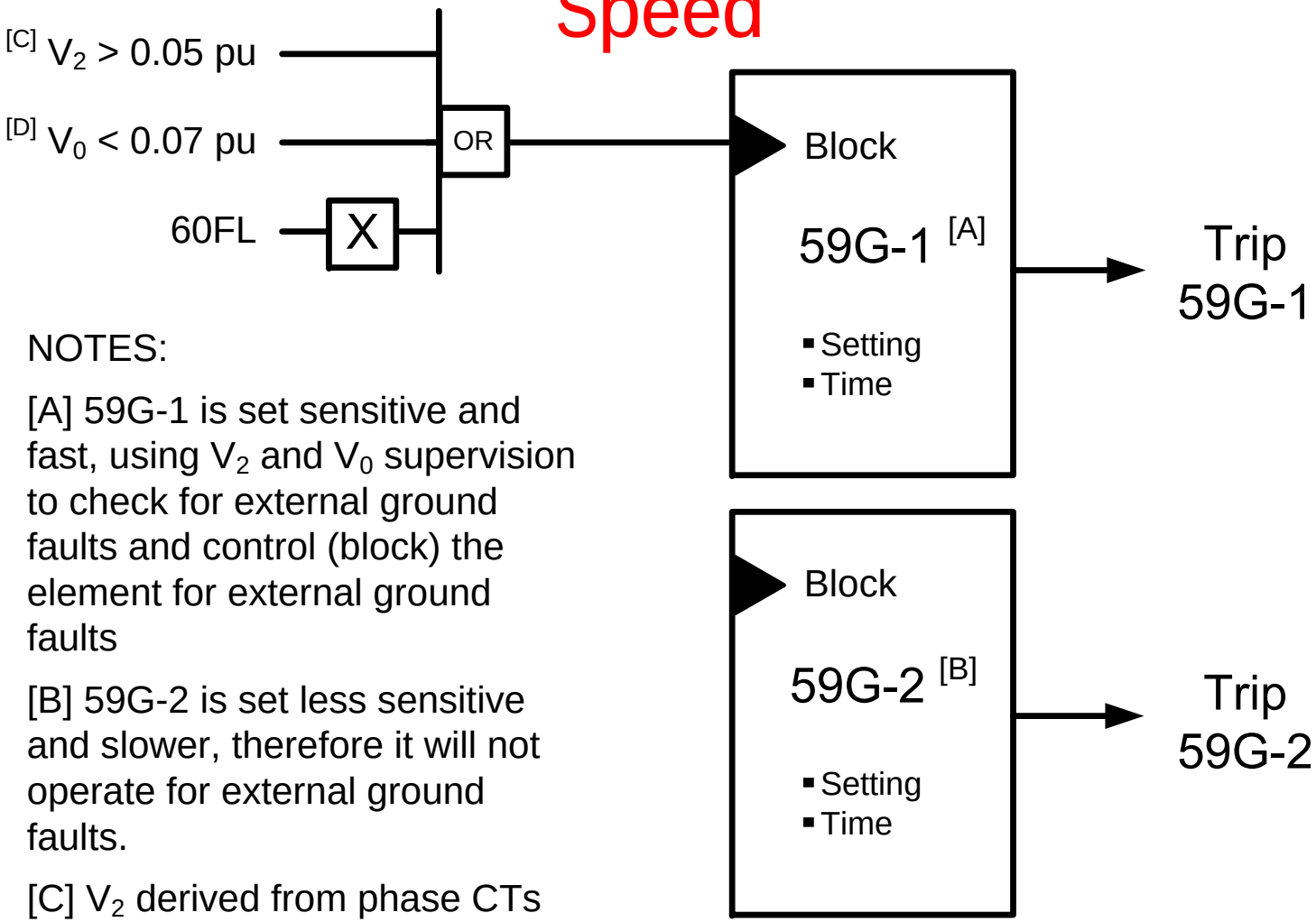


NOTES:

[A] 59G-1 is set sensitive and fast, using I_2 supervision to check for external ground faults and control (block) the element for external ground faults

[B] 59G-2 is set less sensitive and slower, therefore it will not operate for external ground faults.

Use of V_2 /V_0 to Supervise 59G Tripping Speed



NOTES:

[A] 59G-1 is set sensitive and fast, using V_2 and V_0 supervision to check for external ground faults and control (block) the element for external ground faults

[B] 59G-2 is set less sensitive and slower, therefore it will not operate for external ground faults.

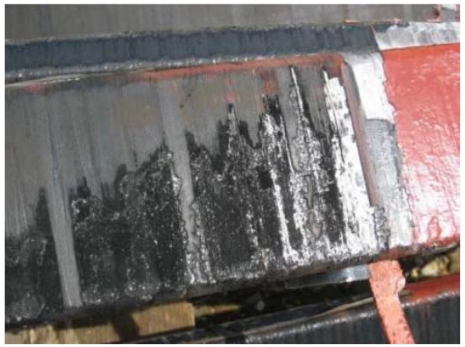
[C] V_2 derived from phase CTs

[D] V_0 derived from 3Y VTs

Intermittent Arcing Ground Faults

- Can be very destructive, especially at neutral
- At neutral, even though AC current is very low, arcing fault develops a high voltage DC transient
- If enough arcs occur in a short time, destructive insulation damage can occur
- Conventional time delayed ground fault protection cannot protect for these events

