Generator Protection: M-3425A
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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.
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.
M-3425A Typical Connection Diagram

- Targets (Optional)
- Integral HMI (Optional)
- Metering
- Waveform Capture
- IRIG-B
- Front RS232 Communication
- Rear RS232 Communication
- Rear Ethernet Port (Optional)
- Rear RS-485 Communication
- Multiple Setting Groups
- Programmable I/O
- Self Diagnostics
- Dual Power Supply (Optional)
- Breaker Monitoring
- Trip Circuit Monitoring
- Event Log

This function is available as an optional protective function.
This function provides control for the function to which it points.

These functions are available in the Comprehensive Package. A subset of these functions are also available in a Base Package.

Utility System

1-Line Diagram

Low-impedance Grounding with 50N/51N and [87GD or 67N] and Ground Fault Protection

High-impedance Grounding with 59N and [27N or 59D] 100% Ground Fault Protection
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

- One or more “OUTPUT” LEDs illuminated
Trip Cleared and Target Present

Target, Time, Outputs, Function, Phase

• All “OUTPUT” LEDs Extinguished
• 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 Neutr. 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 Energizing
- 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.

LOSS OF FIELD RELAY
- pwr LOF fuse dist
  - 40 Loss of Field

VOLTS PER HERTZ RELAY
- volt curr freq V/Hz
  - 24 Definite Time Volts/Hertz
  - 24 Inverse Time Volts/Hertz

V. T. FUSE LOSS RELAY
- pwr lof FUSE dist
  - 60 FL V.T. Fuse Loss

POWER RELAY
- PWR lof fuse dist
  - 32 Directional Power

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

**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

- 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
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 Sensing:** 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
M-3425A Connections

3-Line Diagram Partial: A

1. Wire to split phase differential CTs for use with 50D 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 50ΩT 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 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 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.
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.*
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
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.):

<table>
<thead>
<tr>
<th>VT Configuration</th>
<th>Nominal Voltage</th>
<th>Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>L-G</td>
<td>$V_{nom} = \frac{GEN\ V_{LL}}{(1.732*VTR)}$</td>
<td>(21, 32, 40, 46, 50/27, 51V)</td>
</tr>
<tr>
<td>L-L</td>
<td>$V_{nom} = \frac{GEN\ V_{LL}}{VTR}$</td>
<td></td>
</tr>
<tr>
<td>L-G to L-L</td>
<td>$V_{nom} = \frac{GEN\ V_{LL}}{VTR}$</td>
<td></td>
</tr>
</tbody>
</table>

**Nominal Current**

$$I_{nom} = \frac{GEN\ VA}{1.732*GEN\ V_{LL}*CTR}$$

(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**

<table>
<thead>
<tr>
<th>Test Set</th>
<th>M-3425A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Va</td>
<td>Va +</td>
</tr>
<tr>
<td>Vb</td>
<td>Vb +</td>
</tr>
<tr>
<td>Vc</td>
<td>Vc +</td>
</tr>
<tr>
<td>Vn</td>
<td>No connection</td>
</tr>
</tbody>
</table>

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.
Connect the relay currents for today’s training:

### M-34XX Test Connection

<table>
<thead>
<tr>
<th>Test Set currents 1</th>
<th>M-3425A</th>
<th>Test Set currents 2</th>
<th>M-3425A</th>
</tr>
</thead>
<tbody>
<tr>
<td>IA</td>
<td>IA +</td>
<td>IA</td>
<td>ia +</td>
</tr>
<tr>
<td>IB</td>
<td>IB +</td>
<td>IB</td>
<td>ib +</td>
</tr>
<tr>
<td>IC</td>
<td>IC +</td>
<td>IC</td>
<td>ic +</td>
</tr>
<tr>
<td>IN</td>
<td>Jumper</td>
<td>IN</td>
<td>Jumper</td>
</tr>
</tbody>
</table>

**Differential Currents**

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)
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

Impedance of the longest transmission line

\[ Z_{LL1} = 0.01095 + j0.11546 \text{ pu on 100 MVA base} \]
\[ Z_{LL0} = 0.07370 + j0.37449 \text{ pu} \]

