Generator G1 Relay Protection
Description of Operation

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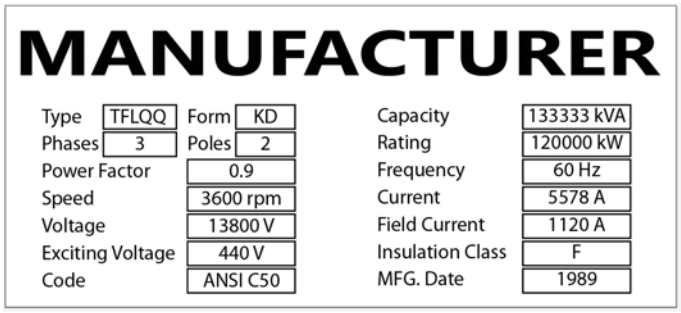
1. Introduction

This document has been created to explain the protection settings and application for the 120MW generator [G1] installed at the Dennison Power Station. The generator has the following nameplate data:



MANUFACTURER

Type	TFLQQ	Form	KD	Capacity	133333 kVA
Phases	3	Poles	2	Rating	120000 kW
Power Factor	0.9			Frequency	60 Hz
Speed	3600 rpm			Current	5578 A
Voltage	13800 V			Field Current	1120 A
Exciting Voltage	440 V			Insulation Class	F
Code	ANSI C50			MFG. Date	1989

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2. Manufacturer's Specifications

The manufacturer provided the following specifications regarding the generator's capabilities:

Descriptions	Rated @ 40.0°C	Curve A @ 15.0°C	Curve B @ 10.0°C
Apparent Power (MVA)	133.3	160.0	165.3
Active Power (MW)	120.0	144.1	148.8
Power Factor / Frequency	0.85 / 60	0.85 / 60	0.85 / 60
Stator Current (kA)	5.578	6.694	6.917
Rated Voltage (kV)	13.8	13.8	13.8
Cold Air Temperature	40.0	15.0	10.0
Voltage Range (%)	-5.0 / +5.0		
Type of Excitation	Stationary		
Standard	ANSI /IEC		
Insulation Class B	B		

Stator Winding

Type of Cooling	Indirect
Cooling Medium	Air
Heat Loss Dissipated at Rated Load	222.4 kW

Stator Core

Type of Cooling	Radial
Cooling Medium	Air
Heat Loss Dissipated at Rated Load	237.0 kW

Rotor Winding

Type of Cooling	Direct Radial
Cooling Medium	Air
Heat Loss Dissipated at Rated Load	287.7 kW
Stator Winging – Slot Temperature Rise	62.8°K
Rotor Winding – Average Temperature rise	71.1°K

Efficiencies

Descriptions	Rated At	Curve A	Curve B
Output (MVA)	133.3	160.0	165.3
Power Factor	0.85	0.85	0.85
Cold Gas Temperature (°C)	40.0	15.0	10.0
Stationary – 100% Load	98.46%	98.47%	98.46%
Stationary – 75% Load	98.32%	98.42%	98.43%
Stationary – 50% Load	97.88%	98.11%	98.15%
Stationary – 25% Load	96.32%	96.85%	96.94%

Output and Allowable Load Unbalance

Continuous Load Unbalance – Permissible I2	10%
Short Time ($K=I_2^2t$)	30
Output at Deviating Cold Air Temperature	ΔT = 0.8% / °K
Output Limit with 1 Cooler Section Out of Service	67%
Output at CosΘ = 0 – Under-Excited (MVAR)	58.5
Output at CosΘ = 0 – Over-Excited (MVAR)	91.3
Output at CosΘ = 0 – Over-Excited – Curve A (15°C) (MVAR)	109.6
Output at CosΘ = 0 – Over-Excited – Curve B (10°C) (MVAR)	91.3

Generator – Exciter Currents and Voltages

Generator Load	Rated @ 40.0°C		Curve A @ 15.0°C		Curve B @ 10.0°C	
	Current (A)	Field Voltage (V)	Current (A)	Field Voltage (V)	Current (A)	Field Voltage (V)
No Load	298	142	-	-	-	-
125% Load	1011	480	-	-	-	-
100% Load	822	391	970	459	1003	476
75% Load	662	314	-	-	-	-
50% Load	519	247	-	-	-	-
25% Load	395	188	-	-	-	-

Reactances Base MVA = 125MVA

D-Axis Sub-Transient	XD'' UNSAT	19.3%	XD'' SAT	15.6%
D-Axis Transient	XD' UNSAT	27.2%	XD' SAT	24.5%
D-Axis Synchronous	XD UNSAT	206.8%	-	-
Q-Axis Sub-Transient	XQ'' UNSAT	21.2%	XQ'' SAT	17.2%
Q-Axis Transient	XQ' UNSAT	51.3%	XQ' SAT	46.1%
Q-Axis Synchronous	XQ UNSAT	196.4%	-	-
Negative Phase Sequence	X2 UNSAT	20.3%	X2 SAT	16.4%
Zero Phase Sequence	X0	10.9%	-	-
Potier	Xp	26.8%	-	-
Stator Leakage	XSLG	15.1%	-	-
No Load Short Circuit Ratio SAT.	0.57			

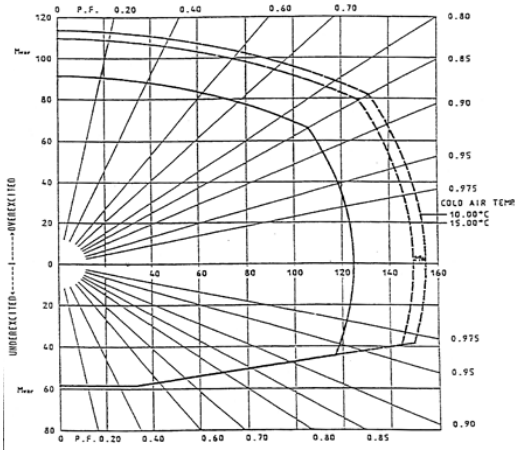
Time Constants

D-Axis Sub-Transient	TD'' Short Circuit	0.031s	TDO'' No-Load	0.045s
D-Axis Transient	TD' Short Circuit	0.873s	TDO' No-Load	7.150s
Q-Axis Sub-Transient	TQ'' Short Circuit	0.068s	TQO'' No-Load	0.150s
Q-Axis Transient	TQ' Short Circuit	0.534s	TQO' No-Load	2.500s
DC Time Constraint	TA	0.030s		

Resistances

Of Stator Windings @ 20°C	RA20	0.001674Ω
Of Rotor Windings @ 20°C	RF20	0.3501Ω
Positive-sequence	R1	0.367%
Inverse Sequence	R2	3.201%
Null Sequence	R0	0.267%

Reactive Capability Curve



3. Power System Specifications

A. Generator Relays

Two generator protection relays from two different manufacturers have been chosen to provide redundant protection for the generator. The generator relay details are:

Beckwith Electric Company M-3425A	Schweitzer Engineering Laboratories SEL-300G
Model Number = M-3425A#8736 Frequency = 60Hz Output Contacts = 23 Input Contacts = 14 Aux = 125VDC Com 2 = Ethernet Rated Voltage Inputs = 60 – 140 VAC Rated Current Inputs = 5A, Nom Power Supply 1 = 85 – 165VAC/DC Power Supply 2 = 85 – 165VAC/DC	Model Number = 0300G30H425XX4X Output Contacts = 7 Input Contacts = 6 Logic Input Voltage = 125VDC Rated Current Inputs = 5A, Nom Power Supply 1 = 125/250VDC

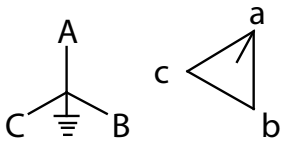
B. Instrument Transformers

The generator is connected to the power system via the following instrument transformers:

- G1-PT = Two Delta-connected PTs with a 120:1 ratio [14400:120V] connected to the generator terminals.
- G1-CTN = Three Wye-connected C800 CTs installed around the generator neutral conductors with a 1600:1 ratio [8000:5A].
- G1-NPT = One single-phase power transformer connected between the generator neutral star point and ground to provide a high-impedance ground connection. The PT ratio is 31.75 [7620:240V] with a secondary resistor connected across its secondary terminals.
- 52-G1-CT = Three Wye-connected C800 CTs installed around the generator circuit breaker phase conductors with a 1600:1 ratio [8000:5A].

C. Generator Step-Up Transformer

The generator is connected to a Generator Step-Up Transformer [GSU] with the following specifications:

- Designation = GSU1
- Type = ONAN/ONAF/ONAF
- MVA = 130 / 175 / 215 MVA
- Primary Volts = 148,600 V
- Secondary Volts = 13,800 V
- Number of Taps = 5
- Impedance [Tap3] = 12.29 %Z
- Connection Type: Yd1 

Therefore, the transformer impedances are:

The transformer impedance in ohms at 13.8kV is:	The transformer impedance measured by the relay in ohms is:
$Z(\Omega) = \frac{kV_{BASE}^2 \times Z\%}{100 \times MVA_{BASE}}$ $Z(\Omega) = \frac{13.8^2 \times 12.29}{100 \times 130}$ $Z(\Omega) = 0.18\Omega$	$Z_{SEC}(\Omega) = \frac{Z_{PRI} \times CT\ Ratio}{PT\ Ratio}$ $Z_{SEC}(\Omega) = \frac{0.18\Omega \times 1600}{120}$ $Z_{SEC}(\Omega) = 2.40\Omega$

D. Power System

A power system model was created, and the positive-sequence power system impedance was calculated to be 0.15225Ω @ 80.00°. The power system impedance measured by the relay will be:

$$Z_{SEC}(\Omega) = \frac{Z_{PRI} \times CT\ Ratio}{PT\ Ratio}$$

$$Z_{SEC}(\Omega) = \frac{0.15225\Omega@80.00° \times 1600}{120}$$

$$Z(\Omega) = 2.03\Omega@80.00°$$

4. General Relay Principles

The generator protection provided by these relays fall into the following categories:

- Some of the elements inside the relay [21, 24, 27, 32, 40, 46, 50/27, 59, 78, and 81] are set to detect problems with the generator or power system that can potentially harm the generator, but the protective element will operate before generator damage can occur. Any of these trips should open the generator circuit breaker to isolate the generator from the power system, but the generator should remain energized, which will allow the operators to re-synchronize the generator after the problem has been corrected. The operators will also receive a normally-open (NO) trip signal through the SCADA system so they can evaluate the situation and respond accordingly.
- The following elements inside the relays [27TN, 59N, and 87] indicate a possible problem inside the generator. These elements will trip a generator lockout relay that will:
  - open the generator circuit breaker,
  - open the generator's excitation circuit breaker,
  - send a shutdown signal to the generator's prime mover, and
  - send a normally-open trip signal to the operators via a SCADA system.
- A breaker-failure scheme [50BF] will start timing when any of the internal relay trip elements operate when the circuit breaker is closed. The circuit breaker will be considered closed if the 52b contact connected to the relay opens, OR any measured phase current through the circuit breaker is greater than 0.50 secondary amps. The breaker-failure scheme will seal itself in when any trip is received. If the circuit breaker does not open [52b contact closes or all phase currents drop below 0.50 secondary amps] within 0.17 seconds after the trip signal is detected, the relay will operate an 86BF-Lockout relay, which will trip all circuit breakers directly connected to the generator circuit breaker to isolate the generator from the rest of the power system. The breaker-failure scheme will disarm itself if the generator circuit breaker opens within 0.17s after a trip signal is detected.
- The relay will send a normally-closed [NC] alarm signal to the SCADA system if an over-excitation [24], unbalance overcurrent [46], or fuse problem [60] is detected.
- All aspects of the enabled protective elements and control functions should be recorded in the relay's sequence of event report to assist maintenance and troubleshooting personnel.
- All protective elements should have clear targets or messages on the front panel of the relay to help operators determine what caused a generator trip.
- All settings are based on the generator manufacturer's supplied data, IEEE recommendations in *IEEE Guide for AC Generator Protection, IEEE Std C37.102 ™ -2006(R2012)*, and NERC requirements for the Western Interconnection in *Standard PRC-024-2 — Generator Frequency and Voltage Protective Relay Settings*.

5. Global Settings

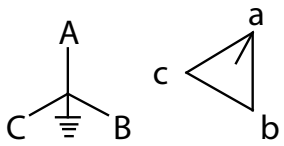
The following general settings should be applied to the protection relays to ensure they adequately protects the generator and power system:

A. M-3425A Settings

a) M-3425A System Settings - Setup System Menu

The following settings should be applied to ensure the relay properly interprets the signals from the power system:

- The "Nominal Voltage" sets the nominal generator voltage [13,800V] through the PTs [120:1], which should be 115.0V [13,800V / 120] phase-phase [P-P] secondary volts because the PTs are Delta connected.
- The "Nominal Current" sets the nominal generator current [5,578A] through the CTs [1,600:1], which should be 3.49A [5,578A / 1600] secondary amps.
- The "Phase Rotation" of the generator and power system is ABC, as shown on the single-line and three-line drawings.
- The "59/27 Magnitude Select" setting should be RMS to ensure maximum metering inside the relay, which will add additional time delays for some non-time sensitive elements.
- The "50DT Split Phase Diff" setting is disabled because no split phase conductors are available to monitor.
- The "Delta-Y Transform" setting should be Delta-AC to match the transformer nameplate's phase shift specification [Yd1] and nameplate images:



- The "V.T. Configuration" setting should be "Line to Line" to reflect the Delta-connected PTs.
- The "V.T. Phase Ratio" should be 120.0 to match the 14,400:120V PTs connected to the relay.
- The "V.T. Neutral Ratio" should be 31.8 to match the 7,620:240V neutral grounding transformer connected to the relay. The actual ratio [31.75:1] has been rounded up to 31.8V because the relay only allows one decimal point.
- The "V.T. VX Ratio" is 1.0 because there is nothing connected to the VX terminals and this setting cannot be disabled.

- The "C.T. Phase Ratio" should be 1600 to match the 8000:5 CTs connected to the IA, IB, and IC terminals on the relay, which should be the CTs installed on the generator circuit breaker.
- The "C.T. Neutral Ratio" should be 1600 to match the 8000:5 CTs connected to the Ia, Ib, and Ic terminals on the relay, which should be the CTs installed around the generator neutral conductors.

b) M-3425A I/O Setup - Setup System Menu

The following settings should be applied to ensure the relay properly interprets the input and output signals from the power system:

- All of the "Input Active State" input settings should be "Close" to match normal functionality.
- All of the "Latched Outputs" settings should be blank because none of the output relays on the relay should latch.
- All of the "Pulsed Outputs" settings should be blank because this application does not use pulsed outputs.

c) M-3425A Output Seal-In Time - Setup System Menu

All of the "Relay Output Seal-In Time (Cycles)" settings should be set to 15 cycles, which means that all outputs should stay closed at least 15 cycles after the element that caused the trip resets. Relay output contacts can be damaged when they open while under load, and this setting is applied to allow external devices to open the 125VDC control circuit before the relay contact can open.

d) Set Date & Time

The relay tester should make sure the M-3425A clock is turned on and set at the correct date and time to ensure all event records are properly recorded and can be compared to other recording devices during troubleshooting tasks.

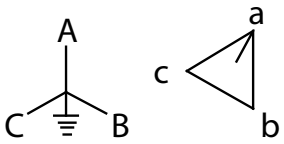
B. SEL-300G Settings

a) SEL-300G Global Settings (SET G)

- The FNOM (Nominal Frequency) setting should be “60” Hz to match the nominal generator and power system frequency.
- The PHROT (Phase Rotation) setting should be “ABC” to match the phase rotation of the generator and power system, as shown on the single-line and three-line drawings.
- The DELTA_Y (Phase Potential Connection) setting should be “D” to reflect the Delta-connected PTs.
- The TGR (Group Change Delay) can be any value because the group settings inside the relay are disabled.
- The SS1 (Group 1 Select Input) setting should be “1” to ensure that the relay always stays in Group 1 because only Group 1 settings have been set to protect the generator.
- The SS2 (Group 2 Select Input) setting should be “0” to ensure that the Group 2 settings are never applied because they are set to default settings and will not protect the generator correctly.
- All IN#0#D (Input Debounce time) settings should be “0.5” cycles to ensure that an input has been closed for at least 0.5 cycles before it will be considered ON in the relay’s logic. These settings will prevent nuisance operations caused by chattering contacts.

b) SEL-300G Group 1 Settings (SET)

- The RID (Relay Identifier) setting should be “G1_SEL-300G” to match the lamacoid above the relay, the designation for this relay on all drawings, and the designation of all of this relay’s coordination curves in the coordination and arc flash study.
- The ID (Terminal Identifier) setting should be “DENNISON SUBSTATION” to match the substation the relay is installed in. All drawing should reflect this location.
- The CTR (Phase (IA,IB,IC) CT Ratio) setting should be “1600” to match the 8000:5 CTs connected to the IA, IB, and IC terminals on the relay, which should be the CTs installed around the generator neutral conductors.
- The CTRD (Differential (IA87,IB87,IC87) CT Ratio) setting should be “1600” to match the 8000:5 CTs connected to the IA87, IB87, and IC87 terminals on the relay, which should be the CTs installed on the generator circuit breaker.
- The CTRN (Neutral (IN) CT Ratio) setting should be “1600” to stop errors from appearing in the SEL AcSELerator QuickSet software. This input is not used and can be any value the software/relay will accept.
- The PTR (Phase (VA,VB,VC) PT Ratio) setting should be “120.0” to match the 14,400:120V PTs connected to the relay.

- The PTRN (Neutral (VN) PT Ratio) setting should be “31.75” to match the 7,620:240V neutral grounding transformer connected to the relay.
- The PTRS (Synch. Voltage (VS) PT Ratio) is set at “120”, but it can be any value because this input is not used in this application.
- The VNOM (Nominal Machine Voltage) setting sets the nominal generator voltage [13,800V] through the PTs [120:1], which should be “115.0” V [13,800V / 120] phase-phase [P-P] secondary volts because the PTs are Delta connected.
- The INOM (Nominal Current) sets the nominal generator current [5,578A] through the CTs [1,600:1], which should be 3.49A [5,578A / 1600] secondary amps. However, the relay only allows one decimal point for this setting, so it has been rounded up to “3.5” A.
- The Z1CMP (Zone 1 XFMR Comp Angle) and the Z2CMP (Zone 2 XFMR Comp Angle) setting should be “-30” to match the transformer nameplate’s phase shift specification [Yd1] and nameplate images: 

- The 50LP (Load Detection Phase Pickup) setting should be set at the minimum possible level, which is 0.25A in the SEL-300G relay. Therefore, the 50L Word Bit will turn ON if the measured primary load current flowing in any phase is greater than 400 primary amps [0.25 x CTR = 0.25 x 1600].
- The IN101 input is connected to a generator circuit breaker 52b contact. Therefore, the 52A setting should be “!IN101”, which means the relay will think the generator circuit breaker is closed when no input signal is measured on IN101.
- The TRIP1 logic is used for all faults that should isolate the generator from the power system by opening the generator circuit breaker. A generator shutdown signal should not be sent so that the operators can bring the generator back online immediately after the problem that caused the trip is corrected. The TRIP1 logic will stay latched until the ULTR1 logic turns ON [or resolves to the TRUE]. The ULTR1 setting should be “3PO”, which will keep the TRIP1 output logic latched until the 52A input turns OFF AND the measured load current (50L) is less than 400 amps. This ensures that the generator circuit breaker opens before the TRIP1 signal disappears.
- The TRIP2 logic is used for all elements that detect a problem inside the generator. The TRIP2 signal should: open the generator circuit breaker to isolate the generator from the power system, open the generator excitation breaker to minimize the amount of damage created while the generator is offline, and send a shutdown signal to the prime mover to minimize the damage caused while the generator spins at rated speed. The TRIP2 logic will stay latched until the ULTR2 logic turns ON [or resolves to the TRUE]. The ULTR2 setting should be “!TR2” to ensure the TRIP2 output stays latched until the problem

disappears. This setting is used instead of 3PO because the generator's magnetic field can cause damage during an internal fault when it is offline, but energized.