Burned away copper of a fractured connection ring

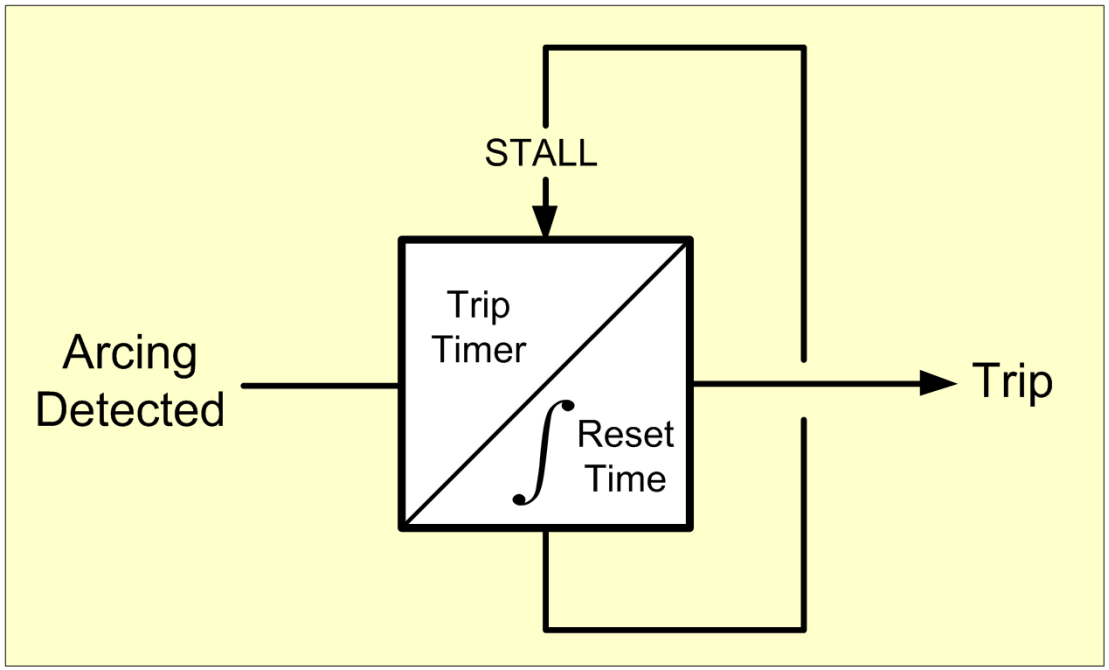


Side of a bar deeply damaged by vibration sparking

Premature Failure of Modern Generators, Clyde V. Maughan

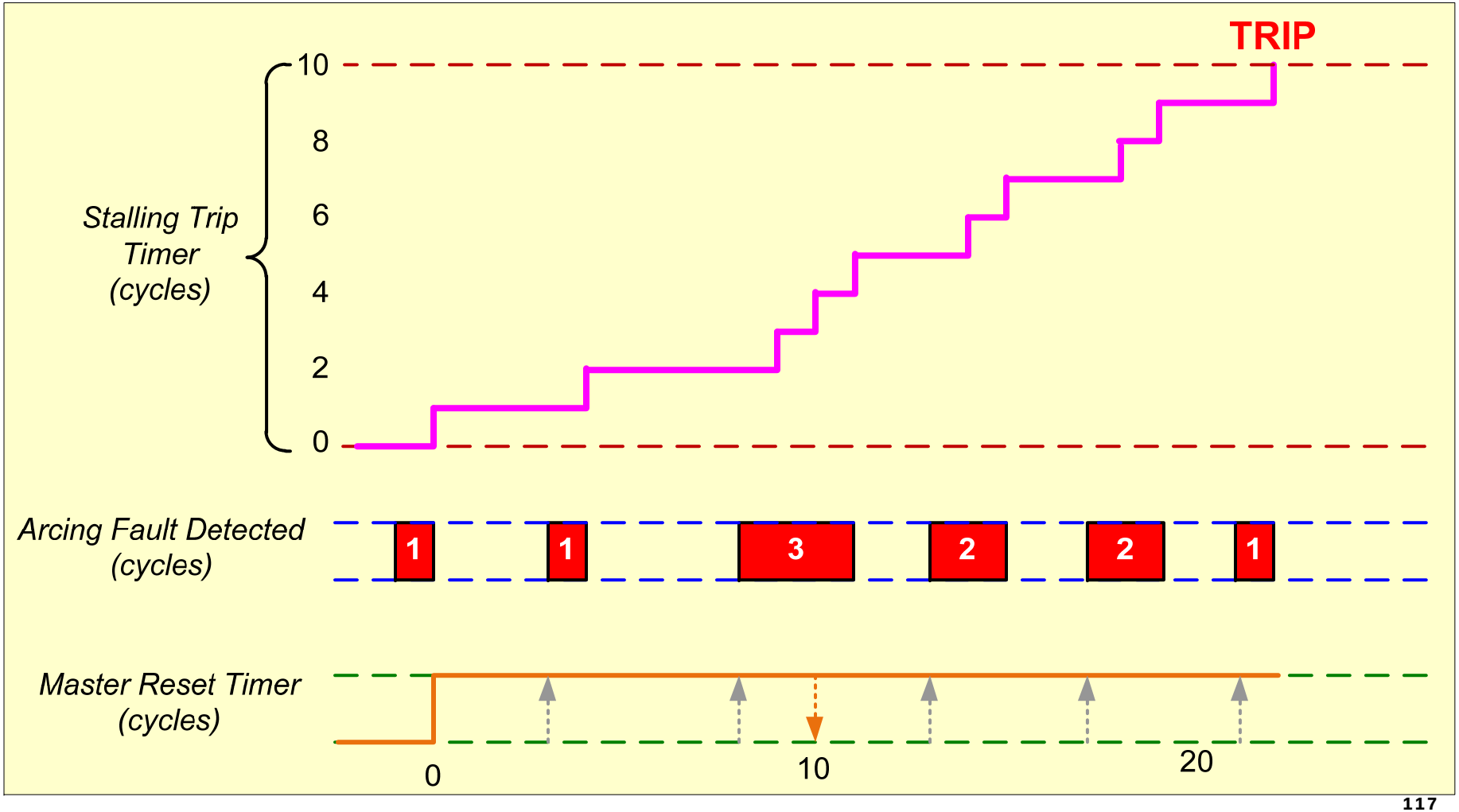
