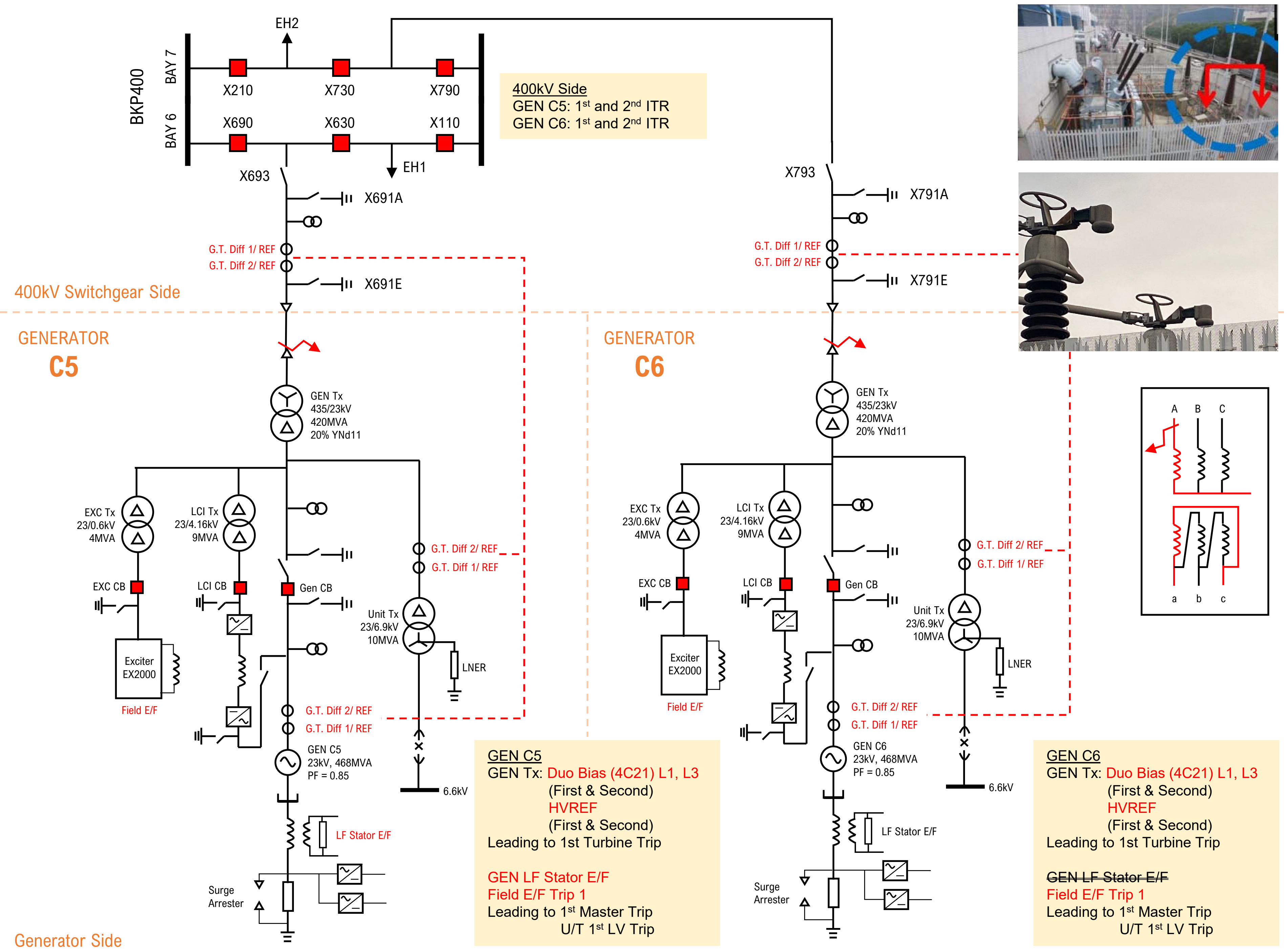