- OUT101 is connected to the generator circuit breaker trip coil and its logic setting is "TRIP1", which means the generator circuit breaker should operate when TRIP1 turns on.
- OUT102 is connected to the generator lockout relay, which will: open the generator circuit breaker, open the generator excitation breaker, and send a shutdown signal to the prime mover. The OUT102 logic setting is "TRIP2", which means the generator lockout relay should operate when TRIP2 turns on.
- OUT103 is connected to a normally-open SCADA input signal that will warn the operators when any protective element inside the relay operates. The OUT103 logic setting is "TRIP1 + TRIP2", which means the SCADA system should send an alarm to the operators when TRIP1 OR TRIP2 turns ON.
- OUT105 is connected to a breaker-fail lockout relay, which will open all circuit breakers connected to the generator circuit breaker when OUT105 operates. The OUT105 logic setting is "SV9T", which means that OUT105 will operate when the SELogic Variable #9 turns on longer than the SV9PU time delay. The SV9 logic setting should create a breaker-fail scheme, as described in the breaker-fail section of this document.
- OUT107 is connected to a SCADA alarm that will warn the operators when one of the following abnormal system conditions are detected: Over-Excitation (24), Current Unbalance (46), or PT Fuse problem (60). The SCADA system is expecting a normally-closed contact, so a NOT symbol "!" was added in front of each of the elements in the logic "!24D1T * !46Q1T * !SV2T" [SV2T adds a time delay to the 60LOP Word Bit and ensures it doesn't operate under normal operating conditions, as described later in this document] with AND symbols between each element to create a virtual NC contact because the relay was ordered with physical NO contacts.
- The SER1 equation should include the 50L, IN101, 52A, TRIP1, 3PO, TRIP2, TR2, OUT101, OUT102, OUT103, OUT105, and OUT107 Word Bits to ensure future personnel have as much data as possible when troubleshooting.

c) Set Date & Time

The relay tester should make sure the SEL-300G is set at the correct date and time to ensure all event records are properly recorded and can be compared to other recording devices during troubleshooting tasks.

6. Protection Settings

A. Phase Distance (21) Protection

The phase distance protection element is used as backup protection to isolate the generator from a power system fault when all of the power system protective relays have failed to operate. This relay will apply two zones of protection. Zone-1 should operate if a fault is detected inside the GSU for longer than 20 cycles. Zone-2 should operate if a nearby power system fault is detected for longer than 45 cycles.

a) 21#1 Phase Distance Settings

The transformer impedance [2.40Ω] was calculated in Section 3, Part C of this document. The CTs connected to the relay are rated C800, which means they have a 10% accuracy class up to 20x their rating. Therefore, the Zone-1 Pickup setting should be 90% of the measured transformer impedance to ensure that the zone does not over-reach into the power system, which could cause a mis-coordination with the power system relays. Therefore, the Circle Diameter setting should be 2.16Ω [2.40Ω x 0.90].

No offset is required because the PTs are located at the generator output terminals, which is the zero point for the impedance element.

The transformer is almost a perfect inductive machine, so the expected maximum torque angle for a fault inside the transformer will be near 90°. Therefore, the Impedance Angle setting for this element should be set at 89°.

The expected clearing time for the next upstream relay is 6 cycles, so the Zone-1 time delay should be set at 20 cycles to ensure that the upstream relays have plenty of time to operate.

The 21#1-Element should isolate the generator from the power system by opening the generator circuit breaker and send a trip notification to the operators via SCADA.

The 21#1-Element should only operate when the generator circuit breaker is closed. Impedance elements use voltage in their calculations, so the 21#1-Element should also be blocked if a PT problem is detected.

b) 21#2 Phase Distance Settings

The transformer impedance [2.40Ω] was calculated in Section 3, Part C of this document. The power system impedance was calculated to be [2.03Ω @ 80°], as reported in Section 3, Part D of this document. Therefore, the measured impedance from the generator terminals through the power system is 4.41Ω @ 85.42° [2.40Ω @ 90° + 2.03Ω @ 80° added vectorally]. The CTs connected to the relay are rated C800, which means they have a 10% accuracy class up to 20x their rating. Therefore, the Zone-2 Pickup setting should be 90% of the combined impedance to ensure that the zone does not over-reach beyond the power system, which could cause a mis-coordination with the power system relays. The power system impedance is a calculation, so the relay setting also includes an extra 5% error to compensate for the power system calculation errors. Therefore, the Circle Diameter setting should be 3.75Ω [4.41Ω x 0.85].

No offset is required because the PTs are located at the generator output terminals, which is the zero point for the impedance element.

The Impedance Angle setting for this element should match the sum of the transformer impedance and power system impedance [85.42°].

The maximum clearing time for all power system relays is 30 cycles, so the Zone 2 time delay should be set at 45 cycles to ensure that the power system relays have plenty of time to operate.

The 21#2-Element should isolate the generator from the power system by opening the generator circuit breaker and send a trip notification to the operators via SCADA.

The 21#2-Element should only operate when the generator circuit breaker is closed. Impedance elements use voltage in their calculations, so the 21#2-Element should also be blocked is a PT problem is detected.

c) M-3425A 21: Phase Distance #1 Setpoints

The M-3425A 21#1-Element settings should be:

- Circle Diameter = 2.2Ω [rounded up because the relay only allows one decimal place]
- Offset = 0.0 ohm
- Impedance Angle = 89°
- Load Encr. Angle = N/A [not required by application]
- Load Encr. R Reach = N/A [not required by application]
- Time Delay = 20 Cycles
- Overcurrent Supervision = N/A [not required by application]
- Out of Step Block = Disabled [not required by application]
- Outputs = 1, 3 [Output 1 trips the generator circuit breaker. Output 3 sends a normally-open SCADA trip alarm to the operators]
- Blocking Input(s) = FL, IN1 [FL will block the element if a fuse problem is detected and IN1 will block the element when the generator circuit breaker is open]

d) M-3425A 21: Phase Distance #2 Setpoints

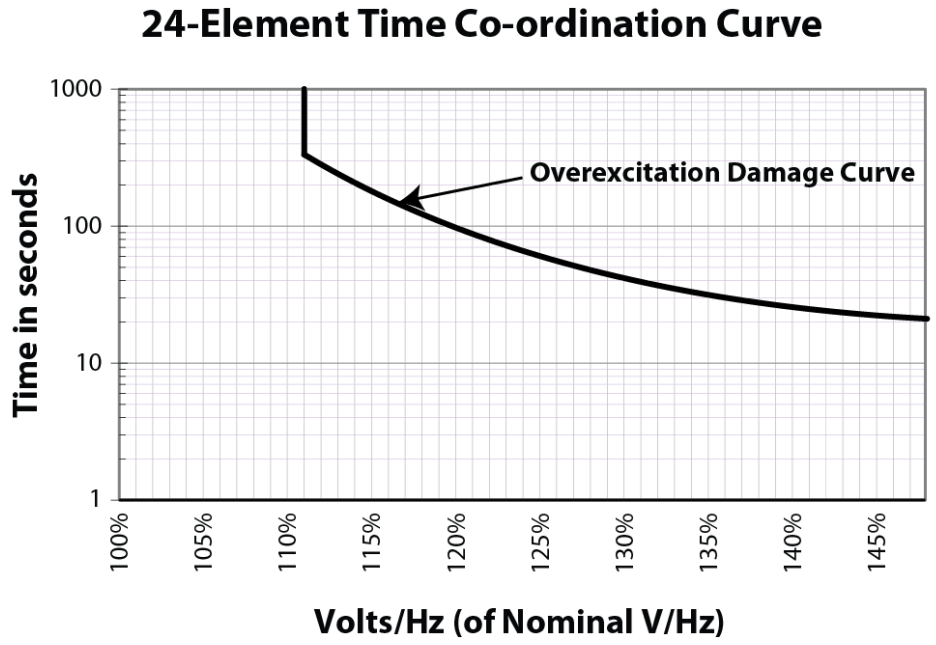
- Circle Diameter = 3.8Ω [rounded up because the relay only allows one decimal place]
- Offset = 0.0 ohm
- Impedance Angle = 85° [rounded down because the relay does not allow decimal places]
- Load Encr. Angle = N/A [not required by application]
- Load Encr. R Reach = N/A [not required by application]
- Time Delay = 45 Cycles
- Overcurrent Supervision = N/A [not required by application]
- Out of Step Block = Disabled [not required by application]
- Outputs = 1, 3 [Output 1 trips the generator circuit breaker. Output 3 sends a normally-open SCADA trip alarm to the operators]
- Blocking Input(s) = FL, IN1 [FL will block the element if a fuse problem is detected, and IN1 will block the element when the generator circuit breaker is open]

e) SEL-300G 21 Mho Element Settings

- EBUP (Enable Backup System Protection) = D [Turns 21-Element protection on]
- Z1R (Zone 1 Phs Dist Reach) = 2.2Ω [21#1 pickup setting rounded up]
- Z1O (Zone 1 Phs Distance Offset) = 0.0 ohm
- MTA1 (Zone 1 Max Torque Ang) = 89° [21#1 MTA setting]
- Z1CMP (Zone 1 XFMR Comp Angle) = -30 [See Section 5., B., b)]
- Z1D (Zone 1 Phs Distance Time Delay) = 0.33 seconds [21#1 time delay setting = 20 cycles / 60 cycles]
- Z2R (Zone 2 Phs Dist Reach) = 3.8Ω [21#2 pickup setting rounded up]
- Z2O (Zone 2 Phs Distance Offset) = 0.0 ohm
- MTA2 (Zone 2 Max Torque Ang) = 85° [21#2 angle rounded down]
- Z2CMP (Zone 2 XFMR Comp Angle) = -30 [See Section 5., B., b)]
- Z2D (Zone 1 Phs Distance Time Delay) = 0.75 seconds [21#2 time delay setting = 45 cycles / 60 cycles]
- MPF (Minimum Power Factor) = OFF [Not required by application]
- MXLD (Maximum Generator Load) = 3.0 [Not required by application, but there is no disable option. Therefore, it is set above the maximum expected load the generator can produce.]
- 21PTC (21P Element Torque Control) = 52A * !60LOP [The 21-Zones can only operate if the generator circuit breaker is closed AND no PT problem is detected]
- TR1 (Trip Equation 1) = 21P1T + 21P2T
- OUT101 (Output Contact 101) = TRIP1 [Trips the generator circuit breaker]
- OUT103 (Output Contact 103) = TRIP1 [Sends trip alarm to SCADA via NO contact]
- ER (Event Trigger Equation) = /21P1P + /21P2P [To trigger an oscillography report when the element picks up. The "/" stands for rising edge, so it only triggers an event when it picks up, not when it drops out.]
- SET1 (Set Latch Bit 1) = 21P1T + 21P2T [LT1 will be used to display a message on the front panel when the 21-Element operates]
- RST1 (Reset Latch Bit 1) = TRGTR [Target reset command must be applied to clear the message on front panel]
- ALIAS1 (Relay Word Bit Alias 1) = LT1 SYS_BACKUP_TRIP TRIPPED RESET [Renames LT1 as SYS_BACKUP_TRIP in the SER]
- DP1 (Display Point 1) = LT1 [To display a message on the front panel after 21-Element operates until the target reset command is issued to the relay]
- DP1_1 (Display Point 1 Label) = SYS BACKUP TRIP [Message displayed on front panel after 21-Element operates until the target reset command is issued]
- DP1_0 (Display Point 1 Label) = NA [No message unless a 21-Element operates]
- SER1 (Sequential Events Recorder 1) = … 21P1P,21P1T,21PTC,LT1,21P2P,21P2T

B. Volts/Hertz (24) Protection

Volts/Hertz protection ensures the generator is not over-excited beyond its capabilities. The generator can be overexcited by raising the voltage without a corresponding rise in frequency, or lowering the frequency without a corresponding drop in voltage. The following graph represents the generator's excitation damage curve, which indicates that damage will occur if the generator volts/hertz value is greater than 111% of nominal.



This application will include a 24-Alarm to warn the operators when an over-excitation is detected for longer than 10 seconds, which should prevent nuisance alarms and give them a chance to correct the problem before the relay trips.

The 24-Element trip protection will be applied using combined inverse- and definite-time elements, as recommended by the IEEE. The 24-Trip elements should operate the circuit breaker below the equipment damage curve to protect the generator.

a) 24-Alarm Settings

Most generators can tolerate up to 105% over-excitation without problems. Therefore, the 24-Alarm element will be set to pick up if the measured excitation [volts/hertz] exceeds 105% of nominal [115V/60Hz].

The 24-Alarm will operate the normally-closed (NC) SCADA alarm contact if an over-excitation is detected for longer than 10s.

The 24-Elements use voltage to detect excitation, so the 24-Alarm will be blocked if the relay detects a PT problem.

b) M-3425 24: Volts/Hertz Overexcitation Definite Time #1 Settings

The 24-Definite Time #1-Element settings will create the 24-Alarm characteristic and should have the following settings:

- Pickup = 105%
- Time Delay = 600 cycles [10s x 60Hz]
- Outputs = 7 [Opens the NC Alarm contact via the Output 7 NC contacts on the relay]
- Blocking Inputs = FL [FL will block the element if a fuse problem is detected]

c) SEL-300G 24 Element Settings - Level 1

The Level 1 Volts/Hertz settings will create the 24-Alarm characteristic and should have the following settings

- E24 (Enable Volts/Hertz Protection) = Y [Turns 24-Elements on]
- 24D1P (Level 1 Volts/Hertz Pickup) = 105%
- 24D1D (Level 1 Time Delay) = 10.00 seconds
- 24TC (24 Element Torque Control) = !60LOP [The 24-Elements can only operate if no fuse problem is detected]
- OUT107 (Output Contact 107) = !24D1T [Not(!) added to turn the OUT107 physical NO contact into a functional NC contact]
- ER (Event Trigger Equation) = … + /24D1 [To trigger an oscillography report when the element picks up. The "/" stands for rising edge, so it only triggers an event when it picks up, not when it drops out.]
- ALIAS2 (Relay Word Bit Alias 2) = 24D1T V_HZ_ALARM ACTIVE RESET [Renames 24D1T as V_HZ_ALARM in the SER]
- DP16 (Display Point 16) = 24D1 [Message appears on front panel only when 24-Alarm is currently active]
- DP16_1 (Display Point 1 Label) = V/HZ ALARM [Message displayed on front panel when 24-Alarm is currently active]
- DP16_0 (Display Point 1 Label) = NA [No message unless a 24-Alarm is active]
- SER1 (Sequential Events Recorder 1) = …,24D1,24D1T,24TC

d) 24-Trip Settings

The IEEE recommends that a combined Inverse- / Definite-Time protection curve be applied to protect the generator, which will be the configuration used in this application.

The IEEE recommends that the inverse-time part of an Inverse- / Definite-Time protection curve be set at 105% of the nominal V/Hz with a time delay that coordinates with the generator manufacturer's damage curve. Therefore, the 24-Inverse-Time-Trip pickup setting will be 105% of the Nominal V/Hz. The timing curve and settings will be set below the generator damage curve.

The IEEE also recommends that the pickup setting of the definite-time part of the characteristic be set between 118% and 120% of the nominal V/Hz with a 2-to 6-second time delay. Therefore, the 24-Definite-Time-Trip pickup setting will be 120% of the Nominal V/Hz with a 2.00-second time delay.

The 24-Trip will operate the generator circuit breaker trip coil to isolate the generator from the power system and allow the operators to re-synchronize immediately after the problem is corrected. A trip notification will also be sent to the operators via a SCADA alarm contact.

The 24-Elements use voltage to detect excitation, so the 24-Trip will be blocked if the relay detects a PT problem.

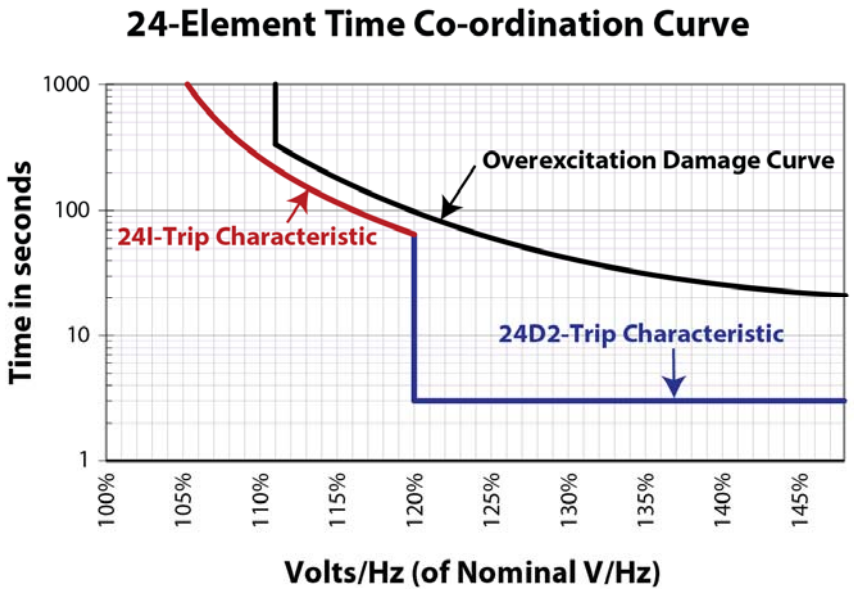
The 24-Element is really an indirect method to detect the extra heat created during an unbalance condition. The temperatures inside a generator do not decrease instantaneously, so the relay allows an indirect thermal-memory-reset time delay, which ensures the generator has enough time to dissipate the extra heat generated during an over-excitation condition. If an unbalance is detected, the generator must be running with no over-excitation for longer than 120 seconds before the 24-Element timer resets to zero.

e) M-3425 24: Volts/Hertz Overexcitation Inverse Time Settings

The 24-Inverse Time Element and the 24-Definite-Time #2 settings will create the combined 24-Inverse Trip characteristic. The 24-Inverse characteristic should have the following settings:

- Pickup = 105%
- Time Delay = 15
- Reset Rate = 120 seconds
- Inverse Time Curve = #1
- Outputs = 1, 3 [Output 1 trips the generator circuit breaker. Output 3 sends a normally-open SCADA trip alarm to the operators]
- Blocking Input(s) = FL [FL will block the element if a fuse problem is detected]

The following graph shows the generator damage curve along with the 24: Inverse and 24: Definite Time #2 protection characteristics.