Intermittent Arcing Ground Fault

Intermittent Arcing Fault Timer Logic



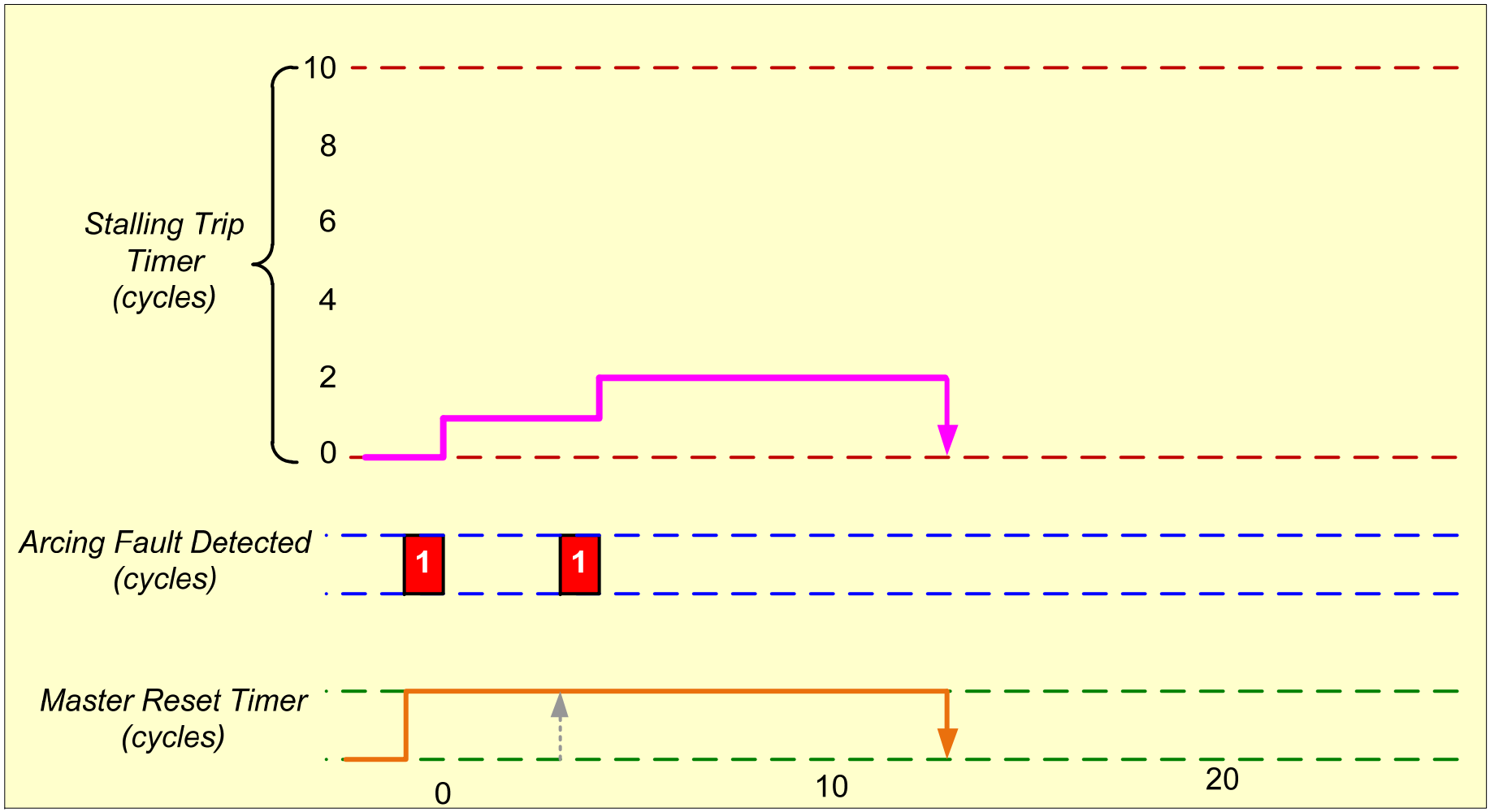
Stallable Trip Timer: Times Out to Trip
Integrating Reset Time: Delays Reset for Interval