Power System

\[ Z_{maxS1} = 0.000511 + j0.010033 \text{ pu on 100 MVA base} \]
\[ Z_{maxS0} = 0.001046 + j0.017206 \text{ pu} \]

145 kV
19 kV

Unit Transformer

\[ X_T = 0.1111 \text{ pu on 425 MVA base} \]

VT
20,000V
120V

492 MVA Base
\[ X_d = 1.1888 \text{ pu} \]
\[ X'_d = 0.20577 \text{ pu} \]
\[ X''_d = 0.17847 \text{ pu} \]
\[ X_2 = 0.17676 \text{ pu} \]

14400
240/120V

1.25 Ohms
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
Generator capability curve viewed on the P-Q plane. This info must be converted to the R-X plane.
Increased Power Out

**P-Q Plane**

**TRANSFORMATION FROM MW-MVAR TO R-X PLOT**

**TYPICAL GENERATOR CAPABILITY CURVE**

Excitation Limiters and Steady State Stability
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

Offset = \frac{X_d'}{2}

Diameter = 1.0 \text{ pu}

Heavy Load

Light Load

Machine Capability

SSSL

Diameter = X_d

MEL
Loss of Field Impedance w/Direction Unit

Offset = \(\frac{X_d}{2}\)

Heavy Load

Light Load

Machine Capability

MEL

SSSL

1.1 \((X_d)\)

Z2 Setting

Z1 Setting

\(X_g\)
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
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

Impedance of the longest transmission line

\[ Z_{LL1} = 0.01095 + j0.11546 \text{ pu on 100 MVA base} \]
\[ Z_{LL0} = 0.07370 + j0.37449 \text{ pu} \]
**40: Calculations for Our Generator (Offset Mho Method)**

\[
Z_{\text{base}} = \frac{\text{GEN kV}^2}{\text{GEN MVA}} \times \frac{1.73}{kV_{\text{base}}} \\
Z_{\text{base}} = \frac{20 \text{ kV}^2}{492 \text{ MVA}} \times \frac{1.73}{20 \text{ kV}_{\text{base}}} \\
Z_{\text{base}} = 0.813 \ \Omega \ _{\text{pri}} \\
\]

\[
I_{\text{base}} = \frac{\text{MVA} \times 1000}{1.73 \times kV_{\text{Base}}} \\
I_{\text{base}} = \frac{492 \text{ MVA} \times 1000}{1.73 \times 20 \text{ MVA}_{\text{Base}}} \\
I_{\text{base}} = 14,219 \ \text{A}_{\text{pri}} \\
\]

\[
\text{VTR} = 20,000 \text{V} / 120 \text{V} = 166.7 \\
\text{CTR} = 18,000 \text{A} / 5 \text{A} = 3,600 \\
\text{CTR/VTR} = 21.5996 \\
\]

\[
I_{\text{base sec}} = \frac{I_{\text{pri}}}{\text{CTR}} \\
I_{\text{base sec}} = 14,219 \ \text{A}_{\text{pri}} / 3,600 \\
I_{\text{base sec}} = 3.945 \ \text{A}_{\text{sec}} \\
\]

\[
V_{\text{LL sec}} = 120 \text{V} \\
V_{\text{LG sec}} = V_{\text{LL sec}} / 1.73 \\
V_{\text{LL sec}} = 69.28 \text{V sec} \\
\]

\[
Z_{\text{Base sec}} = Z_{\text{Base pri}} \times (\text{CTR} / \text{VTR}) \\
Z_{\text{Base sec}} = 0.813 \ \Omega \ _{\text{pri}} \times (3,600 / 166.7) \\
Z_{\text{Base sec}} = 17.55 \ \Omega \ _{\text{sec (1pu)}} \\
\]

**Reactances per unit (492 MVA Base)**

\[
X_d = 1.1888 \ \text{pu} \\
X'd = 0.20577 \ \text{pu} \\
\]