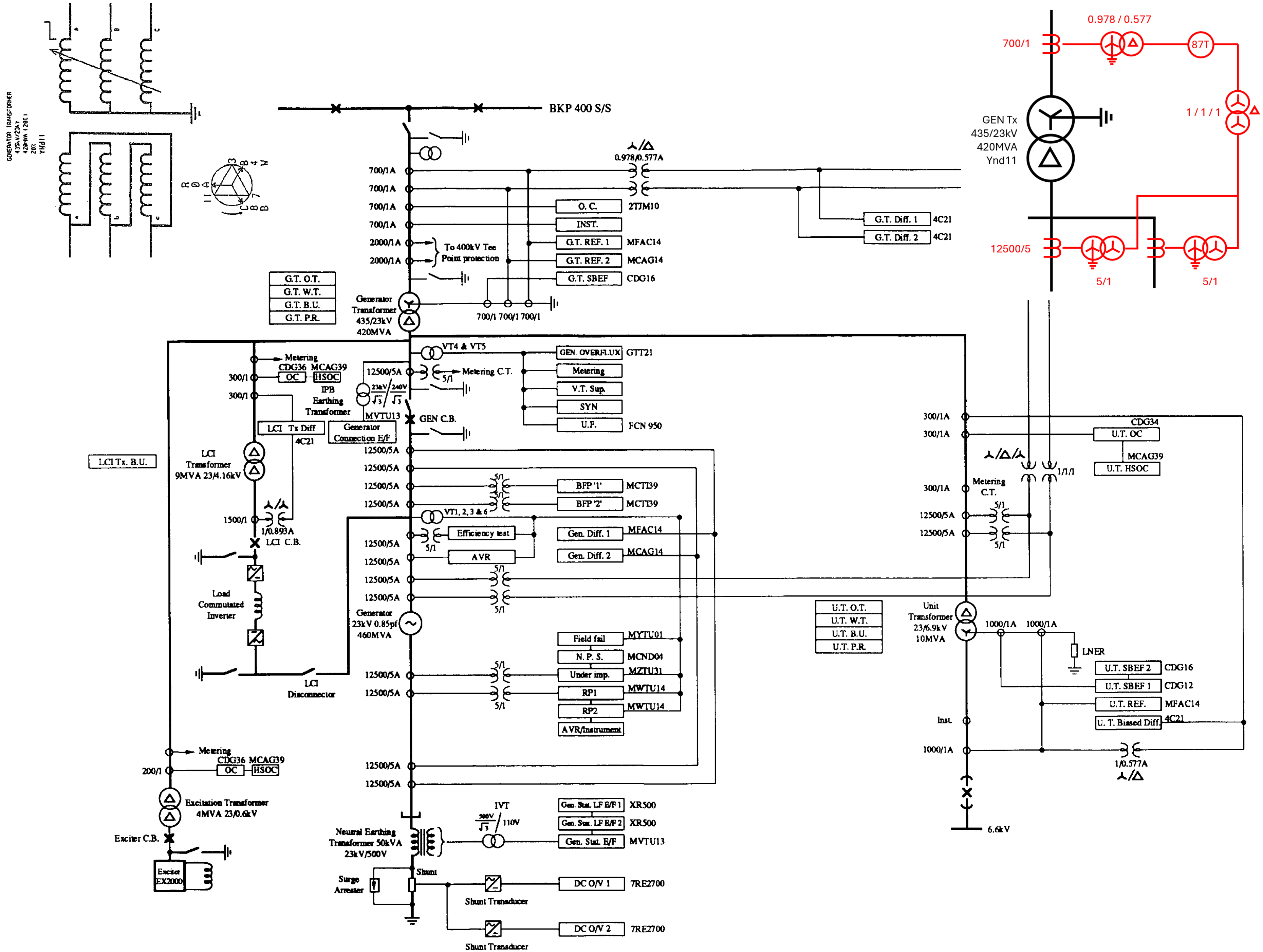