Intermittent Arcing Ground Fault



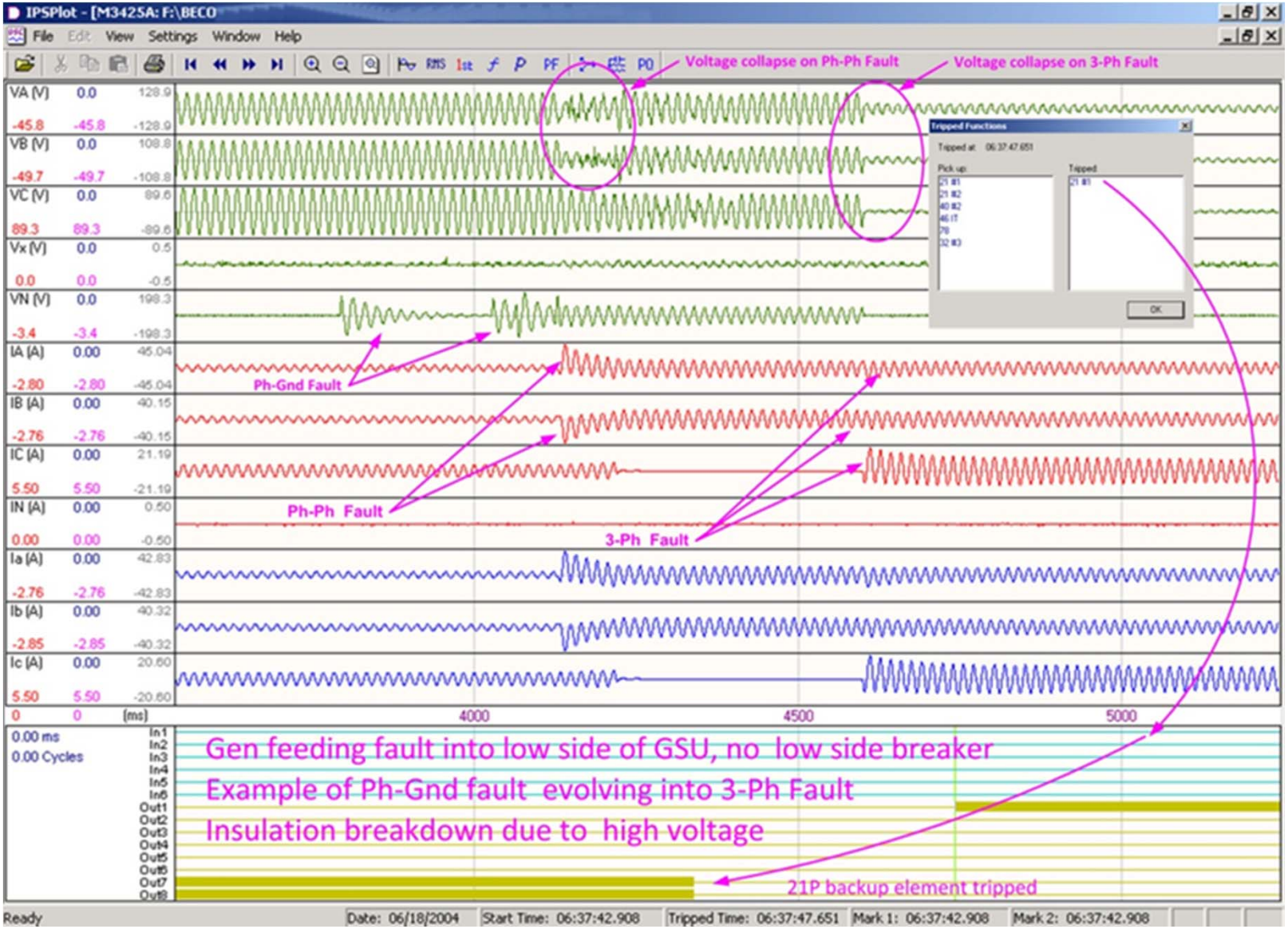
Arcing and Trip

Intermittent Arcing Ground Fault



Arcing and Reset (No Trip)

Intermittent Arcing Ground Fault Turned Multiphase

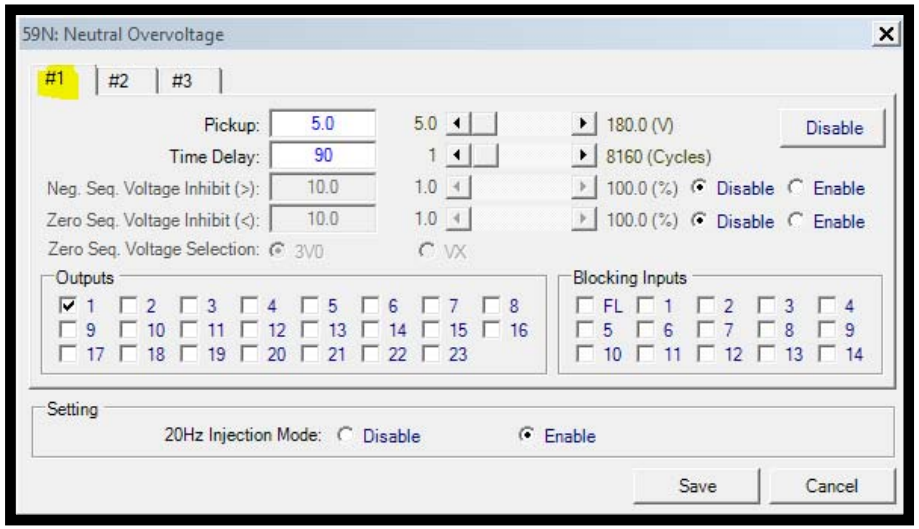


59G Element

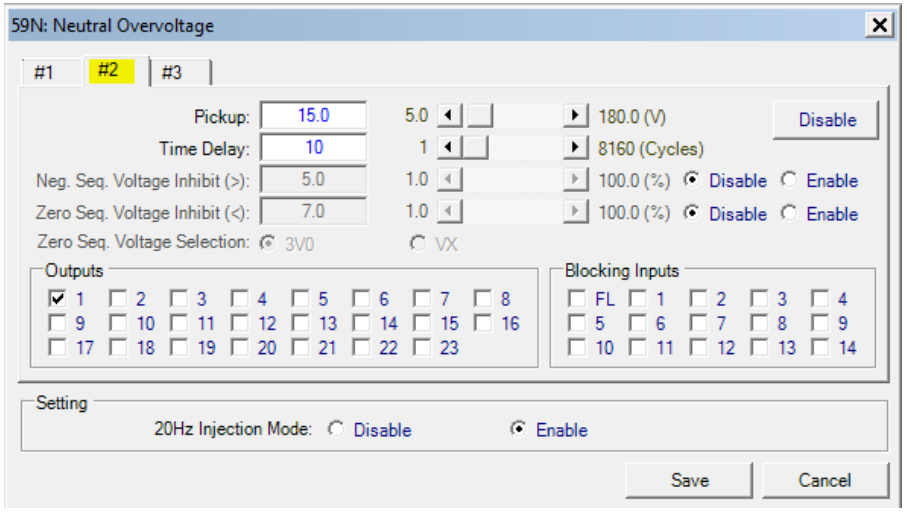
59G – Generator Neutral Overvoltage: Three setpoints

- 1st level set sensitive to cover down to 5% of stator
  - Use long time delay for security from close-in system ground faults capacitively coupled across GSU
  - Use pick up for intermittent arcing detection logic (IPSlogic)
- 2nd level pickup set higher than the GSU capacitively coupled voltage for out-of-zone ground faults, or use I_2 or V_2/V_0 control
  - I_2 or V_2/V_0 control allows higher speed tripping
  - Controls 59G when challenged with out-of-zone ground faults
  - Only need to coordinate with PT fuses
- 3rd level may be set to initiate waveform capture and not trip