**Z2: Bigger Circle**

\[
\text{Diameter sec} = \frac{Z_{\text{Base sec}}}{X_d} \\
\text{Diameter sec} = \frac{17.55 \ \Omega \ _{\text{sec}}}{1.1888 \ \text{pu}} \\
\text{Diameter sec} = 20.88 \ \Omega \ _{\text{sec}} \\
\]

\[
\text{Offset sec} = \frac{(X'd / 2) \times Z_{\text{Base sec}}}{2} \\
\text{Offset sec} = \frac{(0.20577 \ \text{pu} / 2) \times 17.55 \ \Omega \ _{\text{sec}}}{2} \\
\text{Offset sec} = -1.81 \ \Omega \ _{\text{sec}} \\
\]

\[
\text{Time Delay} = 1 \ \text{sec}. \\
\]

**Z1: Small Circle**

\[
\text{Diameter} = 1 \ \text{pu sec} = 17.55 \ \Omega \ _{\text{sec}} \\
\]

\[
\text{Offset sec} = \frac{(X'd / 2) \times Z_{\text{Base sec}}}{2} \\
\text{Offset sec} = \frac{(0.20577 \ \text{pu} / 2) \times 17.55 \ \Omega \ _{\text{sec}}}{2} \\
\text{Offset sec} = -1.81 \ \Omega \ _{\text{sec}} \\
\]

\[
\text{Time Delay} = 0.5 \ \text{sec}. \\
\]
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*
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
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.
- 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
- 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
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).
- The machine is slipping a pole. We are into the first slip cycle.
The machine is slipping a pole. We are into the first slip cycle.
40: Calculations for Our Generator (Offset Mho Method)

\[
Z_{\text{base}} = (\text{GEN kV}^2 / \text{GEN MVA}) / (1.73 \times kV_{\text{base}}) \\
Z_{\text{base}} = (20 \text{ kV}^2 / 492 \text{ MVA}) / (1.73 \times 20 \text{ kV}_{\text{base}}) \\
Z_{\text{base}} = 0.813 \ \Omega_{\text{pri}}
\]

\[
I_{\text{base}} = (\text{MVA} \times 1000) / (1.73 \times kV_{\text{Base}}) \\
I_{\text{base}} = (492 \text{ MVA} \times 1000) / (1.73 \times 20_{\text{Base}}) \\
I_{\text{base}} = 14,219A_{\text{pri}}
\]

\[
V_{\text{TR}} = 20,000V / 120V = 166.7 \\
C_{\text{TR}} = 18,000A / 5A = 3,600 \\
C_{\text{TR/VTR}} = 21.5996
\]

\[
I_{\text{base sec}} = I_{\text{pri}} / C_{\text{TR}} \\
I_{\text{base sec}} = 14,219 \text{ pri} / 3,600 \\
I_{\text{base sec}} = 3.945 \text{ A sec}
\]

\[
V_{\text{LL sec}} = 120V \\
V_{\text{LG sec}} = V_{\text{LL sec}} / 1.73 \\
V_{\text{LL sec}} = 69.28V \text{ sec}
\]

\[
Z_{\text{Base sec}} = Z_{\text{Base pri}} \times (C_{\text{TR}} / V_{\text{TR}}) \\
Z_{\text{Base sec}} = 0.813 \ \Omega_{\text{pri}} \times (3,600 / 166.7) \\
Z_{\text{Base sec}} = 17.55 \ \Omega_{\text{sec}} \ (1\text{pu})
\]

Reactances per unit (492 MVA Base)
\[
X_d = 1.1888 \text{ pu} \\
X'd = 0.20577 \text{ pu}
\]

**Z2: Bigger Circle**

- Diameter sec = \(Z_{\text{Base sec}} / X_d\)
- Diameter sec = \(17.55\ \Omega_{\text{sec}} / 1.188 \) pu
- Diameter sec = \(20.88\ \Omega_{\text{sec}}\)

- Offset sec: \((X'd / 2) \times Z_{\text{Base sec}}\)
- Offset sec: \((0.20577\text{pu} / 2) \times 17.55\ \Omega_{\text{sec}}\)
- Offset sec: \(-1.81\ \Omega_{\text{sec}}\)

Time Delay = 1 sec.