The M-3425A 24-Trip characteristics should operate as per the following characteristics, within the relay tolerances:

- 106% V/Hz = 1,038.062 seconds
- 108% V/Hz = 421.875 seconds
- 110% V/Hz = 270.000 seconds
- 115% V/Hz = 120.000 seconds
- 118% V/Hz = 83.333 seconds
- ≥120% V/Hz = 2.000 seconds

f) M-3425_24: Volts/Hertz Overexcitation Definite Time #2 Settings

The 24-Definite-Time #2-Element settings will create the definite-time part of the 24-Trip characteristic and should have the following settings:

- Pickup = 120%
- Time Delay = 120 cycles [2.00s x 60Hz]
- Outputs = 1, 3 [Output 1 trips the generator circuit breaker. Output 3 sends a normally-open SCADA trip alarm to the operators]
- Blocking Input(s) = FL [FL will block the element if a fuse problem is detected]

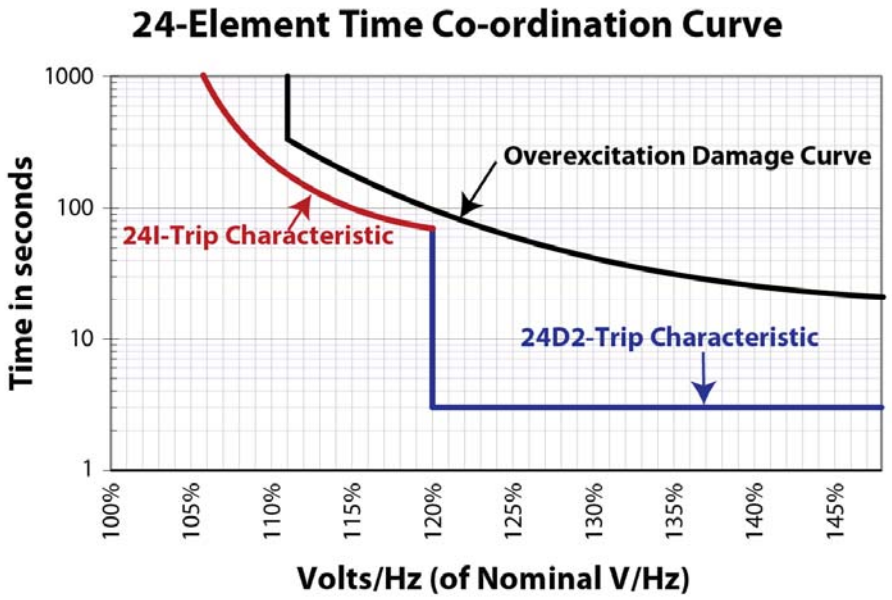
g) SEL-300G 24 Element Settings - Level 2

The Level 2 Volts/Hertz settings will create the 24-Trip characteristic [inverse and definite time] and should have the following settings:

- E24 (Enable Volts/Hertz Protection) = Y [Turns 24-Elements on]
- 24CCS (Level 2 Composite Curve Shape) = ID [inverse and definite time combined in one element's settings]
- 24IP (Level 2 Inverse-time Pickup) = 105%
- 24IC (Level 2 Inverse-time Curve) = 1.0
- 24ITD (Level 2 Inverse-time Factor) = 10.0
- 24D2P2 (Level 2 Pickup Two) = 120%
- 24D2D2 (Level 2 Time Delay Two) = 2.00s
- 24CR (Level 2 Reset Time) = 120.00s
- 24TC (24 Element Torque Control) = !60LOP [The 24-Elements can only operate if no fuse problem is detected]
- TR1 (Trip Equation 1) = ... + 24C2T
- OUT101 (Output Contact 101) = TRIP1 [Trips the generator circuit breaker]
- OUT103 (Output Contact 103) = TRIP1 [Sends trip alarm to SCADA via NO contact]
- ER (Event Trigger Equation) = … + /24C2 [To trigger an oscillography report when the element picks up. The "/" stands for rising edge, so it only triggers an event when it picks up, not when it drops out.]
- SET2 (Set Latch Bit 2) = 24C2T [LT2 will be used to display a message on the front panel when the 24-Trip operates]
- RST2 (Reset Latch Bit 2) = TRGTR [Target reset command must be applied to clear the message on front panel]
- ALIAS2 (Relay Word Bit Alias 2) = LT2 V_HZ_TRIP TRIPPED RESET [Renames LT2 as V_HZ_TRIP in the SER]
- DP2 (Display Point 2) = LT2 [Message appears on front panel after 24-Trip operates, which will stay on until a target reset command is issued to the relay]

- DP2_1 (Display Point 2 Label) = V/HZ TRIPPED [Message displayed on front panel after 24-Trip operates, which will stay on until a target reset command is issued]
- DP2_0 (Display Point 2 Label) = NA [No message unless a 24-Trip operates]
- SER1 (Sequential Events Recorder 1) = … ,24C2,24C2T,24CR
- SER2 (Sequential Events Recorder 1) = LT2

The following graph shows the generator damage curve along with the 24-Inverse and 24-Definite-Time #2 protection characteristics.



The SEL-300G 24-Trip characteristics should operate as per the following characteristics, within the relay tolerances:

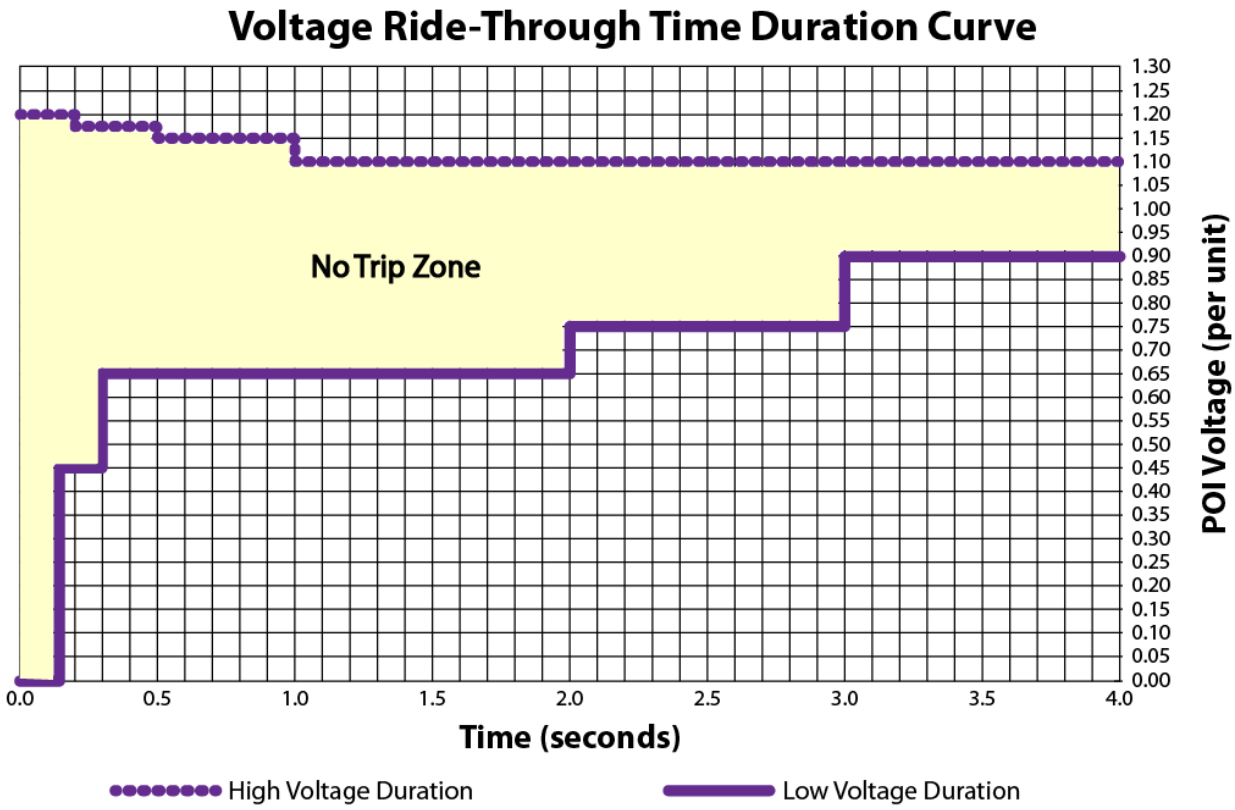
- 106% V/Hz = 1,050.00 seconds
- 108% V/Hz = 350.00 seconds
- 110% V/Hz = 210.00 seconds
- 115% V/Hz = 105.00 seconds
- 118% V/Hz = 80.77 seconds
- ≥120% V/Hz = 2.000 seconds

C. Phase Undervoltage (27) Protection

The Phase Undervoltage protection element is used to isolate the generator from abnormal power system voltages. The manufacturer did not provide any undervoltage damage characteristics; however, the IEEE recommends two definite-time elements with the following settings:

- 27-D1 = 90% nominal voltage pickup with a 10-to-15 second delay.
- 27-D2 = 80% nominal voltage pickup voltage with a 2-second time delay.

These settings were not applied to this relay because the generator installation must meet all NERC standards, which have the following requirements:



The 27-Element settings in this application will be as close to the IEEE recommended pickup settings as possible with modified time delays to be outside the NERC specified no-trip zone:

- 27-D1 = 89% nominal voltage pickup with a 15-second delay.
- 27-D2 = 80% nominal voltage pickup voltage with a 3.1-second time delay.

Any 27-Trip should open the generator circuit breaker and send a normally-open alarm signal to the operators. The 27-Elements use voltage in their calculations, so they will be blocked if a PT fuse is detected. The generator voltage will drop below the 27-Pickup settings whenever the generator is de-energized and offline, which would cause nuisance undervoltage trips and alarms under normal conditions. Therefore, both 27-Element should be blocked when the generator circuit breaker is open to prevent nuisance signals.

The following settings should be applied to the relays to ensure these conditions are met:

a) M-3425A 27#1 Phase Undervoltage Settings

The 27#1-Element settings should follow the 27-D1-Element characteristics described earlier:

- Pickup = 102V [Nominal voltage x 89% = 115.00V x 0.89 = 102.35. Setting was rounded down to 102V because the relay setting does not have decimal points.]
- Time Delay = 900 cycles [60.00Hz x 15.00s]
- Outputs = 1, 3 [Output 1 trips the generator circuit breaker. Output 3 sends a normally-open SCADA trip alarm to the operators]
- Blocking Input(s) = FL, IN1 [FL will block the element if a fuse problem is detected, and IN1 will block the element when the generator circuit breaker is open]

b) M-3425A 27#2 Phase Undervoltage Settings

The 27#2-Element settings should follow the 27-D2-Element characteristics described earlier:

- Pickup = 92V [Nominal voltage x 80% = 115.00V x 0.80 = 92.00]
- Time Delay = 186 cycles [60.00Hz x 3.10s]
- Outputs = 1, 3 [Output 1 trips the generator circuit breaker. Output 3 sends a normally-open SCADA trip alarm to the operators]
- Blocking Input(s) = FL, IN1 [FL will block the element if a fuse problem is detected, and IN1 will block the element when the generator circuit breaker is open]

c) SEL-300G_27 Element Settings - 27PP1

The 27PP1-Element settings should follow the 27-D1-Element characteristics described earlier:

- E27 (Enable Undervoltage (U/V) Protection) = Y [Turns 27-Protection On]
- 27PP1 (Level 1 Phase-phase U/V Pickup) = 102.3V [Nominal voltage x 89% = 115.00V x 0.89 = 102.35V. Setting was rounded down to 102.3V because the relay setting does not have decimal points.]
- SV3 (SELogic Variable 3) = 27PP1 * 52A * !60LOP [SV3 will only turn ON if: any phase-phase (P-P) voltage is less than 102.3V, AND the generator circuit breaker is closed (52A), AND no PT problems are detected (!60LOP)]
- SV3PU (SV3 Pickup Time) = 15.00 seconds [SV3T will turn ON if SV3 is ON for 15.00 seconds]
- SV3DO (SV3 Dropout Time) = 0.00 seconds [SV3T will turn OFF immediately after SV3 turns OFF]
- TR1 (Trip Equation 1) = … + SV3T
- OUT101 (Output Contact 101) = TRIP1 [Trips the generator circuit breaker]
- OUT103 (Output Contact 103) = TRIP1 [Sends trip alarm to SCADA via NO contact]
- ER (Event Trigger Equation) = … + /27PP1 [To trigger an oscillography report when the element picks up. The "/" stands for rising edge, so it only triggers an event when it picks up, not when it drops out.]
- SET3 (Set Latch Bit 3) = SV3T [LT3 will be used to display a message on the front panel when the 27D1-Trip operates]
- RST3 (Reset Latch Bit 3) = TRGTR [Target reset command must be applied to clear the message on front panel]
- ALIAS3 (Relay Word Bit Alias 3) = LT3 UNDER_VOLT1 TRIPPED RESET [Renames LT3 as UNDER_VOLT1 in the SER]
- DP3 (Display Point 3) = LT3 [A message will appear on front panel after the 27D1-Trip operates, which will stay on until a target reset command is issued to the relay]
- DP3_1 (Display Point 3 Label) = UNDER-VOLT TRIP [Message displayed on front panel after 27D1-Trip operates, which will stay on until a target reset command is issued]
- DP3_0 (Display Point 3 Label) = NA [No message unless a 27D1-Trip operates]
- SER2 (Sequential Events Recorder 2) = … ,27PP1,SV3,SV3T,LT3

d) SEL-300G_27 Element Settings - 27PP2

The 27PP2-Element settings should follow the 27-D2-Element characteristics described earlier:

- E27 (Enable Undervoltage (U/V) Protection) = Y [Turns 27-Protection On]
- 27PP2 (Level 2 Phase-phase U/V Pickup) = 92.0V [Nominal voltage x 80% = 115.00V x 0.80 = 92.00V]
- SV4 (SELogic Variable 4) = 27PP2 * 52A * !60LOP [SV4 will only turn ON if: any P-P voltage is less than 92.0V, AND the generator circuit breaker is closed (52A), AND no PT problems are detected (!60LOP)]
- SV4PU (SV4 Pickup Time) = 3.10s [SV4T will turn ON if SV4 is ON for 3.10 seconds]
- SV4DO (SV4 Dropout Time) = 0.00 seconds [SV4T will turn OFF immediately after SV4 turns OFF]
- TR1 (Trip Equation 1) = … + SV4T
- OUT101 (Output Contact 101) = TRIP1 [Trips the generator circuit breaker]
- OUT103 (Output Contact 103) = TRIP1 [Sends trip alarm to SCADA via NO contact]
- ER (Event Trigger Equation) = … + /27PP2 [To trigger an oscillography report when the element picks up. The "/" stands for rising edge, so it only triggers an event when it picks up, not when it drops out.]
- SET3 (Set Latch Bit 3) = SV3T + SV4T [LT3 will be used to display a message on the front panel when the 27D2-Trip operates]
- RST3 (Reset Latch Bit 3) = TRGTR [Target reset command must be applied to clear the message on front panel]
- ALIAS3 (Relay Word Bit Alias 3) = LT3 UNDER_VOLT TRIPPED RESET [Renames LT3 as UNDER_VOLT in the SER]
- DP3 (Display Point 3) = LT3 [A message will appear on front panel after the 27D1 or 27D2-Trip operates, which will stay on until a target reset command is issued to the relay]
- DP3_1 (Display Point 3 Label) = UNDER-VOLT2 TRIP [Message displayed on front panel after 27D2-Trip operates, which will stay on until a target reset command is issued]
- DP3_0 (Display Point 3 Label) = NA [No message unless a 27D2-Trip operates]
- SER2 (Sequential Events Recorder 2) = … ,27PP2,SV4,SV4T

D. 100% Stator Earth (27TH, 27TN, or 64G2) Protection Settings

The generator is installed with a high-impedance Neutral Grounding Transformer (NGTX) inserted between the generator neutral terminals and ground. The 59N-Element [described later in this document] is set to detect ground faults up to 95% of the stator winding, which means 5% of the stator would not be protected if it was the only ground fault protection element installed. A ground fault on the neutral end of the stator might not create enough voltage to operate the 59N-Element, so the 100% Stator Earth Protection Element is installed to protect the neutral end of the generator stator.

No generator stator windings or power systems are 100% balanced, which means that there will always be a small amount of unbalanced current flowing through the generator neutral ground connection. A third-harmonic voltage will be created when the normal unbalanced current flows though the NGTX. This voltage will disappear if a ground fault occurs on the neutral side of the generator stator because a fault in that location will essentially short out the Neutral Grounding Transformer.

The Third-Harmonic Under-Voltage element (27TH-Element) monitors the third-harmonic voltage across the NGTX and operates if the measured third-harmonic voltage drops below the pickup setpoint after a preset amount of time. The 27TH-Element in this application should operate the generator lockout relay, which will open the generator circuit breaker, generator field circuit breaker, and send a shutdown command to the prime mover.

The interaction between generator and power system is unique at every site. Therefore, the pickup setting for this element cannot be determined until the third-harmonic voltage across the NGTX is measured under the following conditions:

- Offline and energized to the nominal generator voltage =
- Online and 0% Load at the nominal generator voltage =
- Online and 25% Load at the nominal generator voltage =
- Online and 50% Load at the nominal generator voltage =
- Online and 75% Load at the nominal generator voltage =
- Online and 100% Load at the nominal generator voltage =
- Online while applying any unusual power factor loading characteristics that site conditions require [Please specify abnormal operating conditions] =
- Online while applying any unusual VAR loading characteristics that site conditions require [Please specify abnormal operating conditions] =

The final pickup setting for this element will be created after these measurements are forwarded to me at chris@relaytraining.com. The temporary settings will be the maximum allowable setpoint, which will likely cause a trip under normal operating conditions. This will hopefully trigger on-site personnel to make the required measurements, which will require them to temporarily disable the 100% Stator Earth Protective Element.

The IEEE recommends a 5.00-second time delay, which is the value that should be used for the 27TH-Element Time Delay settings in both relays.

A 27TH-Trip indicates a ground fault inside the generator, which should trip the 86G-Lockout relay. The 86G-Lockout relay will open the generator circuit breaker, open the generator excitation circuit breaker, and send a shutdown signal to the prime mover. A NO Alarm contact should be sent to the SCADA system to notify the operators.

The third-harmonic neutral voltage setting voltages are based on in-service measurements at 100% generator nominal voltage. Lower operating voltages will likely cause the third-harmonic neutral voltage to drop proportionally, which could cause nuisance trips that indicate a stator fault. Therefore, the 27TN-Element should not operate if the operating voltage is less than 90% of the generator rated voltage.