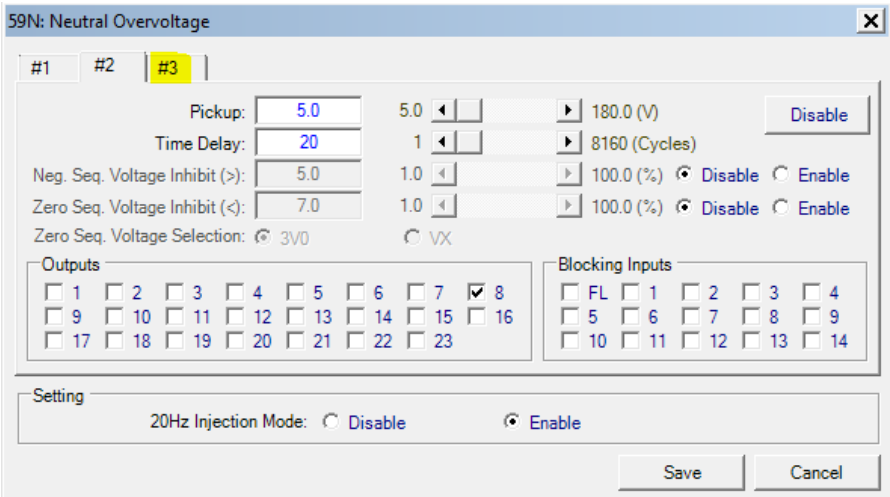
59G Element



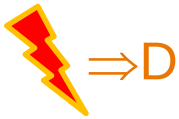
59N-1: Sensitive Setting and Long Trip Time for security against out-of-zone ground faults



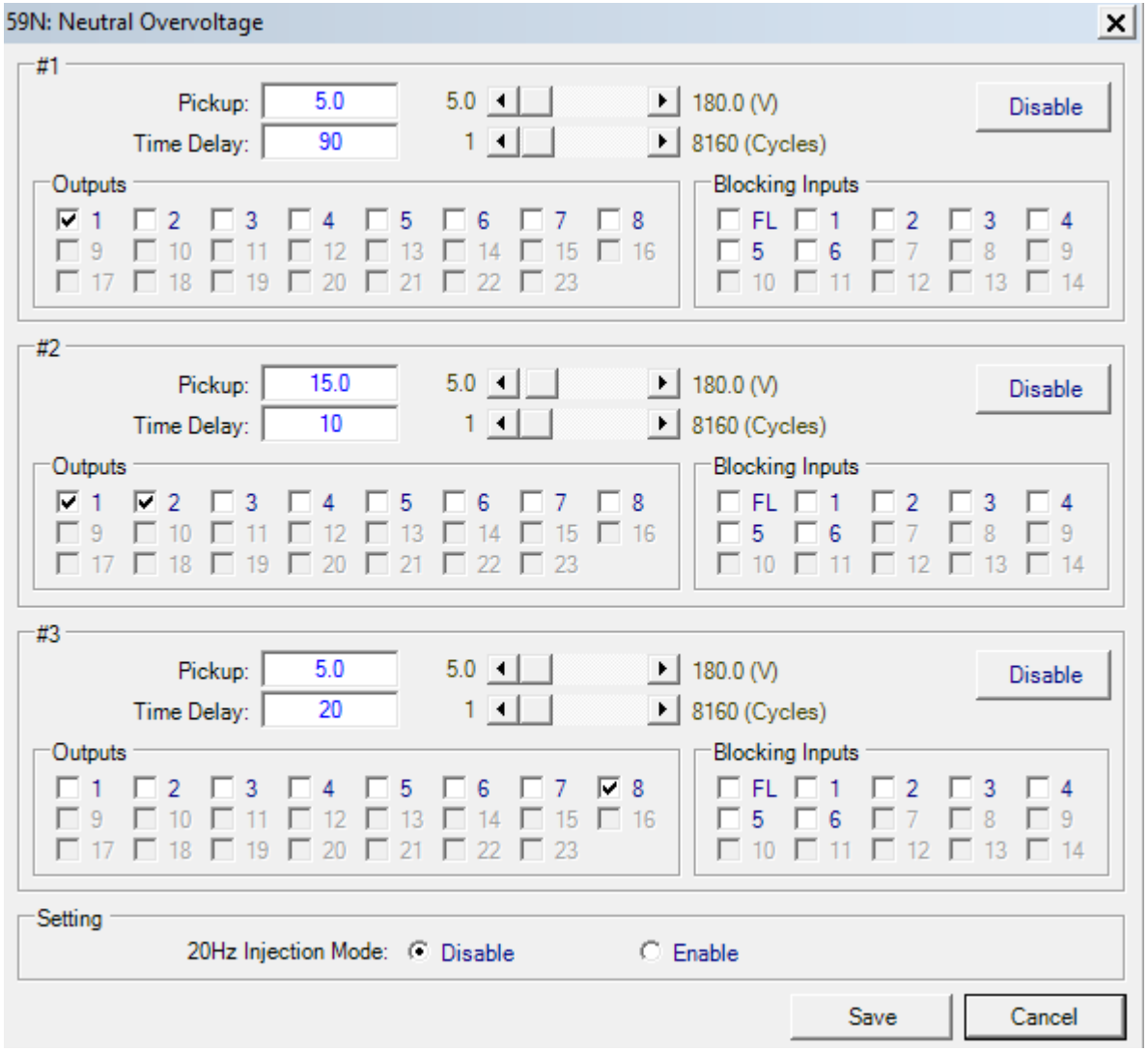
59N-2: Higher Setting and Short Trip Time for security against out-of-zone faults security against out-of-section ground faults



59N-3: Alarm only, trigger oscillography



Settings for Testing



Testing pre-qualifications

1) Test set should have 3 phase voltage
2) Wire additional single phase voltage to terminals -44, +45
3) If test set does not have 4th voltage, must disable 3 phase undervoltage (27)
4) Currents not required for testing
5) Element not sensitive to breaker position
6) Alarm setting (#3) uses separate output (#8)