**Z1: Small Circle**

- Diameter = 1 pu sec = \(17.55\ \Omega_{\text{sec}}\)

- Offset sec: \((X'd / 2) \times Z_{\text{Base sec}}\)
- Offset sec: \((0.20577\text{pu} / 2) \times 17.55\ \Omega_{\text{sec}}\)
- Offset sec: \(-1.81\ \Omega_{\text{sec}}\)

Time Delay = 0.5 sec.
40: “GE” Method”; 2 Offset Mho

Additional output to isolate the test

VT Fuse Loss
What’s missing?

52B Supervision

Two Zone Offset Mho Elements
40: “GE” Method”; 2 Offset Mho Elements
Reach = Circle Diameter + Offset
Pre-Fault Condition:

Mirrored currents, Why?

Loss of Field Monitor
Test Zone 2 Perimeter:

20.8 + 1.8 = 22.6
22.6 ohms X 2 Amps = 45.2 Volts

Loss of Field Monitor

Check Timing Trip 1
Test Zone 1 Perimeter:

17.6 + 1.8 = 19.4
19.4 ohms X 2 Amps = 38.8 Volts

Loss of Field Monitor

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

\[ I_b = I_1 + I_2 \]

\[ I_R = |I_1| + |I_2| \]
Through Current: Imperfect Replication

\[ I_D = I_1 + I_2 \]

\[ I_R = |I_1| + |I_2| \]
Internal Fault: Perfect Replication

\[ I_D = I_1 + I_2 \]

\[ I_R = |I_1| + |I_2| \]
Internal Fault: Imperfect Replication

\[ I_D = I_1 + I_2 \]

\[ I_R = |I_1| + |I_2| \]
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:**
- Inverse of sat. curve slope: $S = 22$
- RMS voltage at 10A exc. current: $V_s = 400$ volts rms
- Turns ratio: $N = 80$
- Winding resistance: $R_w = 0.300$ ohms
- Burden resistance: $R_b = 0.500$ ohms
- Burden reactance: $X_b = 0.500$ ohms
- System X/R ratio: $X_{over}R = 12.0$
- Per unit offset in primary current: $Off = 0.50$ -1 to +1
- Per unit remanence (based on $V_s$): $I_{rem} = 0.50$
- Symmetrical primary fault current: $I_p = 2000$ amps rms

**CALCULATED:**
- $R_t = $ Total burden resistance = Rw + Rb = 0.800 ohms
- $pf = $ Total burden power factor = 0.848
- $Z_b = $ Total burden impedance = 0.943 ohms
- $\tau_1 = $ System time constant = 0.032 seconds
- $L_{max} = $ Peak flux-linkages corresponding to $V_s = 1.501$ Wb-turns
- $\omega = $ Radian freq = 376.99 rad/s
- $RP = $ Rms-to-peak ratio = 0.34584
- $A = $ Coefficient in instantaneous ie versus lambda curve: $ie = A \times \lambda_S = 3.83E-03$
- $\Delta t = $ Time step = 0.000083 seconds
- $L_b = $ Burden inductance = 0.00133 henries

**Graphical Representation:**
- 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:**
- Inverse of sat. curve slope: S = 22
- RMS voltage at 10A exc. current: V_s = 400 volts rms
- Turns ratio: n = 80
- Winding resistance: R_w = 0.300 ohms
- Burden resistance: R_b = 0.500 ohms
- Burden reactance: X_b = 0.500 ohms
- System X/R ratio: X_over_R = 12.0
- Per unit offset in primary current: Off = 0.50
- Per unit remanence (based on V_s): J_remm = 0.50
- Symmetrical primary fault current: I_P = 4000.000 amps rms