BKP400
BAY 7
BAY 6
EH2
EH1
X210
X730
X790
X690
X630
X110
X693
X793
X691A
X691E
X791A
X791E
400kV Side
GEN C5: 1st and 2nd ITR
GEN C6: 1st and 2nd ITR
G.T. Diff 1/ REF
G.T. Diff 2/ REF
400kV Switchgear Side
GENERATOR
C5
GENERATOR
C6
GEN Tx
435/23kV
420MVA
20% YNd11
EXC Tx
23/0.6kV
4MVA
LCI Tx
23/4.16kV
9MVA
EXC CB
LCI CB
Gen CB
Unit Tx
23/6.9kV
10MVA
LNER
Exciter
EX2000
Field E/F
GEN C5
23kV, 468MVA
PF = 0.85
GEN C6
23kV, 468MVA
PF = 0.85
6.6kV
LF Stator E/F
Surge
Arrester
A
B
C
a
b
c
GEN C5
GEN Tx: Duo Bias (4C21) L1, L3
(First & Second)
HVREF
(First & Second)
Leading to 1st Turbine Trip
GEN LF Stator E/F
Field E/F Trip 1
Leading to 1st Master Trip
U/T 1st LV Trip
GEN C6
GEN Tx: Duo Bias (4C21) L1, L3
(First & Second)
HVREF
(First & Second)
Leading to 1st Turbine Trip
~~GEN LF Stator E/F~~
Field E/F Trip 1
Leading to 1st Master Trip
U/T 1st LV Trip
Generator Side