The following settings should be applied to the relays to ensure these conditions are met:

a) M-3425A 27TN#1 Third Harmonic Undervoltage, Neutral Settings

The 27TH-Element is identified as 27TN in the M-3425A relay, which should have the following settings:

- Pickup = 14.00V [Set at the maximum possible voltage until the in-service measurements have been submitted and final settings can be issued]
- Pos. Sequence Voltage Block = 104V [Set at 90% of the nominal generator voltage (0.90 x 115.00 = 103.5V). This setting was rounded up to 104V because no decimal places are allowed by the relay.]
- Forward Power Block = Disable [Unable to determine if this setting should be applied until in-service measurements are submitted]
- Reverse Power Block = Disable [Unable to determine if this setting should be applied until in-service measurements are submitted]
- Lead var Block = Disable [Unable to determine if this setting should be applied until in-service measurements are submitted]
- Lag var Block = Disable [Unable to determine if this setting should be applied until in-service measurements are submitted]
- Lead Power Factor Block = Disable [Unable to determine if this setting should be applied until in-service measurements are submitted]
- Lag Power Factor Block = Disable [Unable to determine if this setting should be applied until in-service measurements are submitted]
- Hi Band Forward Power Block = Disable [Unable to determine if this setting should be applied until in-service measurements are submitted]
- Lo Band Forward Power Block = Disable [Unable to determine if this setting should be applied until in-service measurements are submitted]
- Time Delay = 300 cycles [60.00Hz x 5.00s]
- Outputs = 2, 3 [Output 2 trips the generator lockout relay. Output 3 sends a normally-open SCADA trip alarm to the operators]
- Blocking Input(s) = N/A [No additional blocking logic should be applied]

b) SEL-300G 64G Element Settings – 64G2

The 27TH-Element is identified as 64G2 in the SEL-300G relay, which should have the following settings:

- E59 (Enable Overvoltage (O/V) Protection) = Y [Turns 59-Protection On, which will be used to ensure the three-phase, P-P voltages are above 90% of the generator nominal voltage before the 27TN-Element will issue a trip command]
- E64 (Enable 100% Stator Ground Protection) = Y [Turns 27TH-Protection On]
- 64G2P (Zone 2 Differential Voltage) = 20.00V [Set at the maximum possible voltage until the in-service measurements have been submitted and final settings can be issued]
- 64G2D (Zone 2 Time Delay) = 5.00s
- 64GTC (64G Element Torque Control) = 1 [The 59N-Element (64G1) should always be on, and it shares this setting with 64G2. The 27TH-Element will be blocked by an undervoltage condition in the trip equation]
- 59V1P (Pos.-Seq. (V1) O/V Pickup) = 59.8V [59V1 will be used in the trip equation to block the 27TH operation if the voltage drops below 90% of the generator nominal positive-sequence voltage, which is usually specified in phase-neutral (P-N) values. (0.90 x 115.00V / $\sqrt{3}$ = 59.76V). The relay only allows one decimal place, so the setting was rounded up to 59.8V. The relay tester should verify that the 27TN-Element does NOT operate an output contact if the three-phase, P-P voltages are below 103.50V.]
- TR2 (Trip Equation 2) = (64G2T*59V1)
- OUT102 (Output Contact 102) = TRIP2 [Trips the generator lockout relay]
- OUT103 (Output Contact 103) = TRIP1 + TRIP2 [Sends trip alarm to SCADA via NO contact]
- ER (Event Trigger Equation) = … + /64G2 [To trigger an oscillography report when the element picks up..]
- SET5 (Set Latch Bit 5) = 64G2T [LT5 will be used to display a message on the front panel when the 27TH-Trip operates]
- RST5 (Reset Latch Bit 5) = TRGTR [Target reset command must be applied to clear the message on front panel]
- ALIAS5 (Relay Word Bit Alias 5) = LT5 STATOR_FAULT TRIPPED RESET [Renames LT5 as STATOR_FAULT in the SER]
- DP5 (Display Point 5) = LT5 [A message will appear on front panel after the 27TH-Trip operates, which will stay on until a target reset command is issued to the relay]
- DP5_1 (Display Point 5 Label) = STATOR_FAULT TR [Message displayed on front panel after 27TH-Trip operates, which will stay on until a target reset command is issued]
- DP5_0 (Display Point 5 Label) = NA [No message unless a 27TH-Trip operates]
- SER2 (Sequential Events Recorder 2) = … ,64G2,64G2T,64GTC,LT5

E. Reverse Power (32) Protection

A reverse-power condition occurs when the generator is connected to the power system and the prime mover cannot maintain the power system frequency. The generator must turn at the power system frequency because they are magnetically locked together, so the generator will absorb watts and become a motor in order to maintain the power system frequency. This normally indicates a problem with the prime mover.

The 32-Element monitors the generator terminal voltages via the generator PTs and the current flowing through the generator via the generator neutral CTs. The relay calculates three-phase watts to determine the actual generator power output, which is positive under normal operating conditions and negative when the generator imports watts like a motor.

The generator manufacturer did not supply any motoring specifications. Therefore, the relays should be set with the IEEE recommended settings for a 32-Element, which include a pickup setting set at -0.50% of the rated generator watt output [- equals reverse power] with a 30-second delay.

A 32-Element uses voltage in its calculations, so it should not operate if a PT fuse problem is detected.

A reverse-power fault indicates a problem with the prime mover. Therefore, the 32-Element will trip the generator circuit breaker so that the generator will be isolated from the power system until the problem can be fixed. The operators will be able to immediate put the generator back into service after the problem is corrected.

A normally-open trip alarm should be sent to the SCADA system.

The following settings should be applied to the relays to ensure these conditions are met:

a) M-3425A 32#1 Directional Power Settings

- Pickup = -0.050PU [Set at -0.05% of nominal generator VA]
- Time Delay = 1,800 cycles [60.00Hz x 30.00s]
- Over/Under Power = Over [The 32-Element should trip if the measured negative power is more negative than the setpoint]
- Target LED = Enable [The 32 REVERSE POWER LED should be lit when a 32-Element operates.]
- Outputs = 1, 3 [Output 1 trips the generator circuit breaker. Output 3 sends a normally-open SCADA trip alarm to the operators]
- Blocking Input(s) = FL [The 32-Element will be blocked if a PT fuse problem is detected]

b) SEL-300G 32 Element Settings

The SEL-300G relay's 32-Element should have the following settings:

- E32 (Enable Reverse/Low Forward Power Protection) = Y [Turns 32-Protection On]
- 32P1P (Level 1 Power Threshold) = -0.0500 [Set at -0.0500% nominal generator VA]
- 32P1D (Level 1 Power Time Delay) = 30.00s
- 32P2P (Level 2 Power Threshold) = OFF [Function not used]
- 32PTC (32-Element Torque Control) = !60LOP [The 32-Elements can only operate if no fuse problem is detected]
- TR1 (Trip Equation 1) = … + 32P1T
- OUT101 (Output Contact 101) = TRIP1 [Trips the generator circuit breaker]
- OUT103 (Output Contact 103) = TRIP1 + TRIP2 [Sends trip alarm to SCADA via NO contact]
- ER (Event Trigger Equation) = … + /32P1 [To trigger an oscillography report when the element picks up. The "/" stands for rising edge, so it only triggers an event when it picks up, not when it drops out.]
- SET6 (Set Latch Bit 6) = 32P1T [LT6 will be used to display a message on the front panel when the 27D1-Trip operates]
- RST6 (Reset Latch Bit 6) = TRGTR [Target reset command must be applied to clear the message on front panel]
- ALIAS6 (Relay Word Bit Alias 6) = LT6 REV_POWER TRIPPED RESET [Renames LT6 as REV_POWER in the SER]
- DP6 (Display Point 6) = LT6 [A message will appear on front panel after the 32-Trip operates, which will stay on until a target reset command is issued to the relay]
- DP6_1 (Display Point 6 Label) = REV POWER TRIP [Message displayed on front panel after 32-Trip operates, which will stay on until a target reset command is issued]
- DP6_0 (Display Point 6 Label) = NA [No message unless a 32-Trip operates]
- SER2 (Sequential Events Recorder 2) = … ,32PTC, 32P1, 32P1T, LT6

F. Loss-of-Field (40) Protection

The generator's excitation system creates the magnetic field required to maintain the generator voltage. The generator excitation field can fail if the excitation circuit is open or shorted, the field circuit breaker (also known as the excitation circuit breaker) opens, or something happens to the excitation source. The generator will import VARs from the system when the field isn't strong enough to maintain the system voltage, which can cause up to twice the nominal current to flow in the stator, which will cause stator overheating along with a possible system voltage drop.

VAR-based protection has proven to be unreliable in the past, so the 40-Element uses impedance to detect a problem with the field because a damage characteristic can be calculated using the generator impedances. All impedance calculations use a ratio of voltage to current, which makes the 40-Element characteristic a circle. The generator current will lead the generator voltage during a loss-of-field condition because the generator is importing VARs from the system, which means the 40-Element impedance characteristic is drawn -90° from resistance.

The 40-Elements use the generator PT voltages and generator neutral CT currents to calculate measured ohms using Ohm's Law. If the measured impedance falls inside the 40-Element circles, the element will operate the generator circuit breaker to protect the stator from overheating and damage. This should also stop the generator from causing brownouts by drooping the power system voltage when importing too many VARs.

The IEEE recommends that Loss-of-Field protection use two definite-time mho elements set below the resistance axis with the following settings:

- Zone-1 set at 100% of the Generator Per-Unit Impedance with a 0.1-second time delay.
- Zone-1 set at 100% of the Generator Synchronous Reactance with a 0.5-second time delay.
- Both zones are offset by one-half of the Direct Axis Transient Reactance.

The nominal per unit secondary impedance can be calculated using the nominal generator current [3.49A] and nominal generator voltage [115.00V_{P-P}]:

$$\Omega = \frac{\left(\frac{\text{Voltage}_{P-P}}{\sqrt{3}}\right)}{\text{Current}}$$

$$\Omega = \frac{\left(\frac{115.0}{\sqrt{3}V}\right)}{3.49A}$$

$$\Omega = 19.02\Omega$$

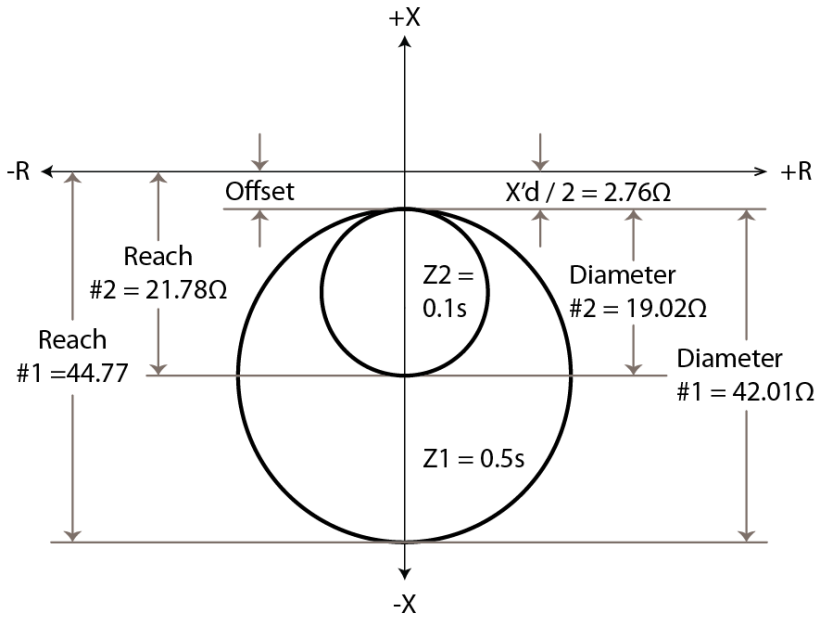
The synchronous reactance was defined by the manufacturer as 206.8% in Section 2 of this document under "Reactances Base MVA = 125MVA". Therefore, the XD reactance can be calculated to be:

The Synchronous Reactance [XD] in primary ohms:	The Synchronous Reactance [XD] measured by the relay in secondary ohms:
$Z(\Omega) = \frac{kV_{BASE}^2 \times Z\%}{100 \times MVA_{BASE}}$	$Z_{SEC}(\Omega) = \frac{Z_{PRI} \times \text{CT Ratio}}{\text{PT Ratio}}$
$Z(\Omega) = \frac{13.8^2 \times 206.8}{100 \times 125}$	$Z_{SEC}(\Omega) = \frac{3.15\Omega \times 1600}{120}$
$Z(\Omega) = 3.15\Omega$	$Z_{SEC}(\Omega) = 42.01\Omega$

The transient reactance was defined by the manufacturer as 27.2% in Section 2 of this document under "Reactances Base MVA = 125MVA". Therefore, one-half of the XD' reactance can be calculated to be:

One-half of the Transient Reactance [XD'] in primary ohms:	One-half of the Transient Reactance [XD'] measured by the relay in secondary ohms:
$Z(\Omega) = 0.5 \times \frac{kV_{BASE}^2 \times Z\%}{100 \times MVA_{BASE}}$	$Z_{SEC}(\Omega) = \frac{Z_{PRI} \times \text{CT Ratio}}{\text{PT Ratio}}$
$Z(\Omega) = 0.5 \times \frac{13.8^2 \times 27.2}{100 \times 125}$	$Z_{SEC}(\Omega) = \frac{0.21\Omega \times 1600}{120}$
$Z(\Omega) = 0.21\Omega$	$Z_{SEC}(\Omega) = 2.76\Omega$

Therefore, the 40-Element characteristic should look like the following impedance drawing:



a) M-3425A 40#1: Loss of Field Settings

The M-3425A 40#1-Element settings should be:

- Circle Diameter = 42.0Ω [rounded down because the relay only allows one decimal place]
- Offset = -2.7Ω [rounded down because the relay only allows one decimal place]
- Time Delay = 30 cycles [0.50s x 60.00Hz]
- Outputs = 1, 3 [Output 1 trips the generator circuit breaker. Output 3 sends a normally-open SCADA trip alarm to the operators]
- Blocking Input(s) = FL [FL will block the element if a fuse problem is detected]
- Directional Element = 0 [Not required by application]
- VC = Disabled [Not required by application]

b) M-3425A 40#2: Loss of Field Settings

The M-3425A 40#2-Element settings should be:

- Circle Diameter = 19.0Ω [rounded down because the relay only allows one decimal place]
- Offset = -2.7Ω [rounded down because the relay only allows one decimal place]
- Time Delay = 6 cycles [0.10s x 60.00Hz]
- Outputs = 1, 3 [Output 1 trips the generator circuit breaker. Output 3 sends a normally-open SCADA trip alarm to the operators]
- Blocking Input(s) = FL [FL will block the element if a fuse problem is detected]
- Directional Element = 0 [Not required by application]
- VC = Disabled [Not required by application]

c) SEL-300G 40 Element Settings

The SEL-300G 40-Element settings should be:

- E40 (Enable Loss-of-Field Protection) = Y [Turns on 40-Element protection]
- 40Z1P (Zone 1 Mho Diameter) = 19.0Ω [Rounded down because the relay only allows one decimal place]
- 40XD1 (Zone 1 Offset Reactance) = -2.7Ω [Rounded down because the relay only allows one decimal place]
- 40Z1D (Zone 1 Pickup Time Delay) = 0.10s
- 40Z2P (Zone 2 Mho Diameter) = 42.0Ω [Rounded down because the relay only allows one decimal place]
- 40XD2 (Zone 2 Offset Reactance) = -2.7Ω [Rounded down because the relay only allows one decimal place]
- 40Z2D (Zone 2 Pickup Time Delay) = 0.50s
- 40PTC (40Z Element Torque Control) =!60LOP [The 40-Element can only operate if no PT problem is detected]
- TR1 (Trip Equation 1) = … + 40Z1T + 40Z2T
- OUT101 (Output Contact 101) = TRIP1 [Trips the generator circuit breaker]
- OUT103 (Output Contact 103) = TRIP1+TRIP2 [Sends trip alarm to SCADA via normally-open contact]
- ER (Event Trigger Equation) = … + /40Z1 + /40Z2 [To trigger an oscillography report when the element picks up. The "/" stands for rising edge, so it only triggers an event when it picks up, not when it drops out.]
- SET7 (Set Latch Bit 7) = 40Z1T+40Z2T [LT7 will be used to display a message on the front panel when the 40-Element operates]
- RST7 (Reset Latch Bit 7) = TRGTR [Target reset command must be applied to clear the message on front panel]
- ALIAS7 (Relay Word Bit Alias 7) = LT7 LOSS-OF-FIELD TRIPPED RESET [Renames LT7 as LOSS-OF-FIELD in the SER]
- DP7 (Display Point 7) = LT7 [To display a message on the front panel after 40-Element operates until a target reset command is issued to the relay]
- DP7_1 (Display Point 7 Label) = LOST FIELD TRIP [Message displayed on front panel after 40-Element operates until a target reset command is issued]
- DP7_0 (Display Point 7 Label) = NA [No message unless a 40-Element operates]
- SER2 (Sequential Events Recorder 2) = … ,40Z1,40Z1T,40Z2,40Z2T,40ZTC,LT7

G. Unbalance Overcurrent (46) Settings

Unbalanced currents flowing through a generator will cause eddy currents to flow in the generator stator and the generator will overheat quickly. Unbalanced current can be caused by stator mismatch inside the generator, but it is usually caused by a problem in the power system.

The 46-Element monitors the generator neutral CT currents and calculates the percentage (I_2 x 100 / I_{Nom}) of negative-sequence current (I_2) to the generator nominal secondary current (I_{Nom}). One 46-Element should operate an alarm contact to warn the operators before another 46-Element operates the generator circuit breaker, which will isolate the generator from an unbalanced power system. The generator can be synchronized to the power system immediately after the unbalance is corrected.

a) 46-Alarm Settings

The 46-Alarm pickup setting should be set at 5% [I_2 x 100 / I_{Nom}] to warn the operators that the generator current is unbalanced, which will allow them to troubleshoot the problem before the 46-Trip isolates the generator from the power system.

The 46-Alarm should operate the normally-closed (NC) SCADA alarm contact if an unbalanced-overcurrent is detected for longer than 30 seconds.

b) M-3425 46: Negative Sequence Overcurrent Definite Time Settings

The 46-Definite-Time Element settings will create the 46-Alarm characteristic and should have the following settings:

- Pickup = 5%
- Time Delay = 1,800 cycles [30s x 60Hz]
- Outputs = 7 [Opens the NC Alarm contact via the Output 7 NC contacts on the relay]
- Blocking Inputs = N/A [Not required by the application]

c) SEL-300G 46 Element Level 1 Settings

The Level 1 Neg-Seq Overcurrent settings will create the 46-Alarm characteristic and should have the following settings

- E46 (Enable Neg-Seq Overcurrent (O/C) Protection) = Y [Turns 46-Elements on]
- 46Q1P (Level 1 Neg.-Seq. O/C Pickup) = 5%
- 46Q1D (Level 1 Neg.-Seq. O/C Time Delay) = 30.00 seconds
- 46QTC (46 Element Torque Control) = 1 [The 46-Elements should always be ON]

- OUT107 (Output Contact 107) = !24D1T*!46Q1T [The NOT(!) added in front of Word Bits with AND in between them should turn the OUT107 physical NO contact into a functional NC contact]
- ER (Event Trigger Equation) = … + /46Q1 [To trigger an oscillography report when the element picks up. The "/" stands for rising edge, so it only triggers an event when it picks up, not when it drops out.]
- DP4 (Display Point 4) = 46Q1 [Message appears on front panel only when 46-Alarm is currently active]
- DP4_1 (Display Point 4 Label) = UNBAL O/C ALARM [Message displayed on front panel when 46-Alarm is currently active]
- DP4_0 (Display Point 1 Label) = NA [No message unless a 46-Alarm is active]
- SER2 (Sequential Events Recorder 2) = … ,46Q1
- SER3 (Sequential Events Recorder 3) = 46Q1T,46QTC

d) 46-Trip Settings

The generator manufacturer specified the following unbalance characteristic, as depicted in Section 2 of this document:

Output and Allowable Load Unbalance

Continuous Load Unbalance – Permissible I2	10%
Short Time ($K=I2^2t$)	30

Therefore, the 46-Trip pickup setting should be 9%, and the $I2^2T$ setting should be 28 to ensure the generator is isolated from the power system before the generator can be damaged by unbalance currents.

e) M-3425 46: Negative Sequence Overcurrent Inverse Time Settings

The 46-Inverse-Time Element settings will create the 46-Inverse Trip characteristic and should have the following settings:

- Pickup = 9% [Less than manufacturer's 10% specification]
- Time Dial = 28 [Less than manufacturer's 30 specification]
- Maximum Time = 65,500 cycles [Set at maximum available setting because 46-Trip settings are below the manufacturer's published damage curve]
- Reset Rate = 240 seconds [The 46-Element is really an indirect method to measure heat inside the generator, which cannot be dissipated instantaneously. This setting creates a thermal memory function that will trip faster unless 240 seconds elapse between unbalance overcurrent events.]