**Calculated:**
- $V_i = \frac{R_b}{R_w} = \frac{0.500}{0.300} = 1.667$ ohms
- $Z_b = R_b + jX_b = 0.500 + j0.500 = 0.707 + j0.707$ ohms
- $R_t = R_b + R_w = 0.500 + 0.300 = 0.800$ ohms
- $f = \frac{1}{2\pi R_t} = \frac{1}{2\pi \times 0.800} = 1256.6$ Hz
- $Z_b = 0.943$ ohms
- $\tau = \frac{1}{2\pi f} = \frac{1}{2\pi \times 1256.6} = 0.005$ seconds
- $L_{msat} = \frac{1}{\omega} = \frac{1}{376.99} = 0.0026$ Wb-turns
- $\omega = \frac{V_s}{L_{msat}} = \frac{400}{0.0026} = 1.538 \times 10^5$ rad/s
- $R_e = \frac{P}{\omega} = \frac{0.800}{3.1416 \times 1.538 \times 10^5} = 2.00 \times 10^{-7}$ ohms
- $A = \frac{\omega}{\sqrt{2}} = \frac{3.1416 \times 1.538 \times 10^5}{\sqrt{2}} = 1.41 \times 10^5$
- $\delta t = \frac{1}{\omega} = \frac{1}{376.99} = 0.0026$ seconds
- $L_b = \frac{V_s}{\omega} = \frac{400}{3.1416 \times 1.538 \times 10^5} = 0.0026$ henries

400:5, C400, R=0.5, Offset = 0.5, 4000A
CT Saturation [3]

INPUT PARAMETERS:
- 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
- Per unit remanence (based on Vs) = Irem = 0.50
- Symmetrical primary fault current = Ip = 8,000 amps rms

CALCULATED:
- R = Total burden resistance = Rw + Rb = 0.800 ohms
- pf = Total burden power factor = 0.848
- Zb = Total burden impedance = 0.943 ohms
- Taur = System time constant = 0.032 seconds
- Lamsat = Peak flux-linkages corresponding to Vs = 1.501 Wb-turns
- \omega = Radian freq = 376.99 rad/s
- RP = Rms-to-peak ratio = 0.34584
- A = Coefficient in instantaneous ie
- versus lambda curve; ie = A \times \lambda : 3.836-03
- dt = Time step = 0.000083 seconds
- Lb = Burden inductance = 0.00133 henries

400:5, C400, R=0.5, Offset = 0.5, 8000A
CT Saturation [4]

400:5, C400, R=0.5, Offset = 0.75, 8000A
CT Saturation [5]

**INPUT PARAMETERS:**
- Inverse of sat. curve slope = \( S = \frac{22}{\text{--}} \)
- RMS voltage at 10A exc. current = \( V_s = 400 \text{ volts rms} \)
- Turns ratio = n2/n1 = \( N = \frac{80}{\text{--}} \)
- Winding resistance = \( R_w = 0.300 \text{ ohms} \)
- Burden resistance = \( R_b = 0.500 \text{ ohms} \)
- System X/R ratio = \( X_{over} = 12.0 \text{ --} \)
- Per unit offset in primary current = \( Off = 0.75 \text{ -1<Off<1} \)
- Per unit remanence (based on Vs) = \( X_{rem} = 0.75 \text{ --} \)
- Symmetrical primary fault current = \( I_p = 8,000 \text{ amperes rms} \)

**CALCULATED:**
- \( R_t = \text{Total burden resistance} = R_w + R_b = 0.800 \text{ ohms} \)
- \( pf = \text{Total burden power factor} = 0.848 \text{ --} \)
- \( Z_o = \text{Total burden impedance} = 0.943 \text{ ohms} \)
- \( \tau_s = \text{System time constant} = 0.032 \text{ seconds} \)
- \( L_{max} = \text{Peak flux-linkages corresponding to Vs} = 1.501 \text{ Wb-turns} \)
- \( \omega = \text{Radian freq} = 376.99 \text{ rad/s} \)
- \( R_P = \text{Rms-to-peak ratio} = 0.34534 \)
- \( A = \text{Coefficient in instantaneous ie} \) vs lambda curve: \( ie = A \times \lambda S = 3.835 \times 10^{-3} \text{ --} \)
- \( \delta t = \text{Time step} = 0.0000083 \text{ seconds} \)
- \( L_b = \text{Burden inductance} = 0.00133 \text{ henries} \)

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
Generator Protection

87 Characteristic

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

87: Phase Differential Current

#1
- Pickup: 0.30
- Time Delay: 3
- Percent Slope: 20
- Outputs:
  - 1
  - 2
  - 3
  - 4
  - 5
  - 6
  - 7
  - 8