BKP 400 S/S
0.978/0.577A
700/1A
2000/1A
O. C.
INST.
G.T. REF. 1
G.T. REF. 2
G.T. SBEF
2TJM10
MFAC14
MCAG14
CDG16
To 400kV Tee Point protection
G.T. Diff. 1
G.T. Diff. 2
4C21
G.T. O.T.
G.T. W.T.
G.T. B.U.
G.T. P.R.
Generator Transformer 435/23kV 420MVA
700/1 700/1 700/1
VT4 & VT5
GEN. OVERFLUX
GTT21
Metering
V.T. Sup.
SYN
U.F.
FCN 950
12500/5A
Metering C.T.
5/1
23kV/240V
IPB Earthing Transformer
MVTU13
GEN C.B.
Generator Connection E/F
Metering
CDG36 MCAG39
OC
HSOC
300/1
LCI Tx Diff
4C21
LCI Tx. B.U.
LCI Transformer 9MVA 23/4.16kV
1500/1
1/0.893A
LCI C.B.
Load Commutated Inverter
LCI Disconnector
BFP '1'
BFP '2'
MCTI39
VT1, 2, 3 & 6
Efficiency test
AVR
Gen. Diff. 1
Gen. Diff. 2
MFAC14
MCAG14
Generator 23kV 0.85pf 460MVA
Field fail
MYTU01
N. P. S.
MCND04
Under imp.
MZTU31
RP1
RP2
MWTU14
AVR/Instrument
200/1
Excitation Transformer 4MVA 23/0.6kV
Exciter C.B.
Exciter EX2000
Neutral Earthing Transformer 50kVA 23kV/500V
IVT
500V 110V
Gen. Stat. LF E/F 1
Gen. Stat. LF E/F 2
Gen. Stat. E/F
XR500
MVTU13
Surge Arrester
Shunt
DC O/V 1
DC O/V 2
7RE2700
Shunt Transducer
300/1A
CDG34
U.T. OC
MCAG39
U.T. HSOC
Metering C.T.
1/1/1
12500/5A
U.T. O.T.
U.T. W.T.
U.T. B.U.
U.T. P.R.
Unit Transformer 23/6.9kV 10MVA
1000/1A
LNER
U.T. SBEF 2
U.T. SBEF 1
U.T. REF.
U. T. Biased Diff.
CDG16
CDG12
MFAC14
4C21
Inst.
1/0.577A
6.6kV
700/1
0.978 / 0.577
87T
1 / 1 / 1
GEN Tx
435/23kV
420MVA
Ynd11
12500/5
5/1
GENERATOR TRANSFORMER
435kV/23kV
420MVA
YNd11

GEN C5

GEN Tx: Duo Bias (4C21) L1, L3
(First & Second)
HVREF
(First & Second)
Leading to 1st Turbine Trip

GEN LF Stator E/F
Field E/F Trip 1
Leading to 1st Master Trip
U/T 1st LV Trip

400kV Side: ITR
(First & Second)

GEN C6

GEN Tx: Duo Bias (4C21) L1, L3
(First & Second)
HVREF
(First & Second)
Leading to 1st Turbine Trip