- Outputs = 1, 3 [Output 1 trips the generator circuit breaker. Output 3 sends a normally-open SCADA trip alarm to the operators]
- Blocking Inputs = N/A [Not required by the application]

f) SEL-300G 46 Element Level 2 Settings

The Level 2 Neg-Seq Overcurrent settings will create the 46-Trip characteristic and should have the following settings:

- E46 (Enable Neg-Seq Overcurrent (O/C) Protection) = Y [Turns 46-Elements on]
- 46Q2P (Level 2 Neg.-Seq. Time-O/C Pickup) = 9% [Less than manufacturer's 10% specification]
- 46Q2K (Level 2 Neg.-Seq. Time-O/C Time Dial) = 28 [Less than manufacturer's 30 specification]
- 46QTC (46 Element Torque Control) = 1 [The 46-Elements should always be ON]
- TR1 (Trip Equation 1) = … + 46Q2T
- OUT101 (Output Contact 101) = TRIP1 [Trips the generator circuit breaker]
- OUT103 (Output Contact 103) = TRIP1+TRIP2 [Sends trip alarm to SCADA via NO contact]
- ER (Event Trigger Equation) = … + /46Q2 [To trigger an oscillography report when the element picks up. The "/" stands for rising edge, so it only triggers an event when it picks up, not when it drops out.]
- SET8 (Set Latch Bit 8) = 46Q2T [LT8 will be used to display a message on the front panel when the 46-Trip operates]
- RST8 (Reset Latch Bit 8) = TRGTR [Target reset command must be applied to clear the message on front panel]
- ALIAS8 (Relay Word Bit Alias 8) = LT8 UNBALANCE_OC TRIPPED RESET [Renames LT8 as UNBALANCE_OC in the SER]
- DP8 (Display Point 8) = LT2 [Message appears on front panel after 46-Trip operates, which will stay on until a target reset command is issued to the relay]
- DP8_1 (Display Point 8 Label) = UNBAL O/C TRIP [Message displayed on front panel after 46-Trip operates, which will stay on until a target reset command is issued]
- DP8_0 (Display Point 8 Label) = NA [No message unless a 46-Trip operates]
- SER3 (Sequential Events Recorder 3) = 46Q1T,46QTC,46Q2,46Q2R,46Q2T,LT8

H. Breaker-Failure (50BF) Protection

Breaker-Failure (50BF) elements operate when the generator circuit breaker has been sent a trip command but the circuit breaker-fails to open. The Breaker-Failure (50BF) element will then isolate the generator from the power system by sending a trip signal to all circuit breakers connected to the generator circuit breaker.

The generator 50BF-Element in this application will monitor the generator circuit breaker status via a 52b contact connected to a generator relay input and/or current flowing above the a 0.25A overcurrent setpoint from the CTs installed on the generator circuit breaker.

The Breaker-Failure scheme monitors all trip commands though internal logic. Any trip will start a Breaker-Failure (50BFD) Timer when a trip command is sent to the generator circuit breaker while the 50BF-Element thinks the generator circuit breaker is closed (via 52b and/or current).

The Breaker-Failure timer is set at 12 cycles, which is greater than the expected generator circuit breaker opening time [3.00 cycles] plus an additional fudge factor for unforeseen circumstances. If the circuit breaker opens before the 50BF timer expires [12.00 cycles], the 50BF-Element protection resets to zero. If the 50BF timer expires before the generator circuit breaker opens, the 50BF-Element will operate a breaker-fail lockout relay that will send trip commands to all the circuit breakers connected to the generator circuit breaker.

The following settings should be applied to the relays to ensure these conditions are met:

a) M-3425A 50BF: Breaker Failure Settings

The 50BF-Element settings should follow the 50BF-Element characteristics described earlier:

- Phase Current Pickup = 0.25A
- Phase Current Select = Enable
- Phase Current Pickup = N/A [Not required by the application]
- Phase Current Select = Disable [Not required by the application]
- Time Delay = 12 cycles
- Output Initiate = 1, 2 , 3 [All trips should operate Outputs 1 , 2, or 3, which will start the 50BF Timer]
- Input Initiate = N/A [Not required by the application]
- Outputs = 5 [Output 5 trips the Breaker-Fail Lockout Relay]
- Blocking Input(s) = N/A [Nothing should block the Breaker-Fail protection]

b) SEL-300G 50BF Breaker Failure Settings

The SEL-300G relay does not have a dedicated 50BF-Element. The following settings will apply the Breaker-failure scheme described earlier:

- E50_87 (Enable 87-Input O/C Protection) = Y [Turns 50-Element protection from generator circuit breaker CTs to use for circuit breaker status detection using current]
- 50H1P (Level 1 Phase O/C Pickup) = 0.25A [50H1 will turn ON if any phase current flowing through the circuit breaker is greater than 0.25A]
- SV9 (SELogic Variable 9) = (TRIP) * (52A + 50H1) [SV9 will only turn ON if TRIP1 OR TRIP2 OR TRIP3 OR TRIP4 operates AND the generator circuit breaker is closed, which is detected if the 52b contact in the generator circuit breaker is open (52A = !IN101) OR any phase current flowing through the circuit breaker is greater than 0.25A secondary (0.25 x 1600:1 = 400A primary)]
- SV9PU (SV9 Pickup Time) = 0.200 seconds [SV9T will turn ON if SV9 is ON for 12 cycles (12 cycles / 60 Hz)]
- SV9DO (SV9 Dropout Time) = 0.00 seconds [SV9T will turn OFF immediately after SV9 turns OFF]
- OUT105 (Output Contact 105) = SV9T [Trips G1 Breaker-fail Relay, which will trip all circuit breakers connected to 52G1 (52G2, 52G3, 52L1)]
- ER (Event Trigger Equation) = … + /SV9T [To trigger an oscillography report when the element picks up. The "/" stands for rising edge, so it only triggers an event when it picks up, not when it drops out.]
- SET9 (Set Latch Bit 9) = SV9T [LT9 will be used to display a message on the front panel when the 50BF-Trip operates]
- RST9 (Reset Latch Bit 9) = TRGTR [Target reset command must be applied to clear the message on front panel]
- ALIAS9 (Relay Word Bit Alias 9) = LT9 BREAKER_FAIL TRIPPED RESET [Renames LT9 as BREAKER_FAIL in the SER]
- DP9 (Display Point 9) = LT9 [A message will appear on front panel after the 50BF-Trip operates, which will stay on until a target reset command is issued to the relay]
- DP9_1 (Display Point 9 Label) = BREAKER-FAIL TR [Message displayed on front panel after 50BF-Trip operates, which will stay on until a target reset command is issued]
- DP9_0 (Display Point 9 Label) = NA [No message unless a 50BF-Trip operates]
- SER3 (Sequential Events Recorder 3) = … ,50H1,TRIP,SV9,SV9T,LT9

I. Inadvertent-Energization (50/27) Protection

This element is used to protect the generator when it is offline and the generator circuit breaker closes unintentionally, which will turn the generator into a poorly designed induction motor.

The transformer impedances between the power system and the generator will limit the inrush current created when the generator tries to instantaneously speed up to the system frequency, but the inrush current could be up to 4x the nominal current. The sudden inrush current and torque on the generator shaft could damage the generator windings and prime mover as the generator motors to rated speed.

The 50/27-Element uses the generator PTs to measure the generator terminal voltage and CTs installed in the generator circuit breaker to measure the current flowing through the generator circuit breaker. The 50/27-Element considers the generator to be offline and arms itself after the generator terminal voltage drops below its Under-Voltage (27) setpoint AND the current drops below a setpoint AND a short time delay passes. If the generator is started normally, the generator voltage will rise above its Under-Voltage (27) setpoint for a significant amount of time and the 50/27-Element will disarm itself. The generator can then be synchronized and generate current without tripping the 50/27-Protection.

If the generator circuit breaker closes while the generator is offline, current and voltage will be applied simultaneously as the generator attempts to motor to rated speed. The 50/27-Element assumes that current and voltage applied simultaneously when the generator is considered offline is an inadvertent-energization condition and will send a trip signal to the generator circuit breaker.

The IEEE recommended 50/27-Element settings are:

- The offline Under-Voltage (27) element pickup should be 50% of the generator nominal voltage with a time delay longer than the system fault clearing time (typically 1.5s).
- The generator is considered online if the voltage rises above the previous pickup setting [with no corresponding current] for a short period of time (typically 15 cycles).
- The overcurrent setpoint should be ≤ 50% of the worst-case calculated starting current.

The overcurrent element used to arm the 50/27-Protection and detect the inadvertent-energization inrush will be set at the lowest possible setting to ensure the 50/27-Element operates even if the inrush current is low during an inadvertent-energization condition.

The 50/27-Element protection should be disabled if a PT problem is detected to prevent mis-operations when in-service.

The following settings should be applied to the relays to ensure these conditions are met:

a) M-3425A 50/27: Inadvertent Energizing Settings

- (50) Overcurrent Pickup = 0.50A [Minimum allowable setting]
- (27) Undervoltage Pickup = 57V [One-half of nominal generator voltage (0.5 x 115.0V = 57.5V). Rounded down because relay only allows one decimal place.)
- (27) Undervoltage Pick-up Delay = 90 cycles [1.5s x 60Hz]
- (27) Undervoltage Drop-out Delay = 15 cycles
- Outputs = 1, 3 [Output 1 trips the generator circuit breaker. Output 3 sends a normally-open SCADA trip alarm to the operators]
- Blocking Input(s) = FL [FL will block the element if a fuse problem is detected]

b) SEL-300G Inadvertent Energization Settings

- E50_87 (Enable 87-Input O/C Protection) = Y [Turns 50-Element protection from generator circuit breaker CTs to use for circuit breaker status detection using current]
- 50H1P (Level 1 Phase O/C Pickup) = 0.25A [50H1 will turn ON if any phase current flowing through the circuit breaker is greater than 0.25A]
- E27 (Enable Undervoltage (U/V) Protection) = Y [Turns 27-Protection On]
- 27V1P (Pos.-Seq. U/V Pickup) = 33.2V [Sets the positive-sequence voltage the 50/27-Element will use to determine if the generator is de-energized. It should be one-half of the generator nominal voltage. Most positive-sequence voltages are expressed in P-N terms, so the setting calculation should determine the P-N voltage (0.5 x 115.0V / √3). The relay tester should verify that the 50/27-Element is armed when all three voltages are less than 57.5V (115.0V / 2)]
- SV10 (SELogic Variable 10) = !50H1*27V1*!60LOP [SV10 will only turn ON if no phase current flowing through the circuit breaker is greater than 0.25A secondary (0.25 x 1600:1 = 400A primary) AND the all P-P generator voltages are less than $57.5V_{P-P}$ AND no PT problems are detected. SV10T will be used to arm the 50/27-Protection.]
- SV10PU (SV10 Pickup Time) = 1.50 seconds [SV10T will turn ON and arm the 50/27-Protection if SV10 is ON for 1.5 seconds]
- SV10DO (SV10 Dropout Time) = 0.25 seconds [SV10T will turn OFF 0.25 seconds after SV10 turns OFF, which will disarm the 50/27-Protection after the generator is energized normally]
- INAD (Inadvertent Energization) = SV10T * 50H1 [The 50/27-Protection will operate if the 50/27-Protection is armed (current less than 0.25A and voltage below $57.5V_{P-P}$ for longer than 1.5 seconds) and then a current greater than 0.25A is detected, which indicates an inadvertent-energization condition]
- INADPU (Inadvertent Energization PU Time) = 0.00 seconds [the 50/27-Protection will operate with no intentional time delay]

- INADDO (Inadvertent Energization DO Time) = 0.10 seconds [The 50/27-Protection will stay ON and latched for 0.10 seconds after a inadvertent-energization event is detected to ensure that there isn't a race between the !50H1 in SV10 and the 50H1 in the INAD logic]
- TR1 (Trip Equation 1) = … + INADT
- SET10 (Set Latch Bit 10) = INADT [LT10 will be used to display a message on the front panel when the 50/27-Trip operates]
- RST10 (Reset Latch Bit 10) = TRGTR [Target reset command must be applied to clear the message on front panel]
- ALIAS10 (Relay Word Bit Alias 10) = LT10 INAD_ENERGIZED TRIPPED RESET [Renames LT10 as INAD_ENERGIZED in the SER]
- DP10 (Display Point 10) = LT10 [A message will appear on front panel after the 50/27-Trip operates, which will stay on until a target reset command is issued to the relay]
- DP10_1 (Display Point 10 Label) = INAD_ENERGZ TRIP [Message displayed on front panel after 50/27-Trip operates, which will stay on until a target reset command is issued]
- DP10_0 (Display Point 10 Label) = NA [No message unless a 50BF-Trip operates]
- SER3 (Sequential Events Recorder 3) = … ,27V1,SV10,SV10T,INAD,INADT,LT10

J. Phase Undervoltage (59) Protection

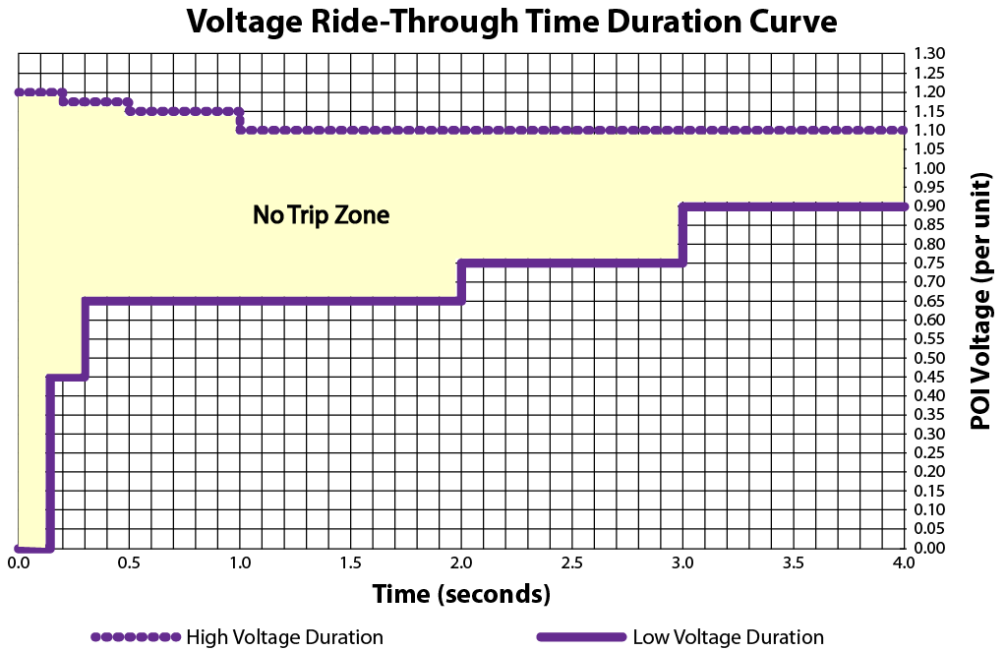
Generators are designed to operate within specific voltage, frequency, power factor, and load characteristics. A generator voltage higher than the nominal generator voltage could stress the generator insulation or over-excite the generator, which will cause stator overheating and damage.

The 59-Element monitors the generator terminal voltage through the generator PTs and typically operates the generator circuit breaker to isolate the generator from a power system voltage that may be higher than the generator characteristics.

The IEEE recommends the following settings with two definite-time elements:

- Stage 1 set at 110% of the nominal generator voltage with a 10-to-15-second time delay.
- Stage 2 set at 150% of the nominal generator voltage with a 2-to-5-cycle time delay.

These settings are compatible with the NERC standards, which have the following requirements:



Therefore, the 59-Element settings for this application should be:

- 59D1-Pickup at 110% of the nominal generator voltage (115V) with a 10.00-second time delay.
- 59D2-Pickup at 150% of the nominal generator voltage (115V) with a 2-cycle time delay.

Any 59-Trip should open the generator circuit breaker and send a normally-open alarm signal to the operators.

The following settings should be applied to the relays to ensure these conditions are met:

a) M-3425A 59#1 Phase Undervoltage Settings

The 59#1-Element settings should follow the 59-D1-Element characteristics described earlier:

- Pickup = 127V [Nominal voltage x 110% = 115.00V x 1.10 = 126.50V. Setting was rounded up to 127V to keep the pickup value above the NERC required pickup level and because the relay setting does not have decimal points.]
- Time Delay = 600 cycles [60.00Hz x 10.00s]
- Outputs = 1, 3 [Output 1 trips the generator circuit breaker. Output 3 sends a normally-open SCADA trip alarm to the operators]
- Blocking Input(s) = N/A [No blocking functions are required]

b) M-3425A 59#2 Phase Undervoltage Settings

The 59#2-Element settings should follow the 59-D2-Element characteristics described earlier:

- Pickup = 172V [Nominal voltage x 150% = 115.00V x 1.50 = 172.50. Setting was rounded down because the relay does not allow decimal points for this setting.]
- Time Delay = 2 cycles
- Outputs = 1, 3 [Output 1 trips the generator circuit breaker. Output 3 sends a normally-open SCADA trip alarm to the operators.]
- Blocking Input(s) = N/A [No blocking functions are required]

c) SEL-300G 59 Element Settings - 59PP1

The 59PP1-Element settings should follow the 59-D1-Element characteristics described earlier:

- E59 (Enable Overvoltage (O/V) Protection) = Y [Turns 59-Protection On]
- 59PP1 (Level 1 Phase-phase O/V Pickup) = 127.0V [Nominal voltage x 110% = 115.00V x 1.10 = 126.50V. Setting was rounded up to 127V to keep the pickup value above the NERC required pickup level.]
- SV11 (SELogic Variable 11) = 59PP1 [SV11 will only turn ON if any phase-phase (P-P) voltage is greater than 127.0V)]
- SV11PU (SV11 Pickup Time) = 10.00 seconds [SV11T will turn ON if SV11 is ON for 10.00 seconds]
- SV11DO (SV11 Dropout Time) = 0.00 seconds [SV11T will turn OFF immediately after SV11 turns OFF]
- TR1 (Trip Equation 1) = …+ SV11T
- OUT101 (Output Contact 101) = TRIP1 [Trips the generator circuit breaker]
- OUT103 (Output Contact 103) = TRIP1+TRIP2 [Sends trip alarm to SCADA via NO contact]
- ER (Event Trigger Equation) = … + /59PP1 [To trigger an oscillography report when the element picks up. The "/" stands for rising edge, so it only triggers an event when it picks up, not when it drops out.]
- SET11 (Set Latch Bit 11) = SV11T [LT11 will be used to display a message on the front panel when the 59D1-Trip operates]
- RST11 (Reset Latch Bit 11) = TRGTR [Target reset command must be applied to clear the message on front panel]
- ALIAS11 (Relay Word Bit Alias 11) = LT11 OVER_VOLT TRIPPED RESET [Renames LT11 as OVER_VOLT in the SER]
- DP11 (Display Point 11) = LT11 [A message will appear on front panel after the 59D1-Trip operates, which will stay on until a target reset command is issued to the relay]
- DP11_1 (Display Point 11 Label) = OVER-VOLT TRIP [Message displayed on front panel after 59D1-Trip operates, which will stay on until a target reset command is issued]
- DP11_0 (Display Point 11 Label) = NA [No message unless a 59D1-Trip operates]
- SER3 (Sequential Events Recorder 3) = …,59PP1,SV11,SV11T,LT11

d) SEL-300G 59 Element Settings - 59PP2

The 59PP2-Element settings should follow the 59-D2-Element characteristics described earlier:

- E59 (Enable Overvoltage (O/V) Protection) = Y [Turns 59-Protection On]
- 59PP2 (Level 2 Phase-phase O/V Pickup) = 172.5V [Nominal voltage x 150% = 115.00V x 1.50 = 172.50V]
- SV12 (SELogic Variable 12) = 59PP2 [SV12 will only turn ON if any P-P voltage is greater than 172.5V]
- SV12PU (SV12 Pickup Time) = 0.03 seconds [SV12T will turn ON if SV12 is ON for 0.03 seconds (2 cycles / 60Hz)]
- SV12DO (SV12 Dropout Time) = 0.00 seconds [SV12T will turn OFF immediately after SV12 turns OFF]
- TR1 (Trip Equation 1) = …+ SV12T
- OUT101 (Output Contact 101) = TRIP1 [Trips the generator circuit breaker]
- OUT103 (Output Contact 103) = TRIP1+TRIP2 [Sends trip alarm to SCADA via NO contact]
- ER (Event Trigger Equation) …+ /59PP2 [To trigger an oscillography report when the element picks up. The "/" stands for rising edge, so it only triggers an event when it picks up, not when it drops out.]
- SET11 (Set Latch Bit 11) = SV11T + SV12T [LT12 will be used to display a message on the front panel when the 59D2-Trip operates]
- RST11 (Reset Latch Bit 12) = TRGTR [Target reset command must be applied to clear the message on front panel]
- ALIAS11 (Relay Word Bit Alias 11) = LT11 OVER_VOLT TRIPPED RESET [Renames LT12 as OVER_VOLT in the SER]
- DP11 (Display Point 11) = LT11 [A message will appear on front panel after the 59D2-Trip operates, which will stay on until a target reset command is issued to the relay]
- DP11_1 (Display Point 11 Label) = OVER-VOLT TRIP [Message displayed on front panel after 59D2-Trip operates, which will stay on until a target reset command is issued]
- DP11_0 (Display Point 11 Label) = NA [No message unless a 59D2-Trip operates]
- SER3 (Sequential Events Recorder 3) = …59PP2,SV12,SV12T

K. Neutral Overvoltage (59N or 64G1) Protection Settings

The application has a high-impedance Neutral Grounding Transformer (NGTX) inserted between the generator neutral terminals and ground. Any ground fault in the generator stator or power system will create a ground current through the NGTX. The 59N-Element is connected across the NGTX secondary terminals and will operate if the ground current flowing through the impedance creates a voltage greater than its setpoint.