#2
- Pickup: 3.00
- Time Delay: 1
- Percent Slope: 90
- Outputs:
  - 1
  - 2
  - 3
  - 4
  - 5
  - 6
  - 7
  - 8

Blocking Inputs

Setting
- Phase CT Correction: 1.00
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

\[
I_{\text{diff}} = \bar{I}_1 - \bar{I}_2
\]

\[
I_{\text{res}} = \frac{\bar{I}_1 + \bar{I}_2}{2}
\]

\[
\text{Slope(%)} = \frac{I_{\text{diff}}}{I_{\text{res}}} \times 100
\]
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 terminal Side currents

\[ \text{Slope(\%)} = \frac{\text{Idiff}}{\text{Ires}} \times 100 \]
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

<table>
<thead>
<tr>
<th>Set Mode</th>
<th>Direct</th>
</tr>
</thead>
<tbody>
<tr>
<td>V A-N</td>
<td>69.28 V, 0.00 °, 60.000 Hz</td>
</tr>
<tr>
<td>V B-N</td>
<td>69.28 V, -120.00 °, 60.000 Hz</td>
</tr>
<tr>
<td>V C-N</td>
<td>69.28 V, 120.00 °, 60.000 Hz</td>
</tr>
<tr>
<td>I A</td>
<td>5.000 A, 0.00 °, 60.000 Hz</td>
</tr>
<tr>
<td>I B</td>
<td>5.000 A, -120.00 °, 60.000 Hz</td>
</tr>
<tr>
<td>I C</td>
<td>5.000 A, 120.00 °, 60.000 Hz</td>
</tr>
<tr>
<td>I Prim A</td>
<td>6.100 A, 0.00 °, 60.000 Hz</td>
</tr>
<tr>
<td>I Prim B</td>
<td>6.100 A, -120.00 °, 60.000 Hz</td>
</tr>
<tr>
<td>I Prim C</td>
<td>6.100 A, 120.00 °, 60.000 Hz</td>
</tr>
</tbody>
</table>

---

### Restraint Current

- Operating Current: 0 to 30 A
- Restraint Current: 0 to 40 A
-_slope_30.0_25.0_20.0_15.0_10.0_5.0_0.0
- Restraint Current (A): 0 to 40 A
- Operating Current (A): 0 to 30 A
- Graph showing the relationship between restraint current and operating current.
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
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
Generator Protection

Fuse Loss

Two VTs

One VT

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
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

Pre-fault

Single phase-fault

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!
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
- Cannot 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 zero sequence voltage
  • Negligible $V_2$, $I_2$ or $I_0$
• A fault in the VT secondary or system (GSU coupled) generates negative 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

$I_2 > 0.05 \text{ pu}$

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

Stalling Trip Timer (cycles)

Arcing Fault Detected (cycles)

Master Reset Timer (cycles)

TRIP
Interrruptent Arcing Ground Fault

Stalling Trip Timer (cycles)

Arcing Fault Detected (cycles)

Master Reset Timer (cycles)

Arcing and Reset (No Trip)
Intermittent Arcing Ground Fault Turned Multiphase

Gen feeding fault into low side of GSU, no low side breaker
Example of Ph-Gnd fault evolving into 3-Ph Fault
Insulation breakdown due to high voltage

21P backup element tripped
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

59N: Neutral Overvoltage

#1
Pickup: 5.0
Time Delay: 90
Output:

#2
Pickup: 15.0
Time Delay: 10
Output:

#3
Pickup: 5.0
Time Delay: 20
Output:

Blocking Inputs

Setting
20Hz Injection Mode: Disable
Enable

Save  Cancel
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 4\textsuperscript{th} 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

<table>
<thead>
<tr>
<th>Set Mode</th>
<th>Direct</th>
</tr>
</thead>
<tbody>
<tr>
<td>I A</td>
<td>5.000 A</td>
</tr>
<tr>
<td>I B</td>
<td>5.000 A</td>
</tr>
<tr>
<td>I C</td>
<td>5.000 A</td>
</tr>
<tr>
<td>V Fault</td>
<td>3.000 V</td>
</tr>
<tr>
<td>V(1)-1</td>
<td>69.28 V</td>
</tr>
<tr>
<td>V(2)-2</td>
<td>69.28 V</td>
</tr>
<tr>
<td>V(3)-3</td>
<td>69.28 V</td>
</tr>
<tr>
<td>I Sec A</td>
<td>5.000 A</td>
</tr>
<tr>
<td>I Sec B</td>
<td>5.000 A</td>
</tr>
<tr>
<td>I Sec C</td>
<td>5.000 A</td>
</tr>
</tbody>
</table>