Pre-fault

Analog Outputs			
Set Mode	Direct		
I A	5.000 A	0.00 °	60.000 Hz
I B	5.000 A	-120.00 °	60.000 Hz
I C	5.000 A	120.00 °	60.000 Hz
V Fault	3.000 V	0.00 °	60.000 Hz
V(1)-1	69.28 V	0.00 °	60.000 Hz
V(2)-2	69.28 V	-120.00 °	60.000 Hz
V(3)-3	69.28 V	120.00 °	60.000 Hz
I Sec A	5.000 A	0.00 °	60.000 Hz
I Sec B	5.000 A	-120.00 °	60.000 Hz
I Sec C	5.000 A	120.00 °	60.000 Hz

Test alarm timing

Analog Outputs			
Set Mode	Direct		
I A	5.000 A	0.00 °	60.000 Hz
I B	5.000 A	-120.00 °	60.000 Hz
I C	5.000 A	120.00 °	60.000 Hz
V Fault	5.100 V	0.00 °	60.000 Hz
V(1)-1	69.28 V	0.00 °	60.000 Hz
V(2)-2	69.28 V	-120.00 °	60.000 Hz
V(3)-3	69.28 V	120.00 °	60.000 Hz
I Sec A	5.000 A	0.00 °	60.000 Hz
I Sec B	5.000 A	-120.00 °	60.000 Hz
I Sec C	5.000 A	120.00 °	60.000 Hz

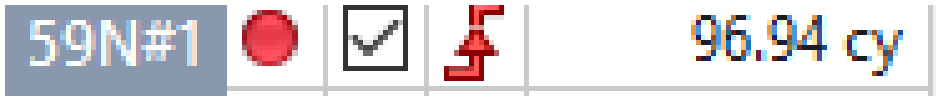
59N#3		☑		20.72 cy

Pre-fault

Analog Outputs			
Set Mode	Direct		
I A	5.000 A	0.00 °	60.000 Hz
I B	5.000 A	-120.00 °	60.000 Hz
I C	5.000 A	120.00 °	60.000 Hz
V Fault	3.000 V	0.00 °	60.000 Hz
V(1)-1	69.28 V	0.00 °	60.000 Hz
V(2)-2	69.28 V	-120.00 °	60.000 Hz
V(3)-3	69.28 V	120.00 °	60.000 Hz
I Sec A	5.000 A	0.00 °	60.000 Hz
I Sec B	5.000 A	-120.00 °	60.000 Hz
I Sec C	5.000 A	120.00 °	60.000 Hz

Test trip timing

Analog Outputs			
Set Mode	Direct		
I A	5.000 A	0.00 °	60.000 Hz
I B	5.000 A	-120.00 °	60.000 Hz
I C	5.000 A	120.00 °	60.000 Hz
V Fault	5.100 V	0.00 °	60.000 Hz
V(1)-1	69.28 V	0.00 °	60.000 Hz
V(2)-2	69.28 V	-120.00 °	60.000 Hz
V(3)-3	69.28 V	120.00 °	60.000 Hz
I Sec A	5.000 A	0.00 °	60.000 Hz
I Sec B	5.000 A	-120.00 °	60.000 Hz
I Sec C	5.000 A	120.00 °	60.000 Hz



Pre-fault

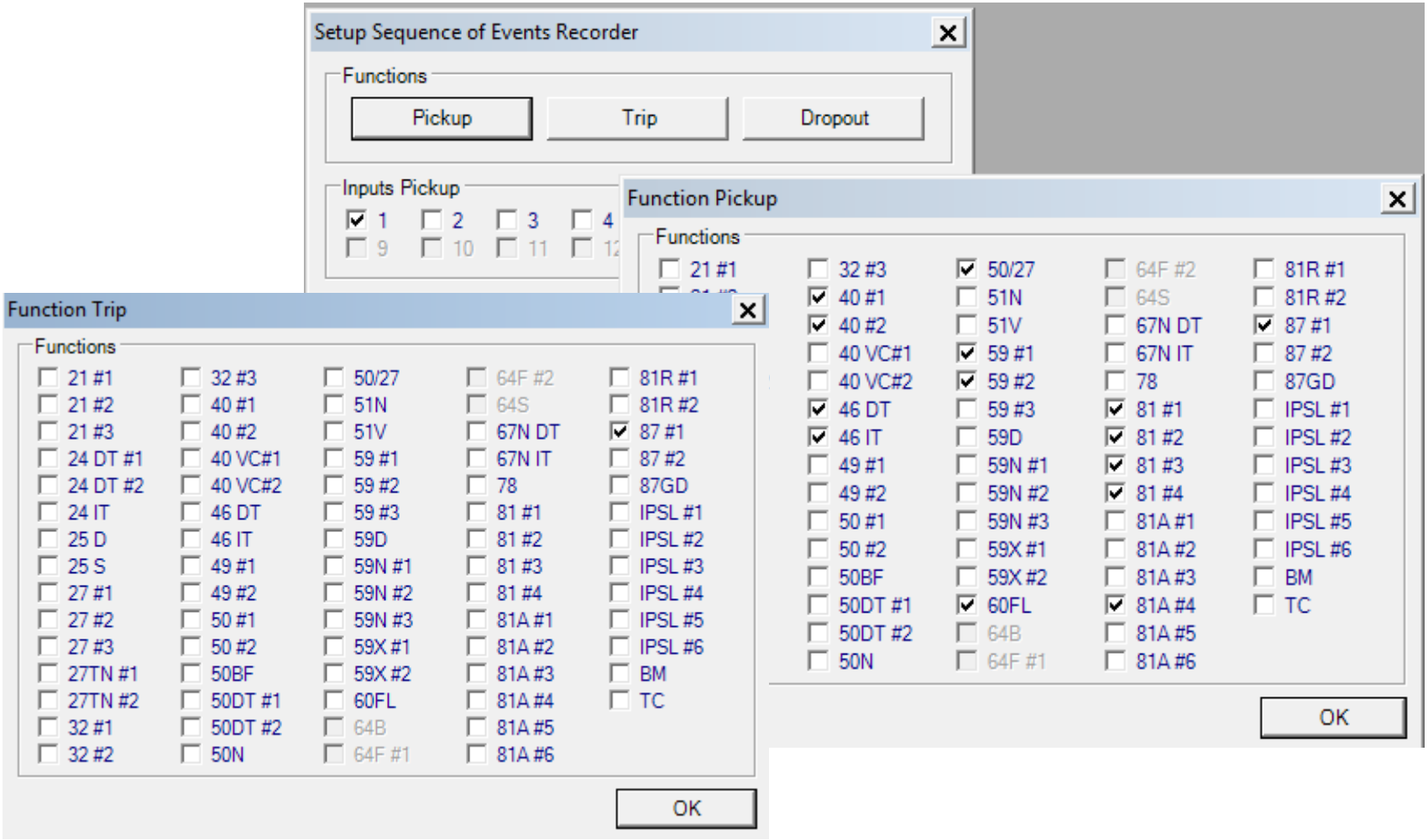
Analog Outputs			
Set Mode	Direct		
I A	5.000 A	0.00 °	60.000 Hz
I B	5.000 A	-120.00 °	60.000 Hz
I C	5.000 A	120.00 °	60.000 Hz
V Fault	3.000 V	0.00 °	60.000 Hz
V(1)-1	69.28 V	0.00 °	60.000 Hz
V(2)-2	69.28 V	-120.00 °	60.000 Hz
V(3)-3	69.28 V	120.00 °	60.000 Hz
I Sec A	5.000 A	0.00 °	60.000 Hz
I Sec B	5.000 A	-120.00 °	60.000 Hz
I Sec C	5.000 A	120.00 °	60.000 Hz