The 59N-Element typically operates the generator circuit breaker to isolate the generator or power system from the ground fault. It should also operate the generator field circuit breaker and send a shutdown signal to the prime mover to stop the generator from feeding into a ground fault located inside the generator.

The IEEE recommends a Neutral Over-Voltage scheme with a pickup setting that will protect 95% of the stator (typically > 5.00V) with a time delay (typically 5 seconds) that should coordinate with other system protective devices (such as PT fuses, power system ground protection, or buss ground protection).

A phase-ground fault on one of the generator terminals will apply 100% of the generator's nominal phase-ground voltage across the NGTX, which would be 7,967.43V [13,800 / √3] across the NGTX primary winding. The NGTX secondary voltage would be 250.94V (7967.43V / 31.75) because the NGTX has a 31.75:1 transformer ratio. A ground fault located 5% away from the generator neutral voltage will produce 5% of the voltage at the generator terminals, or 12.55V [250.94V x 0.05]. Therefore, the 59N-Pickup setting should be 12.55V. Any stator ground fault from the generator output terminals to 95% of the winding will cause the 59N-Element to trip the generator lockout relay. Any faults in the last 5% of the winding not protected by the 59N-Element should trip the 100% Stator Earth (27TH, 27TN, 64G2) protection.

The 59N-Element should have a 5.00-second time delay to follow the IEEE recommendations and coordinate with other protection.

The following settings should be applied to the relays to ensure these conditions are met:

a) M-3425A 59N: Neutral Overvoltage Settings

The 59N-Element is identified as 59N in the M-3425A relay, which should have the following settings:

- Pickup = 12.6V [12.55V rounded up because the relay only allows one decimal place]
- Time Delay = 300 cycles [60.00Hz x 5.00s]
- Outputs = 2, 3 [Output 2 trips the generator lockout relay. Output 3 sends a normally-open SCADA trip alarm to the operators]
- Blocking Input(s) = N/A [No additional blocking logic should be applied]
- 20Hz Injection Mode = Disable [Not required by the application]

b) SEL-300G 64G Element Settings – 64G1

The 59N-Element is identified as 64G1 in the SEL-300G relay, which should have the following settings:

- E64 (Enable 100% Stator Ground Protection) = Y [Turns 59N-Protection On]
- 64G1P (Zone 1 Neutral O/V Pickup) = 12.6V [12.55V rounded up because the relay only allows one decimal place]
- 64G1D (Zone 1 Time Delay) = 5.00s
- 64GTC (64G Element Torque Control) = 1 [The 59N-Element (64G1) should always be on]
- TR2 (Trip Equation 2) = … +64G1T
- OUT102 (Output Contact 102) = TRIP2 [Trips the generator lockout relay]
- OUT103 (Output Contact 103) = TRIP1 + TRIP2 [Sends trip alarm to SCADA]
- ER (Event Trigger Equation) = … + /64G1 [To trigger an oscillography report when the element picks up. The "/" stands for rising edge, so it only triggers an event when it picks up, not when it drops out.]
- SET5 (Set Latch Bit 5) = … + 64G1T [LT5 will be used to display a message on the front panel when the 59N-Trip operates]
- RST5 (Reset Latch Bit 5) = TRGTR [Target reset command must be applied to clear the message on front panel]
- ALIAS5 (Relay Word Bit Alias 5) = LT5 STATOR_FAULT TRIPPED RESET [Renames LT5 as STATOR_FAULT in the SER]
- DP5 (Display Point 5) = LT5 [A message will appear on front panel after the 59N-Trip operates, which will stay on until a target reset command is issued to the relay]
- DP5_1 (Display Point 5 Label) = STATOR FAULT TR [Message displayed on front panel after 59N-Trip operates, which will stay on until a target reset command is issued]
- DP5_0 (Display Point 5 Label) = NA [No message unless a 59N-Trip operates]
- SER4 (Sequential Events Recorder 4) = 64G1,64G1T

L. Loss-of-Potential (60, 60FL, 60LOP) Settings

Many of the protective elements in a generator relay use voltage in their calculations, which can be a problem if the measured voltages are compromised by PT malfunctions, incorrect wiring that causes open and short circuits, PT cabinets left open after maintenance, PT fuses not installed, or PT fuse operations. Any of these problems can cause the protective elements to believe that the voltage is lower than it actually is, which usually indicates a problem that should trip the relay. The VT Fuse-Loss (60FL) / Loss-of-Potential (60LOP) protection is designed to detect any of these problems and then prevent any elements that use voltage in their calculations from operating when incorrect voltages are applied to the relay.

The operators should be warned when a 60-Element issue is detected so that they can correct the problem before a fault occurs and the relay is unable to isolate the fault because of a PT problem.

The following setting will warn the operators 30 seconds after the relays detect a PT fuse problem:

a) M-3425 60FL: VT Fuse Loss Detection Settings

- Time Delay = 1,800 cycles [30s x 60Hz]
- Three Phase Fuse Loss Detection = Enable
- Input Initiate = FL [Use internal 60FL detection instead of an external voltage balance relay]
- Outputs = 7 [Opens the NC Alarm contact via the Output 7 NC contacts on the relay]
- Blocking Inputs = N/A [Not required by the application]

b) SEL-300G 60-Alarm Settings

The SEL does not have dedicated settings for a 60-Alarm, and the 60LOP functionality turns ON whenever the generator is offline. The following settings are applied to create a normally-closed alarm that only operates when a PT problem is detected to prevent nuisance alarms under normal operating conditions.

- E27 (Enable Undervoltage (U/V) Protection) = Y [Turns 27-Protection On]
- 27V1P (Pos.-Seq. U/V Pickup) = 33.2V [Sets the positive-sequence voltage the 50/27-Element will use to determine if the generator is de-energized]
- 50LP (Load Detection Phase Pickup) = 0.25 [Set at lowest possible setting]
- SV2 (SELogic Variable 2) = 60LOP * (!27V1 + 50L) [SV2 will only turn ON if a PT problem is detected (60LOP) AND the generator is online (!27V1 OR 50L). The generator is considered online if the measured positive-sequence voltage is NOT smaller than 50% of the nominal generator voltage (27V1) OR the measured generator current is greater than 0.25A secondary (0.25A x 1600 = 400A primary).]
- SV2PU (SV2 Pickup Time) = 30 seconds [SV2T will turn ON if SV2 is ON for 30 seconds]
- SV2DO (SV2 Dropout Time) = 0.00 seconds [SV2T will turn OFF immediately after SV1 turns OFF]
- OUT107 (Output Contact 107) = !24D1T*!46Q1T*!SV2T [The NOT(!) added in front of Word Bits with AND in between them should turn the OUT107 physical NO contact into a functional NC contact]
- SV1 (SELogic Variable 1) = /60LOP [The ER equation is full, so SV1 will be used trigger an oscillography report]
- SV1PU (SV1 Pickup Time) = 0.00 seconds [SV1T will turn ON if SV1 is ON]
- SV1DO (SV1 Dropout Time) = 0.00 seconds [SV1T will turn OFF immediately after SV1 turns OFF]
- ER (Event Trigger Equation) = … +/SV1 [To trigger an oscillography report when the any element in SV1 picks up. The "/" stands for rising edge, so it only triggers an event when it picks up, not when it drops out.]
- DP12 (Display Point 12) = SV2 [Message appears on front panel only when 60-Alarm is currently active]
- DP12_1 (Display Point 12 Label) = PT PROBLEM ALARM [Message displayed on front panel when 60-Alarm is currently active]
- DP12_0 (Display Point 12 Label) = NA [No message unless a 60-Alarm is active]
- SER4 (Sequential Events Recorder 4) = ... ,60LOP, SV1

M. Out-Of-Step / Loss-Of-Synchronism (78) Protection Settings

The power system applies a rotating magnetic field inside the generator poles. The rotor follows the stator's rotating magnetic field via the interaction between the rotor's and stator's magnetic fields and is magnetically locked to the stator frequency. The angular difference between the rotor's and stator's magnetic fields changes with load, which means the rotor moves further ahead of the stator as the generator output increases. The rotor can momentarily lose the magnetic lock with the stator if:

- a fault close to the power plant overloads the generator, which can increase the rotor angle beyond stability limits,
- the system voltage drops too low and weakens the stator's magnetic field,
- the generator's excitation system is too weak to maintain the rotor's magnetic field,
- the impedance between the power system and the generator is too large to maintain a system lock, or
- a line switching operation causes problems between the generator and power system.

If the generator rotor loses its magnetic lock with the system, the rotor will turn at the prime mover's frequency instead of the power system's frequency, which will create large current swings and mechanical problems until the generator is isolated from the power system or the generator is irreparably damaged.

There are several different styles of Loss-of-Synchronism elements. All of them calculate an impedance characteristic with impedance blinders. The 78-Element uses the generator PT voltages and generator neutral CT currents to calculate impedance using Ohm's Law. If the measured impedance crosses one or more impedance characteristic(s) or blinder(s) within a preset amount of time, the 78-Element will operate the generator circuit breaker to isolate the generator from the power system.

The 78-Element settings will vary depending on the style of characteristic used, and they should be based on a stability study of the power system. The following conservative settings could be used in absence of a stability study:

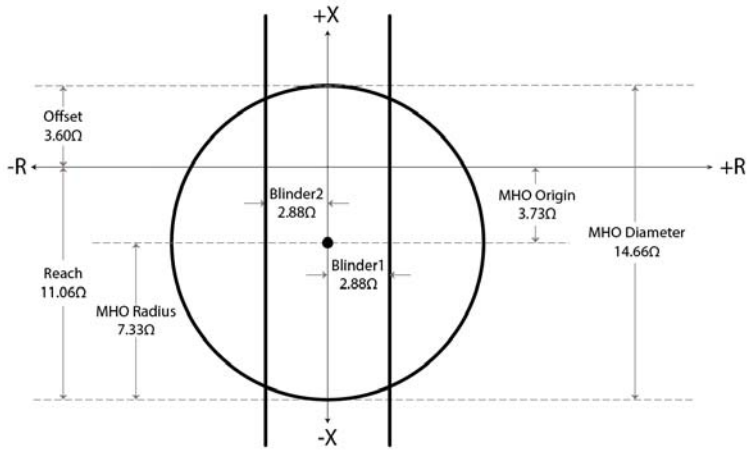
- MHO characteristic = 2 x X'_d + 1.5 x X_{TG} [Transformer Impedance]
- Blinder Distance = ((X'_d + X_{TG} + X_{maxSG1}[System Impedance])/2) x tan (90-(d/2)); where d is the angular separation between the generator and the system that the relay thinks will cause instability. If there is no stability study available, then set d = 120º.
- Time = 40.00 to 100.00ms.

The 78-MHO characteristics were calculated with the following formulas using the impedances previously calculated in this document:

- Transformer impedance from Section 3. C. = 2.40Ω
- Power system impedance from Section 3. D. = 2.03Ω @ 80°

<table>
<tr>
<td>Transient Reactance [XD'] in primary ohms:
$Z(\Omega) = 0.5 \times \frac{kV_{BASE}^{2} \times Z\%}{100 \times MVA_{BASE}}$
$Z(\Omega) = \frac{13.8^{2} \times 27.2}{100 \times 125}$
$Z(\Omega) = 0.41\Omega$</td>
<td>Transient Reactance [XD'] measured by the relay in secondary ohms:
$Z_{SEC}(\Omega) = \frac{Z_{PRI} \times CT\ Ratio}{PT\ Ratio}$
$Z_{SEC}(\Omega) = \frac{0.41\Omega \times 1600}{120}$
$Z_{SEC}(\Omega) = 5.53\Omega$</td>
</tr>
<tr>
<td>$Diameter = (2 \times X'_{d}) + (1.5 \times X_{TG})$
$Diameter = (2.00 \times 5.53\Omega) + (1.500 \times 2.40\Omega)$
$Diameter = 14.66\Omega$</td>
<td>$Offset = ((1.5\ to\ 2) \times X_{TG})$
$Offset = (1.5 \times 2.40\Omega)$
$Offset = 3.60\Omega$</td>
</tr>
<tr>
<td>$MHO\ Reach = -(Diameter - Offset)$
$MHO\ Reach = -(14.66 - 3.60)$
$MHO\ Reach = -11.06\Omega$</td>
<td>$MHO\ Center = -\left(\frac{Diameter}{2.00} - Offset\right)$
$MHO\ Center = -\left(\frac{14.66}{2.00} - 3.60\right)$
$MHO\ Center = -3.73\Omega$</td>
</tr>
<tr>
<td colspan="2">$Blinder = \frac{(X'd + Xt + Xs)}{2} \times \tan\left(90 - \left(\frac{120}{2}\right)\right)$
$Blinder = \frac{\left(X'd + Xt + \left(Zs \times \sin(\theta)\right)\right)}{2} \times \tan(90 - (60))$
$Blinder = \frac{\left(5.53\Omega + 2.40\Omega + \left(2.03\Omega \times \sin(80.00°)\right)\right)}{2} \times \tan(30)$
$Blinder = 2.88\Omega$</td>
</tr>
</table>

The 78-Element in this application will use the single blinder scheme, as shown in the following characteristic:



A 78-Element time delay setting will be replaced with functionality that prevents the 78-Element from tripping until the 78-Swing exits the impedance characteristic to minimize the clearing energy that will occur in the generator circuit breaker.

The following settings should be applied to the relays to ensure these conditions are met:

a) M-3425A 78: Out of Step Settings

- Circle Diameter = 14.7Ω [14.66Ω rounded up because the relay only allows one decimal place]
- Offset = -11.1Ω [The Offset setting in the M-3425A relay is the bottom of the 78-MHO circle, which is usually called the reach. The value was rounded up because the relay only allows one decimal place. The relay tester should verify that the top of the 78-MHO circle is +3.6Ω with the applied settings.]
- Blinder Impedance = 2.9Ω [The value was rounded up because the relay only allows one decimal place]
- Impedance angle = 90° [All calculations use X, which is at 90°]
- Pole Slip Counter = 1 [The 78-Element should trip during the first swing through the characteristic]
- Pole Slip Reset Time = 1 [Not required by the application]
- Time Delay = 1 [The minimum setting equals no intentional time delay]
- Trip on MHO exit = Enable [78-Element should not trip until it exits the 78-MHO characteristic
- Outputs = 1, 3 [Output 1 trips the generator circuit breaker. Output 3 sends a normally-open SCADA trip alarm to the operators]
- Blocking Input(s) = N/A [No additional blocking logic should be applied]

b) SEL-300G 78 Element Settings

- E78 (Enable Out-of-Step Protection) = 1B [Turns single blinder 78-Protection On]
- 78FWD (Forward Reach Reactance) = 11.1Ω [The forward reach setting in the SEL-300G relay is the bottom of the 78-MHO circle. The value was rounded up because the relay only allows one decimal place.]
- 78REV (Reverse Reach Reactance) = 3.6Ω [The reverse reach setting in the SEL-300G relay is the top of the 78-MHO circle]
- 78R1 (Right Hand Blinder) = 2.9Ω [The value was rounded up because the relay only allows one decimal place]
- 78L1 (Left Hand Blinder) = 2.9Ω [The value was rounded up]
- 78TD (Out-of-Step Trip Delay) = 0.00
- 78TDURD (Out-of-Step Trip Duration) = 0.00 [Not required for application]
- 50ABC (Pos. Seq. Current Supervision) = 0.25 [Not required for application, set at the minimum setting to ensure operation]
- OOSTC (78 Element Torque Control) = 1 [The 78-Element should always be ON]
- TR1 (Trip Equation 1) = … +OOST
- OUT101 (Output Contact 101) = TRIP1 [Trips the generator circuit breaker]
- OUT103 (Output Contact 103) = TRIP1 + TRIP2 [Sends trip alarm to SCADA via NO contact]
- SV1 (SELogic Variable 1) = … +/OOS [The ER equation is full, so SV1 will be used trigger an oscillography report]
- SV1PU (SV1 Pickup Time) = 0.00 seconds [SV1T will turn ON if SV1 is ON]
- SV1DO (SV1 Dropout Time) = 0.00 seconds [SV1T turns OFF when SV1 turns OFF]
- ER (Event Trigger Equation) = … +/SV1 [To trigger an oscillography report when the any element in SV1 picks up.]
- SET13 (Set Latch Bit 13) = … OOST [LT13 will be used to display a message on the front panel when the 78-Trip operates]
- RST13 (Reset Latch Bit 13) = TRGTR [Target reset command must be applied to clear the message on front panel]
- ALIAS13 (Relay Word Bit Alias 13) = LT13 OUT_OF_STEP TRIPPED RESET [Renames LT13 as OUT_OF_STEP in the SER]
- DP13 (Display Point 13) = LT13 [A message will appear on front panel after the 78-Trip operates, which will stay on until a target reset command is issued to the relay]
- DP13_1 (Display Point 13 Label) = OUT OF STEP TRIP [Message displayed on front panel after 78-Trip operates, which will stay on until a target reset command is issued]
- DP13_0 (Display Point 13 Label) = NA [No message unless a 78-Trip operates]
- SER4 (Sequential Events Recorder 4) = … OOS, OOST, OOSTC, LT13, 78R1, 78R2, 78Z1, SWING

N. Under-/Over-Frequency (81) Protection

Generators are designed to operate within specific voltage, frequency, power factor, and load characteristics. Abnormal frequencies usually occur when the delicate balance between load and generation in a power system is unbalanced. The generator frequency will decrease if the load requirements are greater than the available generation in the power system, and increase if the available generation is greater than the connected load.