### Test alarm timing

<table>
<thead>
<tr>
<th>Set Mode</th>
<th>Direct</th>
</tr>
</thead>
<tbody>
<tr>
<td>I A</td>
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</tr>
<tr>
<td>I B</td>
<td>5.000 A</td>
</tr>
<tr>
<td>I C</td>
<td>5.000 A</td>
</tr>
<tr>
<td>V Fault</td>
<td>5.100 V</td>
</tr>
<tr>
<td>V(1)-1</td>
<td>69.28 V</td>
</tr>
<tr>
<td>V(2)-2</td>
<td>69.28 V</td>
</tr>
<tr>
<td>V(3)-3</td>
<td>69.28 V</td>
</tr>
<tr>
<td>I Sec A</td>
<td>5.000 A</td>
</tr>
<tr>
<td>I Sec B</td>
<td>5.000 A</td>
</tr>
<tr>
<td>I Sec C</td>
<td>5.000 A</td>
</tr>
</tbody>
</table>

![59N#3](image)
### Pre-fault

<table>
<thead>
<tr>
<th>Set Mode</th>
<th>Analog Outputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>I A</td>
<td>5.000 A, 0.00 °, 60.000 Hz</td>
</tr>
<tr>
<td>I B</td>
<td>5.000 A, -120.00 °, 60.000 Hz</td>
</tr>
<tr>
<td>I C</td>
<td>5.000 A, 120.00 °, 60.000 Hz</td>
</tr>
<tr>
<td>V Fault</td>
<td>3.000 V, 0.00 °, 60.000 Hz</td>
</tr>
<tr>
<td>V(1)-1</td>
<td>69.28 V, 0.00 °, 60.000 Hz</td>
</tr>
<tr>
<td>V(2)-2</td>
<td>69.28 V, -120.00 °, 60.000 Hz</td>
</tr>
<tr>
<td>V(3)-3</td>
<td>69.28 V, 120.00 °, 60.000 Hz</td>
</tr>
<tr>
<td>I Sec A</td>
<td>5.000 A, 0.00 °, 60.000 Hz</td>
</tr>
<tr>
<td>I Sec B</td>
<td>5.000 A, -120.00 °, 60.000 Hz</td>
</tr>
<tr>
<td>I Sec C</td>
<td>5.000 A, 120.00 °, 60.000 Hz</td>
</tr>
</tbody>
</table>

### Test trip timing

<table>
<thead>
<tr>
<th>Set Mode</th>
<th>Analog Outputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>I A</td>
<td>5.000 A, 0.00 °, 60.000 Hz</td>
</tr>
<tr>
<td>I B</td>
<td>5.000 A, -120.00 °, 60.000 Hz</td>
</tr>
<tr>
<td>I C</td>
<td>5.000 A, 120.00 °, 60.000 Hz</td>
</tr>
<tr>
<td>V Fault</td>
<td>5.100 V, 0.00 °, 60.000 Hz</td>
</tr>
<tr>
<td>V(1)-1</td>
<td>69.28 V, 0.00 °, 60.000 Hz</td>
</tr>
<tr>
<td>V(2)-2</td>
<td>69.28 V, -120.00 °, 60.000 Hz</td>
</tr>
<tr>
<td>V(3)-3</td>
<td>69.28 V, 120.00 °, 60.000 Hz</td>
</tr>
<tr>
<td>I Sec A</td>
<td>5.000 A, 0.00 °, 60.000 Hz</td>
</tr>
<tr>
<td>I Sec B</td>
<td>5.000 A, -120.00 °, 60.000 Hz</td>
</tr>
<tr>
<td>I Sec C</td>
<td>5.000 A, 120.00 °, 60.000 Hz</td>
</tr>
</tbody>
</table>