Test high set timing

Analog Outputs			
Set Mode	Direct		
I A	5.000 A	0.00 °	60.000 Hz
I B	5.000 A	-120.00 °	60.000 Hz
I C	5.000 A	120.00 °	60.000 Hz
V Fault	15.20 V	0.00 °	60.000 Hz
V(1)-1	69.28 V	0.00 °	60.000 Hz
V(2)-2	69.28 V	-120.00 °	60.000 Hz
V(3)-3	69.28 V	120.00 °	60.000 Hz
I Sec A	5.000 A	0.00 °	60.000 Hz
I Sec B	5.000 A	-120.00 °	60.000 Hz
I Sec C	5.000 A	120.00 °	60.000 Hz

59N#2				10.77 cy

Other Important Diagnostic Tools



BECKWITH ELECTRIC CO. INC.

SOE Viewer

View Sequence of Events Record

Open | Print | Print Preview | Set Print Range | Close

No	Event Summary
1	01/01/2001, 01:01:80.000
	50/27: Pickup/Timeout/
2	01/01/2001, 01:01:80.000
	50/27: Drop
3	01/01/2001, 01:01:80.000
4	01/01/2001, 01:01:80.000
	50/27: Pickup/Timeout/
5	01/01/2001, 01:01:80.000
	50/27: Drop
6	01/01/2001, 01:01:80.000
7	01/01/2001, 01:01:80.000
	50/27: Pickup/Timeout/
8	01/01/2001, 01:01:80.000
	50/27: Drop
9	01/01/2001, 01:01:80.000

#8

Item	Value	Unit
VA	46.3	V
VB	46.3	V
VC	46.3	V
VN	0.0	V
VX	0.0	V
VPS	46.5	V
VNS	0.1	V
VZS	0.1	V
IA	0.00	A
IB	0.00	A
IC	0.00	A
IN	0.00	A
Ia	4.50	A
Ib	4.49	A
Ic	4.48	A
IPS	4.49	A
INS	0.00	A
IZS	0.00	A
Ia Diff	4.49	A