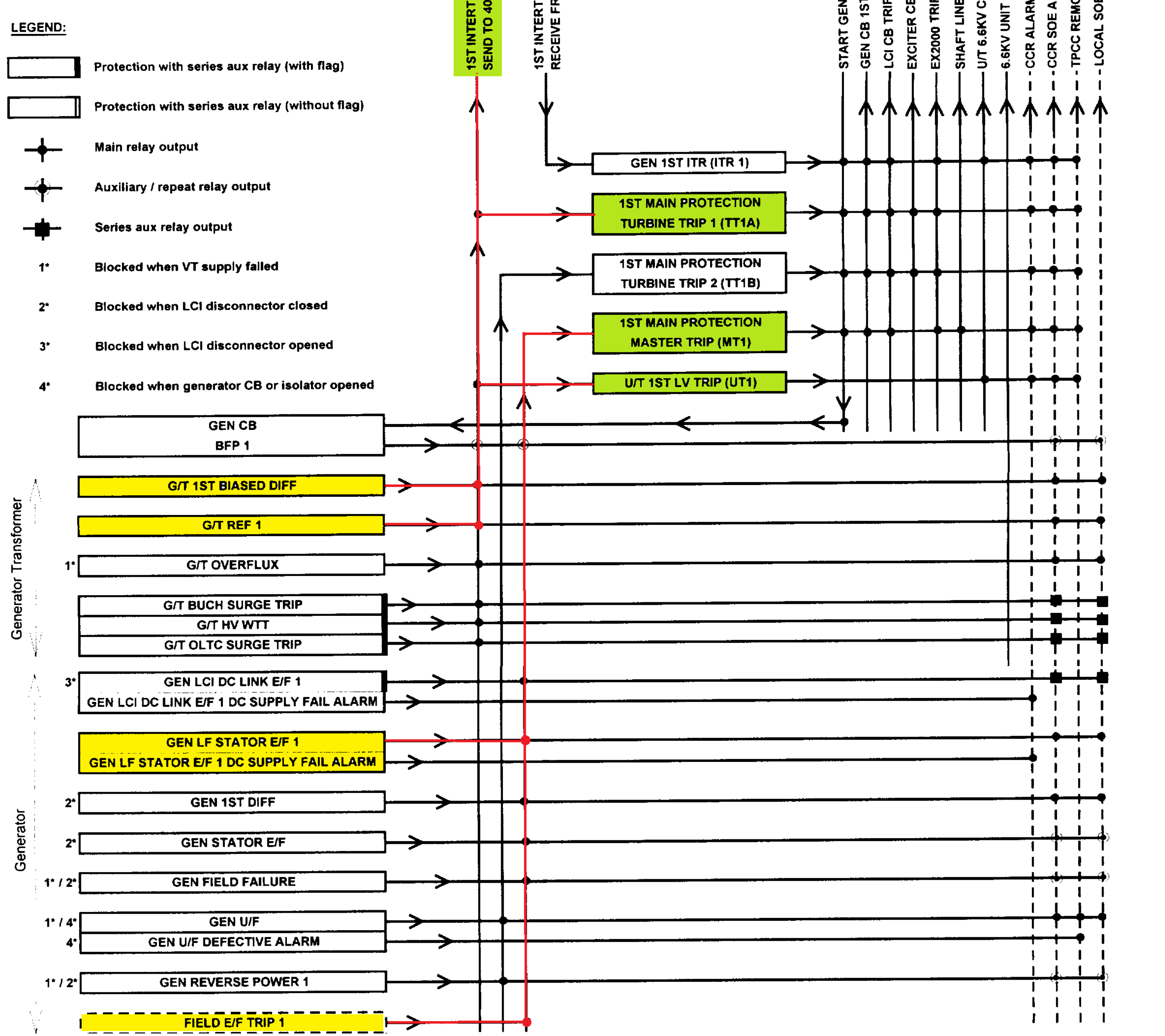
~~GEN LF Stator E/F~~
Field E/F Trip 1
Leading to 1st Master Trip
U/T 1st LV Trip

400kV Side: ITR
(First & Second)

BLACK POINT GENERATOR

TRIP BLOCK DIAGRAM (sheet 1 of 3)