**59N#1**

- **96.94 cy**
### Pre-fault

<table>
<thead>
<tr>
<th>Set Mode</th>
<th>Direct</th>
<th>Analog Outputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>I A</td>
<td>5.000 A</td>
<td>0.00 ° 60.000 Hz</td>
</tr>
<tr>
<td>I B</td>
<td>5.000 A</td>
<td>-120.00 ° 60.000 Hz</td>
</tr>
<tr>
<td>I C</td>
<td>5.000 A</td>
<td>120.00 ° 60.000 Hz</td>
</tr>
<tr>
<td>V Fault</td>
<td>3.000 V</td>
<td>0.00 ° 60.000 Hz</td>
</tr>
<tr>
<td>V(1)-1</td>
<td>69.28 V</td>
<td>0.00 ° 60.000 Hz</td>
</tr>
<tr>
<td>V(2)-2</td>
<td>69.28 V</td>
<td>-120.00 ° 60.000 Hz</td>
</tr>
<tr>
<td>V(3)-3</td>
<td>69.28 V</td>
<td>120.00 ° 60.000 Hz</td>
</tr>
<tr>
<td>I Sec A</td>
<td>5.000 A</td>
<td>0.00 ° 60.000 Hz</td>
</tr>
<tr>
<td>I Sec B</td>
<td>5.000 A</td>
<td>-120.00 ° 60.000 Hz</td>
</tr>
<tr>
<td>I Sec C</td>
<td>5.000 A</td>
<td>120.00 ° 60.000 Hz</td>
</tr>
</tbody>
</table>

### Test high set timing

<table>
<thead>
<tr>
<th>Set Mode</th>
<th>Direct</th>
<th>Analog Outputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>I A</td>
<td>5.000 A</td>
<td>0.00 ° 60.000 Hz</td>
</tr>
<tr>
<td>I B</td>
<td>5.000 A</td>
<td>-120.00 ° 60.000 Hz</td>
</tr>
<tr>
<td>I C</td>
<td>5.000 A</td>
<td>120.00 ° 60.000 Hz</td>
</tr>
<tr>
<td>V Fault</td>
<td>15.20 V</td>
<td>0.00 ° 60.000 Hz</td>
</tr>
<tr>
<td>V(1)-1</td>
<td>69.28 V</td>
<td>0.00 ° 60.000 Hz</td>
</tr>
<tr>
<td>V(2)-2</td>
<td>69.28 V</td>
<td>-120.00 ° 60.000 Hz</td>
</tr>
<tr>
<td>V(3)-3</td>
<td>69.28 V</td>
<td>120.00 ° 60.000 Hz</td>
</tr>
<tr>
<td>I Sec A</td>
<td>5.000 A</td>
<td>0.00 ° 60.000 Hz</td>
</tr>
<tr>
<td>I Sec B</td>
<td>5.000 A</td>
<td>-120.00 ° 60.000 Hz</td>
</tr>
<tr>
<td>I Sec C</td>
<td>5.000 A</td>
<td>120.00 ° 60.000 Hz</td>
</tr>
</tbody>
</table>

![59N#2](image-url)
Other Important Diagnostic Tools
SOE Viewer

View Sequence of Events Record

<table>
<thead>
<tr>
<th>No</th>
<th>Event Summary</th>
<th>Value</th>
<th>Unit</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>01/01/2001, 01:01:00.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>01/01/2001, 01:01:00.000</td>
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</tr>
<tr>
<td>3</td>
<td>01/01/2001, 01:01:00.000</td>
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</tr>
<tr>
<td>4</td>
<td>01/01/2001, 01:01:00.000</td>
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<td></td>
</tr>
<tr>
<td>5</td>
<td>01/01/2001, 01:01:00.000</td>
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</tr>
<tr>
<td>6</td>
<td>01/01/2001, 01:01:00.000</td>
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<td></td>
</tr>
<tr>
<td>7</td>
<td>01/01/2001, 01:01:00.000</td>
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</tr>
<tr>
<td>8</td>
<td>01/01/2001, 01:01:00.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>01/01/2001, 01:01:00.000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Oscillography Recorder
Oscillography-IPSplot Plus