Frequency protection is typically used to protect the prime mover instead of the generator because the blades in steam, water, or gas turbines can be damaged if they operate outside rigid frequency tolerances. The Under/Over-Frequency protection will operate the generator circuit breaker to isolate the generator from an abnormal system frequency so that the generator can be quickly re-synchronized when the problem is corrected.

The Under/Over-Frequency elements measure the generator terminal voltages through the generator PTs and could be set to match the generator characteristics supplied by the manufacturer (see below for specifications for this application) to ensure the prime mover is not damaged during abnormal frequency conditions:

- 59.40Hz to 60.50Hz = no adverse effect on blade life.
- 58.30Hz to 59.40Hz = potential damage in 100.0000 seconds.
- 60.50Hz to 61.80Hz = potential damage in 200.0000 seconds.
- <58.30Hz or >61.80Hz = potential damage in 10.0000 seconds.

NERC also has frequency protection specifications that must be met before the generator can be connected to the power system. The specifications for the Western Interconnection are:

Western Interconnection			
High Frequency Duration		Low Frequency Duration	
Frequency (Hz)	Time (Seconds)	Frequency (Hz)	Time (Seconds)
=> 61.7	Instantaneous Trip	<= 57.0	Instantaneous Trip
=> 61.6	30	<= 57.3	0.75
=> 60.6	180	<= 57.8	7.5
< 60.6	Continuous Operation	<= 58.4	30
		<= 59.4	180
		> 59.4	Continuous Operation

Therefore, the relays should be set with the following frequency protection settings that will only operate when the circuit breaker is closed to prevent nuisance trips during generator start-up and run-down:

- An Under-Frequency-Element (81U1) with a 58.40Hz pickup setting and 30s time delay.
- A 2nd Under-Frequency-Element (81U2) with a 57.80Hz pickup setting and 9.5s time delay.
- An Over-Frequency-Element (81O1) with a 60.60Hz pickup setting and 195s time delay.
- A 2nd Over-Frequency-Element (81O2) with a 61.65Hz pickup setting and 9.5s time delay.

All of the frequency elements will operate the generator circuit breaker to isolate the generator from the power system, which will allow the operators to re-synchronize the generator immediately after the frequency problem is corrected. A normally-open alarm signal should also be sent via the SCADA system.

a) M-3425A Under/Over Frequency Settings - 81#1

The M-3425A 81#1-Element settings should match the 81U1-Element described above:

- Pickup = 58.40Hz
- Time Delay = 1,800 cycles [30s x 60Hz]
- Outputs = 1, 3 [Output 1 trips the generator circuit breaker. Output 3 sends a normally-open SCADA trip alarm to the operators]
- Blocking Input(s) = 1 [The element will be blocked if the generator circuit breaker is open]

b) M-3425A Under/Over Frequency Settings - 81#2

The M-3425A 81#2-Element settings should match the 81U2-Element described above:

- Pickup = 57.80Hz
- Time Delay = 570 cycles [9.5s x 60Hz]
- Outputs = 1, 3 [Output 1 trips the generator circuit breaker. Output 3 sends a normally-open SCADA trip alarm to the operators]
- Blocking Input(s) = 1 [The element will be blocked if the generator circuit breaker is open]

c) M-3425A Under/Over Frequency Settings - 81#3

The M-3425A 81#3-Element settings should match the 81O1-Element described above:

- Pickup = 60.60Hz
- Time Delay = 11,700 cycles [195s x 60Hz]
- Outputs = 1, 3 [Output 1 trips the generator circuit breaker. Output 3 sends a normally-open SCADA trip alarm to the operators]
- Blocking Input(s) = 1 [The element will be blocked if the generator circuit breaker is open]

d) M-3425A Under/Over Frequency Settings - 81#4

The M-3425A 81#4-Element settings should match the 81O1-Element described above:

- Pickup = 61.65Hz
- Time Delay = 570 cycles [9.5s x 60Hz]
- Outputs = 1, 3 [Output 1 trips the generator circuit breaker. Output 3 sends a normally-open SCADA trip alarm to the operators]
- Blocking Input(s) = 1 [The element will be blocked if the generator circuit breaker is open]

e) SEL-300G 81 Element Settings

The SEL-300G 81-Element settings should be:

- E81 (Enable Frequency Protection) = 4 [Turns on four levels of 81-Element protection]
- 27B81P (Undervoltage Block) = 20V [Minimum voltage that must be measured before any of the 81-Elements operate to prevent nuisance trips. Set at the minimum value.]
- 81D1P (Level 1 Pickup) = 58.40Hz [81U1-Element setting]
- 81D1D (Level 1 Time Delay) = 30.00 seconds [81U1-Element setting]
- 81D2P (Level 2 Pickup) = 57.80Hz [81U2-Element setting]
- 81D2D (Level 2 Time Delay) = 9.50 seconds [81U2-Element setting]
- 81D3P (Level 3 Pickup) = 60.60Hz [81U3-Element setting]
- 81D3D (Level 3 Time Delay) = 195.00 seconds [81U3-Element setting]
- 81D4P (Level 4 Pickup) = 61.65Hz [81U4-Element setting]
- 81D4D (Level 4 Time Delay) = 9.50 seconds [81U4-Element setting]
- TR3 (Trip Equation 3) = (81D1T + 81D2T + 81D3T + 81D4T) * 52A [TR1 equation will not allow all of the characters for all of the 81-Elements. TRIP3 will operate when any 81-Element operates AND the generator circuit breaker is closed.]
- ULTR3 (Unlatch Trip Equation 3) = 3PO [TRIP3 will stay latched until the generator circuit breaker opens]
- OUT101 (Output Contact 101) = TRIP1 + TRIP3 [Trips the generator circuit breaker]
- OUT103 (Output Contact 103) = TRIP1+TRIP2 + TRIP3 [Sends trip alarm to SCADA via normally-open contact]
- SV1 (SELogic Variable 1) = … +/81D1+/81D2+/81D3+/81D4 [The ER equation is full, so SV1 will be used trigger an oscillography report]
- SV1PU (SV1 Pickup Time) = 0.00 seconds [SV1T will turn ON if SV1 is ON]
- SV1DO (SV1 Dropout Time) = 0.00 seconds [SV1T will turn OFF immediately after SV1 turns OFF]
- ER (Event Trigger Equation) = … +/SV1 [To trigger an oscillography report when the any element in SV1 picks up.]

- SET14 (Set Latch Bit 14) = (81D1T + 81D2T + 81D3T + 81D4T) * 52A [LT14 will be used to display a message on the front panel when any 81-Element trips while the generator circuit breaker is closed]
- RST14 (Reset Latch Bit 14) = TRGTR [Target reset command must be applied to clear the message on front panel]
- ALIAS14 (Relay Word Bit Alias 14) = LT14 FREQUENCY TRIPPED RESET [Renames LT14 as FREQUENCY in the SER]
- DP14 (Display Point 14) = LT14 [To display a message on the front panel after 81-Element operates until a target reset command is issued to the relay]
- DP14_1 (Display Point 14 Label) = O/U FREQUENCY TR [Message displayed on front panel after 81-Element operates until a target reset command is issued]
- DP14_0 (Display Point 14 Label) = NA [No message unless a 81-Element operates]
- SER4 (Sequential Events Recorder 4) = … 81D1,81D1T,81D2,81D2T,81D3,81D3T,81D4,81D4T,27B81,LT14

O. Phase Differential (87) Protection Settings

Differential relays create a zone of protection using CT inputs that measure the energy flowing into the zone and compare it to the energy leaving the zone. If there is a substantial difference between the two, the 87-Element assumes that there is a fault inside the zone of protection and will trip the generator circuit breaker, the generator field circuit breaker, and the generator lockout relay.

The application creates a zone of protection using the generator neutral CTs and the generator circuit breaker CTs. The differential protection should detect and trip during internal winding faults, but they should ignore external faults.

The IEEE recommends a 0.3A Minimum Pickup setting to prevent nuisance trips when low currents can create large percentage differences. The slope setting should be larger than the combined CT mismatch error (20%) using the relay's restraint current formula. There should be no intentional time delay unless CT saturation is expected during system transients.

The 87-Element should operate the generator lockout relay, which will:

- operate the generator circuit breaker to isolate the generator or power system from the fault,
- operatethe generator field circuit breaker, and
- send a shutdown signal to the prime mover to stop the generator from feeding into a ground fault located inside the generator.

The following settings should be applied to the relays to ensure these conditions are met:

a) M-3425A 87: Phase Differential Current Settings

- Pickup = 0.30A
- Time Delay = 1 cycle [Lowest possible setting that creates no intentional time delay]
- Percent Slope = 25% [Greater than 20%]
- Outputs = 2, 3 [Output 2 trips the generator lockout relay. Output 3 sends a normally-open SCADA trip alarm to the operators]
- Blocking Input(s) = N/A [No additional blocking logic should be applied]
- Phase CT Correction = 1.00 [Both CT inputs are connected to 1600:1 CTs]

b) SEL-300G 87 Element Settings

The 87-Element in the SEL-300G relay should have the following settings:

- E87 (Enable Differential Protection) = G [Turns 87-Protection On and sets it to expect no phase shift between CT inputs]
- TAP1 (Phase Input TAP Value) = 3.50 [Nominal generator current with 1600:1 CTs, as calculated in Section 5]
- TAPD (87 Input TAP Value) = 3.50 [Nominal generator current with 1600:1 CTs, as calculated in Section 5]
- U87P (Unrestrained Element Pickup, mult of TAP) = 10.0 [Can be any value because this element is not used]
- O87P (Restrained Element Pickup, mult of TAP) = 0.09 [Minimum pickup setting / TAP = 0.30A / 3.5A = 0.09A]
- SLP1 (Restraint Slope 1 Percentage) = 25% [Greater than 20%]
- 87B (Restrained Element Block) = 0 [Nothing should block 87-Element operation]
- TR2 (Trip Equation 2) = … + 87R
- OUT102 (Output Contact 102) = TRIP2 [Trips the generator lockout relay]
- OUT103 (Output Contact 103) = TRIP1 + TRIP2 + TRIP3 [Sends trip alarm to SCADA via NO contact]
- SV1 (SELogic Variable 1) = … +/87R [The ER equation is full, so SV1 will be used trigger an oscillography report]
- SV1PU (SV1 Pickup Time) = 0.00 seconds [SV1T will turn ON if SV1 is ON]
- SV1DO (SV1 Dropout Time) = 0.00 seconds [SV1T will turn OFF immediately after SV1 turns OFF]
- ER (Event Trigger Equation) = … +/SV1 [To trigger an oscillography report when the any element in SV1 picks up.]
- SET15 (Set Latch Bit 15) = … 87R [LT15 will be used to display a message on the front panel when the 87-Trip operates]
- RST15 (Reset Latch Bit 15) = TRGTR [Target reset command must be applied to clear the message on front panel]
- ALIAS15 (Relay Word Bit Alias 15) = LT15 DIFF_FAULT TRIPPED RESET [Renames LT15 as DIFFR_FAULT in the SER]
- DP15 (Display Point 15) = LT15 [A message will appear on front panel after the 87-Trip operates, which will stay on until a target reset command is issued to the relay]
- DP15_1 (Display Point 15 Label) = DIFFERENTIAL TR [Message displayed on front panel after 87-Trip operates, which will stay on until a target reset command is issued]
- DP15_0 (Display Point 15 Label) = NA [No message unless a 87-Trip operates]
- SER4 (Sequential Events Recorder 4) = … 87R,LT15

7. Display Settings

The following settings control what appears on the front panel displays

A. SEL-300G Global Settings

- FP-TO (Front Panel Time Out) = 15 minutes [to reset the front panel to the default displays if an operator leaves the display on a specific menu]
- DATE_F (Date Format) = MDY [to match the end-users standard]
- FP-I (Front Panel Current Display) = Y [One of the scrolling front panel messages should show the amount of current flowing through the generator neutral CT]
- FP-VPP (Front Panel Phase-to-Phase Voltage Display) = Y [One of the scrolling front panel messages should show the generator's phase-phase voltage]
- FP-MW (Front Panel Power Display) = Y [One of the scrolling front panel messages should show the generator's power metering values]
- FP-FR (Front Panel Frequency Display) = N [The generator frequency should not appear on the front panel's scrolling messages]
- FP-87 (Front Panel Current Differential Display) = Y [One of the scrolling front panel messages should show the generator's differential metering values]
- DP1 (Display Point 1) = LT1
- DP1_1 (Display Point 1 Label) = SYS BACKUP TRIP
- DP1_0 (Display Point 1 Label) = NA
- DP2 (Display Point 2) = LT2 [Message appears on front panel after 24-Trip operates, which will stay on until a target reset command is issued to the relay]
- DP2_1 (Display Point 2 Label) = V/HZ TRIPPED [Message displayed on front panel after 24-Trip operates, which will stay on until a target reset command is issued]
- DP2_0 (Display Point 2 Label) = NA [No message unless a 24-Trip operates]
- DP3 (Display Point 3) = LT3 [A message will appear on front panel after the 27D1-Trip operates, which will stay on until a target reset command is issued to the relay]
- DP3_1 (Display Point 3 Label) = UNDER-VOLT TRIP [Message displayed on front panel after 27D1-Trip operates, which will stay on until a target reset command is issued]
- DP3_0 (Display Point 3 Label) = NA [No message unless a 27D1-Trip operates]
- DP4 (Display Point 4) = 46Q1 [Message appears on front panel only when 46-Alarm is currently active]
- DP4_1 (Display Point 4 Label) = UNBAL O/C ALARM [Message displayed on front panel when 46-Alarm is currently active]
- DP4_0 (Display Point 1 Label) = NA [No message unless a 46-Alarm is active]
- DP5 (Display Point 5) = LT5 [A message will appear on front panel after the 27TH-Trip operates, which will stay on until a target reset command is issued to the relay]

- DP5_1 (Display Point 5 Label) = STATOR FAULT TR [Message displayed on front panel after 27TH-Trip operates, which will stay on until a target reset command is issued]
- DP5_0 (Display Point 5 Label) = NA [No message unless a 27TH-Trip operates]
- DP6 (Display Point 6) = LT6 [A message will appear on front panel after the 32-Trip operates, which will stay on until a target reset command is issued to the relay]
- DP6_1 (Display Point 6 Label) = REV POWER TRIP [Message displayed on front panel after 32-Trip operates, which will stay on until a target reset command is issued]
- DP6_0 (Display Point 6 Label) = NA [No message unless a 32-Trip operates]
- DP7 (Display Point 7) = LT7 [To display a message on the front panel after 40-Element operates until a target reset command is issued to the relay]
- DP7_1 (Display Point 7 Label) = LOST FIELD TRIP [Message displayed on front panel after 40-Element operates until a target reset command is issued]
- DP7_0 (Display Point 7 Label) = NA [No message unless a 40-Element operates]
- DP8 (Display Point 8) = LT2 [Message appears on front panel after 46-Trip operates, which will stay on until a target reset command is issued to the relay]
- DP8_1 (Display Point 8 Label) = UNBAL O/C TRIP [Message displayed on front panel after 46-Trip operates, which will stay on until a target reset command is issued]
- DP8_0 (Display Point 8 Label) = NA [No message unless a 46-Trip operates]
- DP9 (Display Point 9) = LT9 [A message will appear on front panel after the 50BF-Trip operates, which will stay on until a target reset command is issued to the relay]
- DP9_1 (Display Point 9 Label) = BREAKER-FAIL TR [Message displayed on front panel after 50BF-Trip operates, which will stay on until a target reset command is issued]
- DP9_0 (Display Point 9 Label) = NA [No message unless a 50BF-Trip operates]
- DP10 (Display Point 10) = LT10 [A message will appear on front panel after the 50/27-Trip operates, which will stay on until a target reset command is issued to the relay]
- DP10_1 (Display Point 10 Label) = INAD_ENERGZ TRIP [Message displayed on front panel after 50/27-Trip operates, which will stay on until a target reset command is issued]
- DP10_0 (Display Point 10 Label) = NA [No message unless a 50BF-Trip operates]
- DP11 (Display Point 11) = LT11 [A message will appear on front panel after the 59D1-Trip operates, which will stay on until a target reset command is issued to the relay]
- DP11_1 (Display Point 11 Label) = OVER-VOLT TRIP [Message displayed on front panel after 59D1-Trip operates, which will stay on until a target reset command is issued]
- DP11_0 (Display Point 11 Label) = NA [No message unless a 59D1-Trip operates]
- DP12 (Display Point 12) = SV2 [Message appears on front panel only when 60-Alarm is currently active]
- DP12_1 (Display Point 12 Label) = PT PROBLEM ALARM [Message displayed on front panel when 60-Alarm is currently active]
- DP12_0 (Display Point 12 Label) = NA [No message unless a 60-Alarm is active]

- DP13 (Display Point 13) = LT13 [A message will appear on front panel after the 78-Trip operates, which will stay on until a target reset command is issued to the relay]
- DP13_1 (Display Point 13 Label) = OUT OF STEP TRIP [Message displayed on front panel after 78-Trip operates, which will stay on until a target reset command is issued]
- DP13_0 (Display Point 13 Label) = NA [No message unless a 78-Trip operates]
- DP14 (Display Point 14) = LT14 [To display a message on the front panel after 81-Element operates until a target reset command is issued to the relay]
- DP14_1 (Display Point 14 Label) = O/U FREQUENCY TR [Message displayed on front panel after 81-Element operates until a target reset command is issued]
- DP14_0 (Display Point 14 Label) = NA [No message unless a 81-Element operates]
- DP15 (Display Point 15) = LT15 [A message will appear on front panel after the 87-Trip operates, which will stay on until a target reset command is issued to the relay]
- DP15_1 (Display Point 15 Label) = DIFFERENTIAL TR [Message displayed on front panel after 87-Trip operates, which will stay on until a target reset command is issued]
- DP15_0 (Display Point 15 Label) = NA [No message unless a 87-Trip operates]
- DP16 (Display Point 16) = 24D1 [Message appears on front panel only when 24-Alarm is currently active]
- DP16_1 (Display Point 1 Label) = V/HZ ALARM [Message displayed on front panel when 24-Alarm is currently active]
- DP16_0 (Display Point 1 Label) = NA [No message unless a 24-Alarm is active]

8. Event Recording Settings

The following settings are applied to give future personnel the most infomration possible when they are troubleshooting:

A. M-3425A Settings

a) Relay / Sequence of Events Recorder Settings

The following settings should be applied in the *Relay / Sequence of Events / Setup* menu to ensure future personnel have all the information they need when troubleshooting:

- Functions / Pickup Menu = 21 #1, 21 #2, 24DT #1, 24DT #2, 24 IT, 27 #1, 27 #2, 27TN #1, 32 #1, 40 #1, 40 #2 46 DT, 46 IT, 50BF, 50/27, 59 #1, 59 #2, 59N #1, 60FL, 78, 81 #1, 81 #2, 81 #3, 81 #4, 87 #1
- Functions / Trip Menu = 21 #1, 21 #2, 24DT #1, 24DT #2, 24 IT, 27 #1, 27 #2, 27TN #1, 32 #1, 40 #1, 40 #2 46 DT, 46 IT, 50BF, 50/27, 59 #1, 59 #2, 59N #1, 60FL, 78, 81 #1, 81 #2, 81 #3, 81 #4, 87 #1
- Functions / Dropout Menu = 21 #1, 21 #2, 24DT #1, 24DT #2, 24 IT, 27 #1, 27 #2, 27TN #1, 32 #1, 40 #1, 40 #2 46 DT, 46 IT, 50BF, 50/27, 59 #1, 59 #2, 59N #1, 60FL, 78, 81 #1, 81 #2, 81 #3, 81 #4, 87 #1
- Inputs Pickup = 1
- Inputs Drop = 1
- Outputs Pickup = 1, 2, 3, 5, 7
- Outputs Drop = 1, 2, 3, 5, 7

b) Relay / Setup Oscillograph Recorder Settings

The following selections should be made in the R*elay / Setup Oscillograph Recorder Settings Menu* to ensure future personnel have all the information they need when troubleshooting:

- Partitions = 3 Partitions: 208 Cycles
- Post Trigger Delay = 25%
- Trigger Inputs = N/A
- Trigger Outputs = 1, 2, 3, 5, 7

B. SEL-300G Settings

a) SEL-300G Global Settings

- LER (Length of Event Report) = 30 cycles [to record the most information during a fault, which is the maximum setpoint allowed]
- PRE (Length of Prefault in Event Report) = 4 cycles [to record some information about system conditions before the fault]
- BKMON (Breaker Monitor Input) = TRIP [to trigger the breaker monitoring logic whenever any SEL-300G trip signal is sent (TRIP1, TRIP2, TRIP3, or TRIP4)].
- COSP1 (Close/Open Set Point 1 - max) = 10000 [Default setting because the end user does not plan on using this feature]
- COSP2 (Close/Open Set Point 2 - mid) = 150 [Default setting because the end user does not plan on using this feature]
- COSP3 (Close/Open Set Point 3 - min) = 12 [Default setting because the end user does not plan on using this feature]
- KASP1 (kA Interrupted Set Point 1 - min) = 1.2 [Default setting because the end user does not plan on using this feature]
- KASP2 (kA Interrupted Set Point 2 - mid) = 8.0 [Default setting because the end user does not plan on using this feature]
- KASP3 (kA Interrupted Set Point 3 - max) = 20.0 [Default setting because the end user does not plan on using this feature]

b) SEL-300G Report Settings

- SER1 (Sequential Events Recorder 1) = 50L,IN101,52A,TRIP1,3PO,TRIP2,TR2,OUT101,OUT102,OUT103,OUT105,OUT107, 21P1P,21P1T,21PTC,LT1,21P2P,21P2T,24D1,24D1T,24TC,24C2,24C2T,24CR
- SER2 (Sequential Events Recorder 2) = LT2,27PP1,SV3,SV3T,LT3,27PP2,SV4,SV4T,64G2,64G2T,64GTC,LT5,32PTC,32P1,32P1T,LT6,40Z1,40Z1T,40Z2,40Z2T,40ZTC,LT7,46Q1
- SER3 (Sequential Events Recorder 3) = 46Q1T,46QTC,46Q2,46Q2R,46Q2T,LT8,50H1,TRIP,SV9,SV9T,LT9,27V1,SV10,SV10T,INAD,INADT,LT10,59PP1,SV11,SV11T,LT11,59PP2,SV12,SV12T
- SER4 (Sequential Events Recorder 4) = 64G1,64G1T,60LOP,SV1,OOS,OOST,OOSTC,LT13,78R1,78R2,78Z1,SWING,81D1,81D1T,81D2,81D2T,81D3,81D3T,81D4,81D4T,27B81,LT14,87R,LT15
- ALIAS1 (Relay Word Bit Alias 1) = LT1 SYS_BACKUP_TRIP TRIPPED RESET [Renames LT1 as SYS_BACKUP_TRIP in the SER]
- ALIAS2 (Relay Word Bit Alias 2) = 24D1T V_HZ_ALARM ACTIVE RESET [Renames 24D1T as V_HZ_ALARM in the SER]

- ALIAS3 (Relay Word Bit Alias 3) = LT3 UNDER_VOLT TRIPPED RESET [Renames LT3 as UNDER_VOLT in the SER]
- ALIAS4 (Relay Word Bit Alias 4) = N/A
- ALIAS5 (Relay Word Bit Alias 5) = LT5 STATOR_FAULT TRIPPED RESET [Renames LT5 as STATOR_FAULT in the SER]
- ALIAS6 (Relay Word Bit Alias 6) = LT6 REV_POWER TRIPPED RESET [Renames LT6 as REV_POWER in the SER]
- ALIAS7 (Relay Word Bit Alias 7) = LT7 LOSS-OF-FIELD TRIPPED RESET [Renames LT7 as LOSS-OF-FIELD in the SER]
- ALIAS8 (Relay Word Bit Alias 8) = LT8 UNBALANCE_OC TRIPPED RESET [Renames LT8 as UNBALANCE_OC in the SER]
- ALIAS9 (Relay Word Bit Alias 9) = LT9 BREAKER_FAIL TRIPPED RESET [Renames LT9 as BREAKER_FAIL in the SER]
- ALIAS10 (Relay Word Bit Alias 10) = LT10 INAD_ENERGIZED TRIPPED RESET [Renames LT10 as INAD_ENERGIZED in the SER]
- ALIAS11 (Relay Word Bit Alias 11) = LT11 OVER_VOLT TRIPPED RESET [Renames LT11 as OVER_VOLT in the SER]
- ALIAS12 (Relay Word Bit Alias 12) = N/A
- ALIAS13 (Relay Word Bit Alias 13) = LT13 OUT_OF_STEP TRIPPED RESET [Renames LT13 as OUT_OF_STEP in the SER]
- ALIAS14 (Relay Word Bit Alias 14) = LT14 FREQUENCY TRIPPED RESET [Renames LT14 as FREQUENCY in the SER]
- ALIAS15 (Relay Word Bit Alias 15) = LT15 DIFF_FAULT TRIPPED RESET [Renames LT15 as DIFFR_FAULT in the SER]
- ALIAS16 (Relay Word Bit Alias 16) = TRGTR TARGET_RESET PRESSED RELEASED

c) SEL-300G Group 1 Settings

- SET1 (Set Latch Bit 1) = 21P1T + 21P2T [LT1 will be used to display a message on the front panel when the 21-Element operates]
- RST1 (Reset Latch Bit 1) = TRGTR [Target reset command must be applied to clear the message on front panel]
- SET2 (Set Latch Bit 2) = 24C2T [LT2 will be used to display a message on the front panel when the 24-Trip operates]
- RST2 (Reset Latch Bit 2) = TRGTR [Target reset command must be applied to clear the message on front panel]
- SET3 (Set Latch Bit 3) = SV3T [LT3 will be used to display a message on the front panel when the 27D1-Trip operates]

- RST3 (Reset Latch Bit 3) = TRGTR [Target reset command must be applied to clear the message on front panel]
- SET4 (Set Latch Bit 4) = 0 [Not used by application]
- RST4 (Reset Latch Bit 4) = 0 [Not used by application]
- SET5 (Set Latch Bit 5) = 64G2T [LT5 will be used to display a message on the front panel when the 27TH-Trip operates]
- RST5 (Reset Latch Bit 5) = TRGTR [Target reset command must be applied to clear the message on front panel]
- SET6 (Set Latch Bit 6) = 32P1T [LT6 will be used to display a message on the front panel when the 27D1-Trip operates]
- RST6 (Reset Latch Bit 6) = TRGTR [Target reset command must be applied to clear the message on front panel]
- SET7 (Set Latch Bit 7) = 40Z1T+40Z2T [LT7 will be used to display a message on the front panel when the 40-Element operates]
- RST7 (Reset Latch Bit 7) = TRGTR [Target reset command must be applied to clear the message on front panel]
- SET8 (Set Latch Bit 8) = 46Q2T [LT8 will be used to display a message on the front panel when the 46-Trip operates]
- RST8 (Reset Latch Bit 8) = TRGTR [Target reset command must be applied to clear the message on front panel]
- SET9 (Set Latch Bit 9) = SV9T [LT9 will be used to display a message on the front panel when the 50BF-Trip operates]
- RST9 (Reset Latch Bit 9) = TRGTR [Target reset command must be applied to clear the message on front panel]
- SET10 (Set Latch Bit 10) = INADT [LT10 will be used to display a message on the front panel when the 50/27-Trip operates]
- RST10 (Reset Latch Bit 10) = TRGTR [Target reset command must be applied to clear the message on front panel]
- SET11 (Set Latch Bit 11) = SV11T [LT11 will be used to display a message on the front panel when the 59D1-Trip operates]
- RST11 (Reset Latch Bit 11) = TRGTR [Target reset command must be applied to clear the message on front panel]
- SET12 (Set Latch Bit 12) = 0 [Not used by application]
- RST12 (Reset Latch Bit 12) = 0 [Not used by application]
- SET13 (Set Latch Bit 13) = … OOST [LT13 will be used to display a message on the front panel when the 78-Trip operates]
- RST13 (Reset Latch Bit 13) = TRGTR [Target reset command must be applied to clear the message on front panel]

- SET14 (Set Latch Bit 14) = (81D1T + 81D2T + 81D3T + 81D4T) * 52A [LT14 will be used to display a message on the front panel when any 81-Element trips while the generator circuit breaker is closed]
- RST14 (Reset Latch Bit 14) = TRGTR [Target reset command must be applied to clear the message on front panel]
- SET15 (Set Latch Bit 15) = … 87R [LT15 will be used to display a message on the front panel when the 87-Trip operates]
- RST15 (Reset Latch Bit 15) = TRGTR [Target reset command must be applied to clear the message on front panel]
- SET16 (Set Latch Bit 16) = 0 [Not used by application]
- RST16 (Reset Latch Bit 16) = 0 [Not used by application]

9. Control and Logic Settings

A. M-3425A Settings

The following Elements, Outputs and Blocking Inputs should be applied to the relay:

Element	Outputs	Blocking Inputs
21 #1	1, 3	FL, 1
21 #2	1, 3	FL, 1
24DT #1	7	FL
24DT #2	1, 3	FL
24IT	1, 3	FL
27 #1	1, 3	FL, 1
27 #2	1, 3	FL, 1
27TN #1	2, 3	FL
32 #1	1, 3	FL
40 #1	1, 3	FL
40 #2	1, 3	FL
46 DT	7	
46IT	1, 3	
50BF	5	
50/27	1, 3	FL
59 #1	1, 3	
59 #2	1, 3	
59N #1	2, 3	
60FL	7	
78	1, 3	
81 #1	1, 3	1
81 #2	1, 3	1
81 #3	1, 3	1
81 #4	1, 3	1
87 #1	2, 3	

B. SEL-300G Settings

The following setting operate an output or perform some other control function:

a) SEL-300G Global Settings

- No Local Bits are used and they should all be disabled (NLB#, CLB#, SLB#, & PLB# = N/A)
- DCLOP (DC Battery Undervoltage) = 100V [80% of the nominal DC voltage to provide backup DC Alarm functions in case the battery charger alarm system fails. The DC Undervoltage Alarm will operate the normally-closed SCADA alarm contact (OUT107) if an DC undervoltage is detected for longer than 10s (600 cycles)].

b) DCHIP (DC Battery Undervoltage) = 150V [120% of the nominal DC voltage to provide backup DC Alarm functions in case the battery charger alarm system fails. The DC Overvoltage Alarm will operate the normally-closed SCADA alarm contact contact (OUT107) if an DC undervoltage is detected for longer than 10s (600 cycles)].

c) SEL-300G Group 1 Settings

- TDURD (Minimum Trip Duration) = 0.16 seconds [Seals in all trip outputs for a minimum of 0.16 seconds to prevent output contact chatter]
- TR1 (Trip Equations 1) = 21P1T+21P2T+24C2T+SV3T+SV4T+32P1T+40Z1T+40Z2T+46Q2T+SV9T+INADT+SV11T+SV12T+OOST [Should operate the generator circuit breaker trip coil and send alarm to SCADA]
- ULTR1 (Unlatch Trip Equation 1) = 3PO [TRIP3 will stay latched until the generator circuit breaker opens]
- TR2 (Trip Equations 1) = (64G2T*59V1)+64G1T+87R [Should operate the generator lockout relay and send alarm to SCADA]
- ULTR2 (Unlatch Trip Equation 2) = 3PO [Ensure the TRIP2 output stays latched until the problem disappears]
- TR3 (Trip Equations 3) = (81D1T+81D2T+81D3T+81D4T)*52A [Should operate the generator circuit breaker trip coil and send alarm to SCADA]
- ULTR3 (Unlatch Trip Equation 3) = 3PO [TRIP3 will stay latched until the generator circuit breaker opens]
- ER (Event Trigger Equation) = /21P1P+/21P2P+/24D1+/24C2+/27PP1+/27PP2+/64G2+/32P1+/40Z1+/40Z2+/46Q1+/46Q2+/SV9T+/59PP1+/59PP2+/64G1+/SV1 [To trigger an oscillography report when the element picks up]
- OUT101 (Output Contact 101) = TRIP1+TRIP3 [Trips the generator circuit breaker]
- OUT102 (Output Contact 102) = TRIP2 [Trips the generator lockout relay]
- OUT103 (Output Contact 103) = TRIP1+TRIP3 [Sends trip alarm to SCADA via normally-open contact]
- OUT104 (Output Contact 104) = 0 [Not used]

- OUT105 (Output Contact 105) = SV9T [Trips G1 Breaker-fail Relay, which will trip all circuit breakers connected to 52G1 (52G2, 52G3, 52L1)]
- OUT106 (Output Contact 106) = 0 [Not used]
- OUT107 (Output Contact 107) = !24D1T*!46Q1T*!SV2T [The NOT(!) added in front of Word Bits with AND in between them should turn the OUT107 physical NO contact into a functional NC contact]
- INAD (Inadvertent Energization) = SV10T * 50H1 [The 50/27-Protection will operate if the 50/27-Protection is armed (current less than 0.25A and voltage below 57.5V_{P-P} for longer than 1.5 seconds) and then a current greater than 0.25A is detected, which indicates an inadvertent-energization condition]
- ESV (Enable SELogic Variables) = 12 [Only 8 variables are used, but I wanted to keep the numbers between different logic elements consistent to make them easier to follow]
- SV1 (SELogic Variable 1) = /60LOP [The ER equation is full, so SV1 will be used trigger an oscillography report]
- SV1PU (SV1 Pickup Time) = 0.00 seconds [SV1T will turn ON if SV1 is ON]
- SV1DO (SV1 Dropout Time) = 0.00 seconds [SV1T will turn OFF immediately after SV1 turns OFF]
- SV2 (SELogic Variable 2) = 60LOP * (!27V1 + 50L) [SV2 will only turn ON if a PT problem is detected (60LOP) AND the generator is online (!27V1 OR 50L). The generator is considered online if the measured positive-sequence voltage is NOT smaller than 50% of the nominal generator voltage (27V1) OR the measured generator current is greater than 0.25A secondary (0.25A x 1600 = 400A primary).]
- SV2PU (SV2 Pickup Time) = 30 seconds [SV2T will turn ON if SV2 is ON for 30s]
- SV2DO (SV2 Dropout Time) = 0.00 seconds [SV2T will turn OFF after SV1 turns OFF]
- SV3 (SELogic Variable 3) = 27PP1 * 52A * !60LOP [SV3 will only turn ON if: any phase-phase (P-P) voltage is less than 102.3V, AND the generator circuit breaker is closed (52A), AND no PT problems are detected (!60LOP)]
- SV3PU (SV3 Pickup Time) = 15.00 s [SV3T will turn ON if SV3 is ON for 15.00 s]
- SV3DO (SV3 Dropout Time) = 0.00 seconds [SV3T will turn OFF immediately after SV3 turns OFF]
- SV4 (SELogic Variable 4) = 27PP2 * 52A * !60LOP [SV4 will only turn ON if: any P-P voltage is less than 92.0V, AND the generator circuit breaker is closed (52A), AND no PT problems are detected (!60LOP)]
- SV4PU (SV4 Pickup Time) = 3.10s [SV4T will turn ON if SV4 is ON for 3.10 seconds]
- SV4DO (SV4 Dropout Time) = 0.00 seconds [SV4T will turn OFF immediately after SV4 turns OFF]
- SV5 (SELogic Variable 5) = 0 [Not used]
- SV5PU (SV5 Pickup Time) = 0.00 seconds [Not used]
- SV5DO (SV5 Dropout Time) = 0.00 seconds [Not used]

- SV6 (SELogic Variable 6) = 0 [Not used]
- SV6PU (SV6 Pickup Time) = 0.00 seconds [Not used]
- SV6DO (SV6 Dropout Time) = 0.00 seconds [Not used]
- SV7 (SELogic Variable 7) = 0 [Not used]
- SV7PU (SV7 Pickup Time) = 0.00 seconds [Not used]
- SV7DO (SV7 Dropout Time) = 0.00 seconds [Not used]
- SV8 (SELogic Variable 8) = 0 [Not used]
- SV8PU (SV8 Pickup Time) = 0.00 seconds [Not used]
- SV8DO (SV8 Dropout Time) = 0.00 seconds [Not used]
- SV9 (SELogic Variable 9) = (TRIP) * (52A + 50H1) [SV9 will only turn ON if TRIP1 OR TRIP2 OR TRIP3 OR TRIP4 operates AND the generator circuit breaker is closed, which is detected if the 52b contact in the generator circuit breaker is open (52A = !IN101) OR any phase current flowing through the circuit breaker is greater than 0.25A secondary (0.25 x 1600:1 = 400A primary)]
- SV9PU (SV9 Pickup Time) = 0.200 seconds [SV9T will turn ON if SV9 is ON for 12 cycles (12 cycles / 60 Hz)]
- SV9DO (SV9 Dropout Time) = 0.00 seconds [SV9T will turn OFF immediately after SV9 turns OFF]
- SV10 (SELogic Variable 10) = !50H1*27V1*!60LOP [SV10 will only turn ON if no phase current flowing through the circuit breaker is greater than 0.25A secondary (0.25 x 1600:1 = 400A primary) AND the all P-P generator voltages are less than 57.5V_{P-P} AND no PT problems are detected. SV10T will be used to arm the 50/27-Protection.]
- SV10PU (SV10 Pickup Time) = 1.50 seconds [SV10T will turn ON and arm the 50/27-Protection if SV10 is ON for 1.5 seconds]
- SV10DO (SV10 Dropout Time) = 0.25 seconds [SV10T will turn OFF 0.25 seconds after SV10 turns OFF, which will disarm the 50/27-Protection after the generator is energized normally]
- SV11 (SELogic Variable 11) = 59PP1 [SV11 will only turn ON if any phase-phase (P-P) voltage is greater than 127.0V)]
- SV11PU (SV11 Pickup Time) = 10.00 seconds [SV11T will turn ON if SV11 is ON for 10.00 seconds]
- SV11DO (SV11 Dropout Time) = 0.00 seconds [SV11T will turn OFF immediately after SV11 turns OFF]
- SV12 (SELogic Variable 12) = 59PP2 [SV12 will only turn ON if any P-P voltage is greater than 172.5V]
- SV12PU (SV12 Pickup Time) = 0.03 seconds [SV12T will turn ON if SV12 is ON for 0.03 seconds (2 cycles / 60Hz)]
- SV12DO (SV12 Dropout Time) = 0.00 seconds [SV12T will turn OFF immediately after SV12 turns OFF]