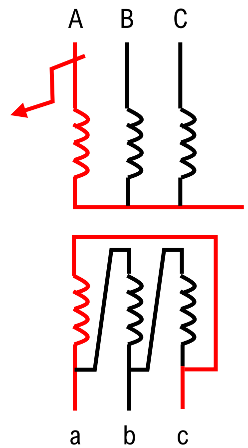
1ST MAIN PROTECTION

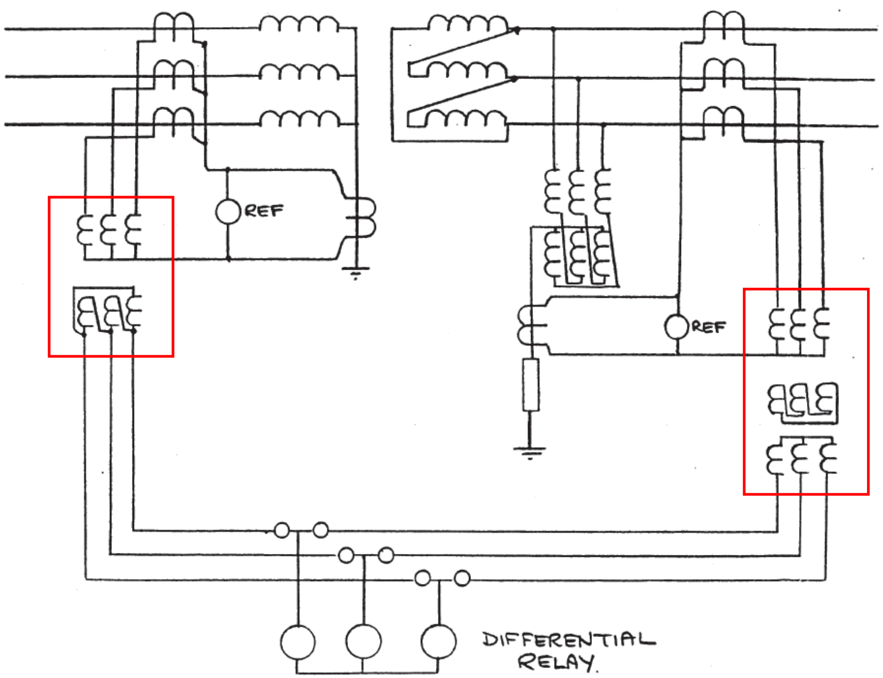


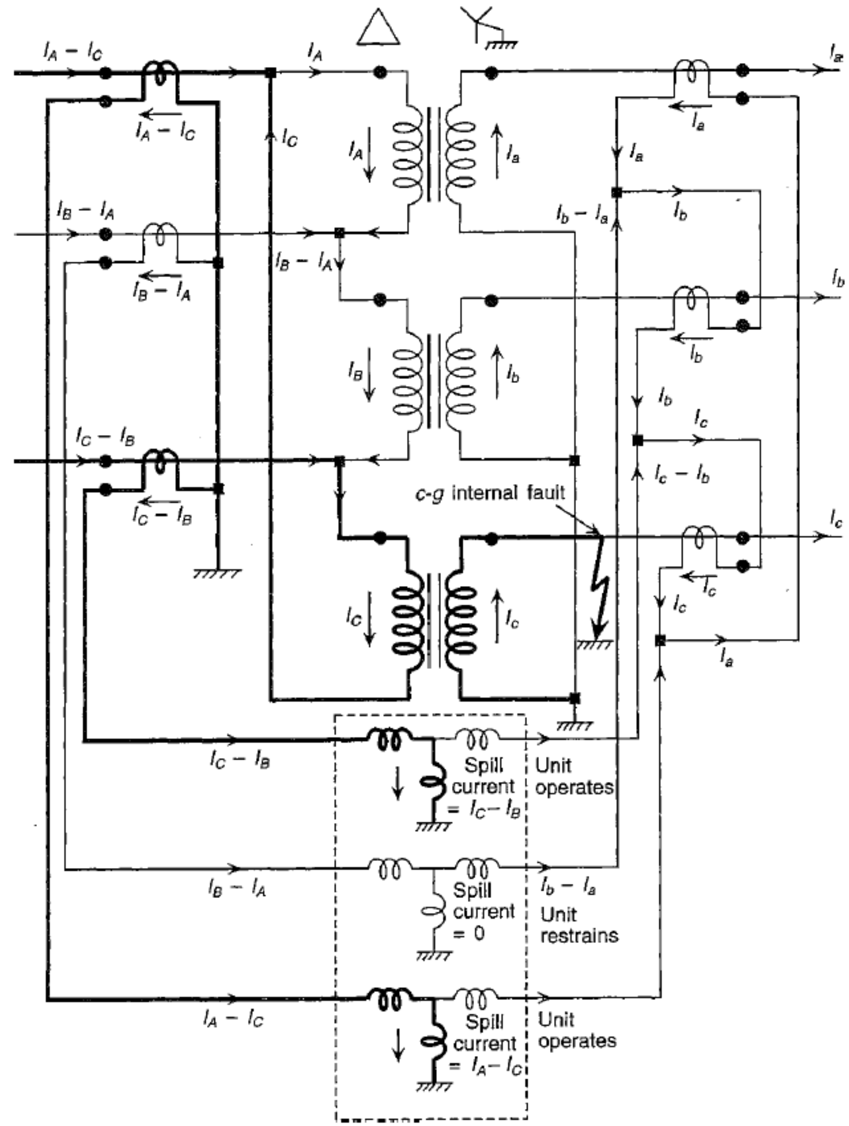
Why 2 phase 4C21 was triggered under a single-phase to ground (SLG) fault?