Inputs Pickup

☐ FL ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐ 11
☐ 12 ☐ 13 ☐ 14

Inputs Drop

☐ FL ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐ 11
☐ 12 ☐ 13 ☐ 14

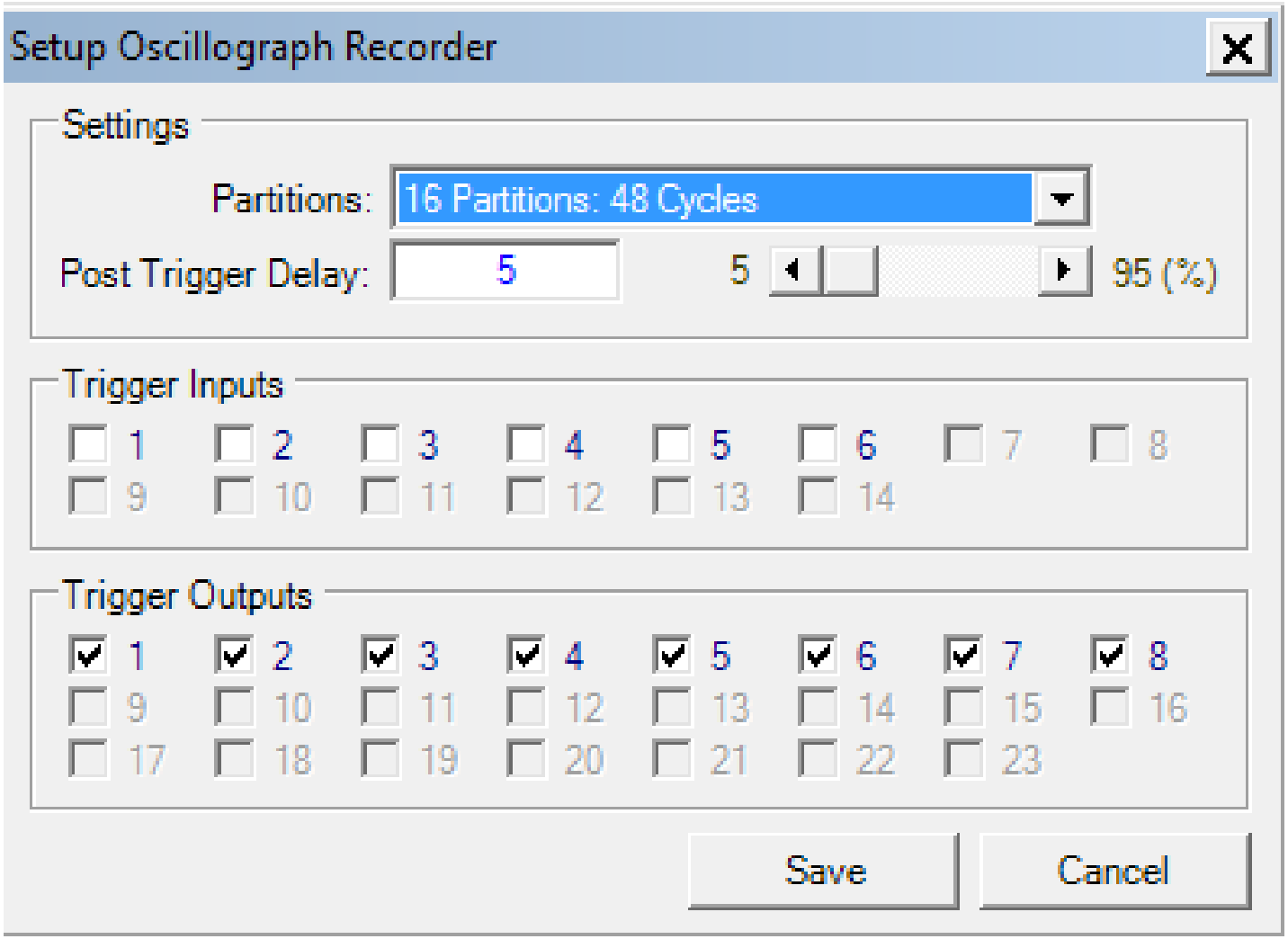
Outputs Pickup

☑ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6
☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐ 11 ☐ 12
☐ 13 ☐ 14 ☐ 15 ☐ 16 ☐ 17 ☐ 18
☐ 19 ☐ 20 ☐ 21 ☐ 22 ☐ 23

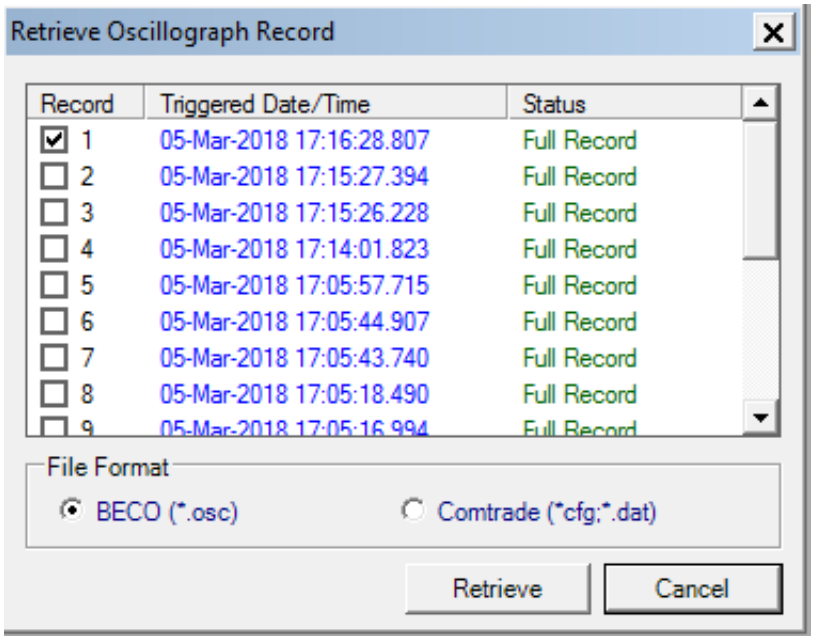
Outputs Drop

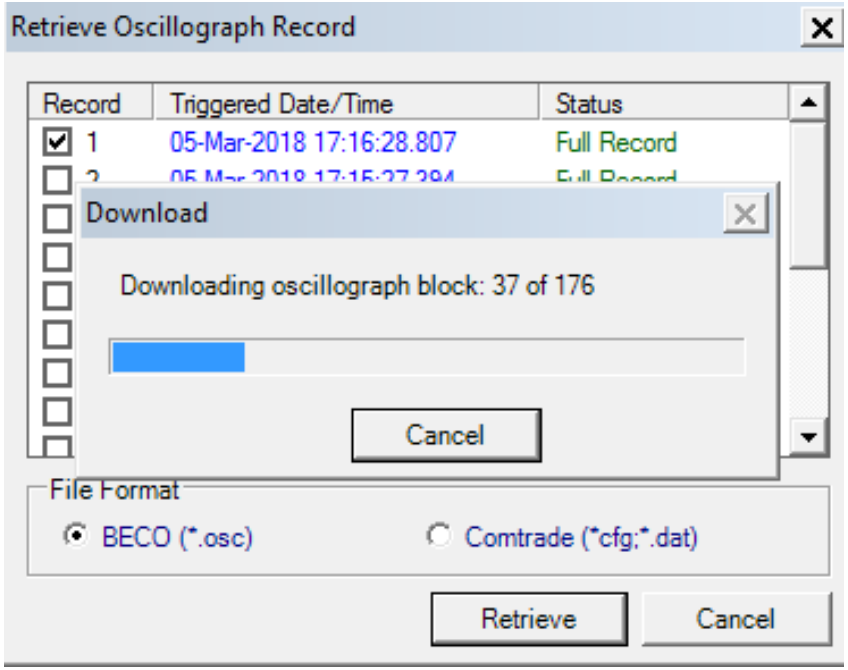
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6
☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐ 11 ☐ 12
☐ 13 ☐ 14 ☐ 15 ☐ 16 ☐ 17 ☐ 18
☐ 19 ☐ 20 ☐ 21 ☐ 22 ☐ 23

Oscillography Recorder



Retrieve Record





Oscillography-IPSplot Plus