Fault at BKP: L1 fault, appears to be L1 – L3 fault at 4C21.

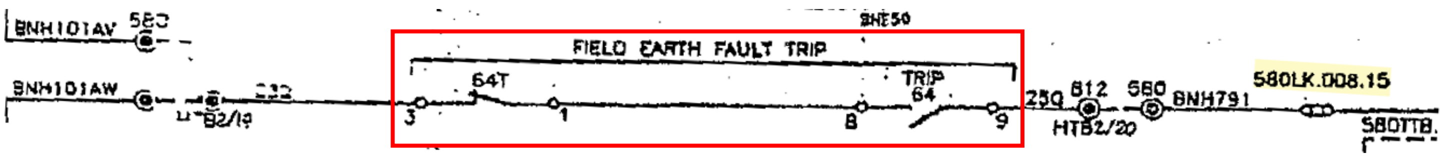
Note – Current Re-distribution after ICT.
SLG fault → 2 phase operated
LL fault → 1 phase or 3 phase operated.







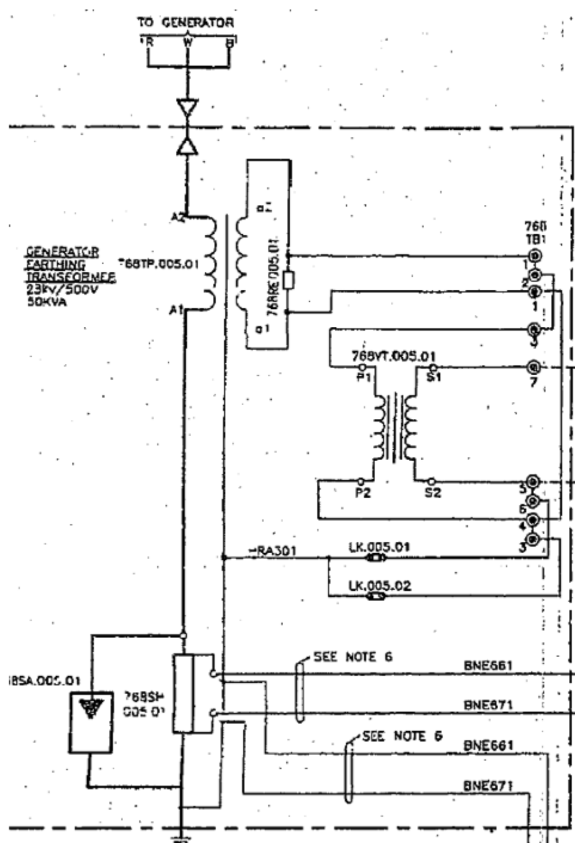
Percentage differential relay

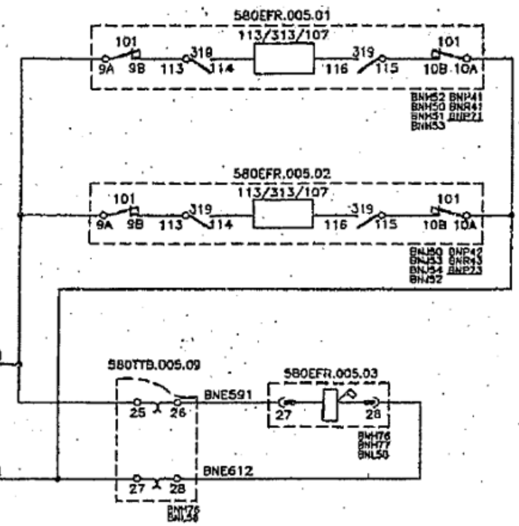


From Generator Cubicle

64 = Machine Ground Detector Relay

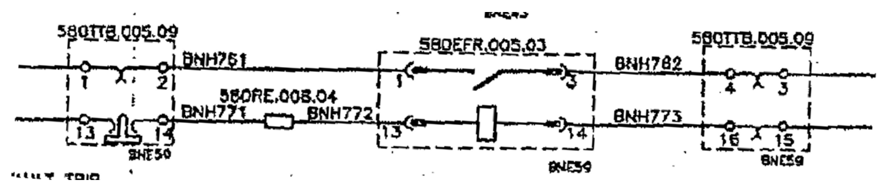
Field E/F Relay (MCAA11) Operated





Note – it is possible that the field E/F detection is made by OC element, or by MCB. During earth fault, generator AVR continuously push the output voltage by further increase field (excitation current), hence leading to MCB trip / OC trip.
→ Need further proof

Obtain voltage across neutral earthing transformer to observe neutral overvoltage (NOV) during earth fault.



Low Frequency Stator E/F Relay (IMRK000454) Operated

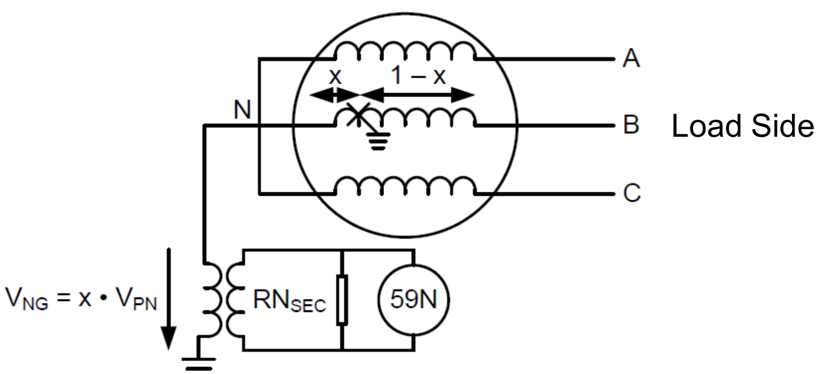
3.1 Voltage setting test

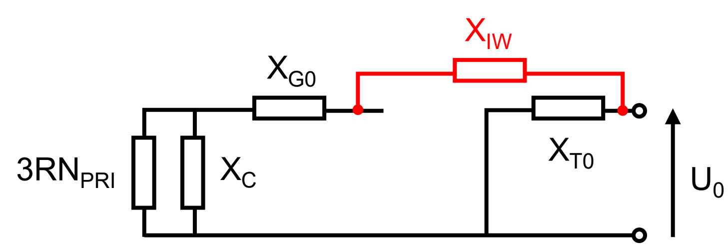
Different Pickup Voltage at Different Hz (Setting = 7V, 1s)

Frequency (Hz)	10	20	30	40	50	60
Spec. Pick-Up Voltage (V)	1.40	2.80	4.10	5.40	7.00	8.20
Pick-Up Voltage (V)	1.58	2.82	4.13	5.46	6.83	8.20
Drop-Off Voltage (V)	1.57	2.80	4.11	5.44	6.80	8.17

What is Low Frequency Stator E/F 59N and Why is it operative in External Fault at GSU case?

- Generators connected to the grid through a generator step-up transformer (GSU) with delta-wye windings, which circulates any ground current on the load side of the GSU and prevents it from flowing through the generator.
- Parasitic capacitance between the transformer windings allows a small percentage of zero-sequence current flows through the generator during a ground fault on the load side of the GSU.
- Hence, the neutral overvoltage relay (59N) can measure a voltage (in order of 1V to 10V) even during external fault, i.e. earth fault at HV side of GSU. [Note – Setting: 7V]
- The interwinding capacitance is typically in the order of nF, resulting in the order of 100kΩ. In zero-sequence network, the GSU delta creates an open circuit, leaving the interwinding capacitance X_{IW} as the only path between the system and the generator.
- During startup, the unit is energized with low frequency through line commutated inverter (LCI) for starting and should be monitored for ground faults on the stator. 59N must use frequency tracking to correctly measure fundamental voltage when the unit is operating at lower speeds.





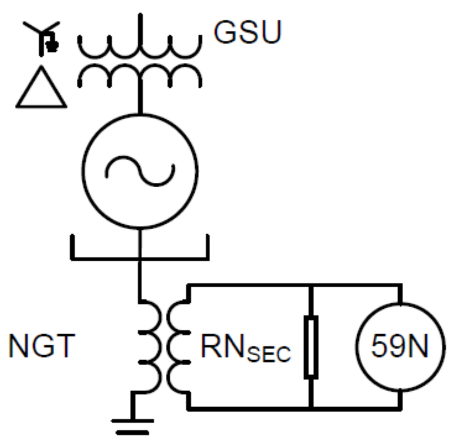
$$Z_N = \frac{-jX_C \cdot 3 \cdot RN_{PRI}}{3 \cdot RN_{PRI} - jX_C}$$

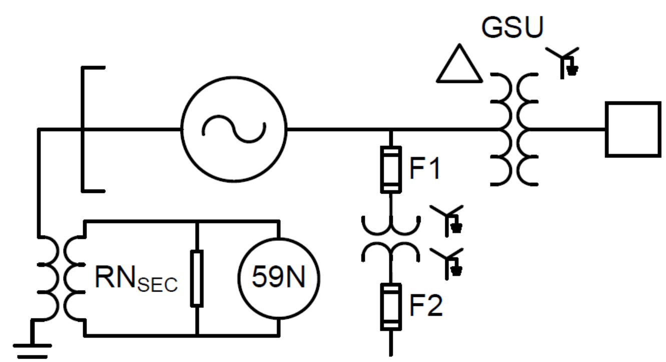
$$VN_{SEC} = \boxed{\frac{V_{SYS}}{3}} \cdot \left| \frac{Z_N}{Z_N - j \cdot X_{IW}} \right| \cdot \frac{1}{n_{NGT}}$$

Worst Case Scenario:
$V_0 = V_{SYS} / 3$

What is Low Frequency Stator E/F 59N and Why is it operative in External Fault at GSU case?

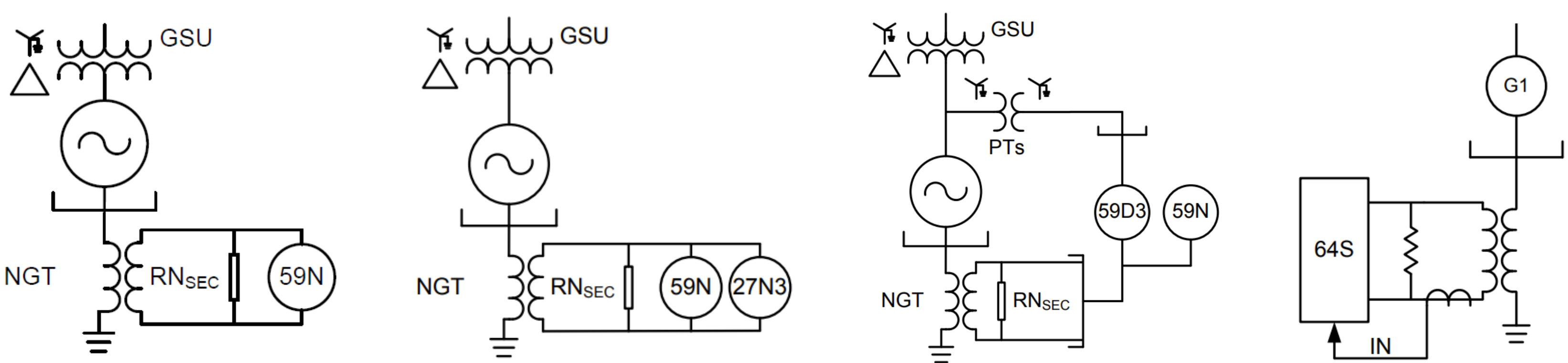
- The terminal voltage will be reduced proportionally with speed to prevent overexcitation (V/f). Since this element is an overvoltage function, security is not impacted, but a loss of coverage is anticipated. The 59N relay, or Low frequency Stator E/F (LFSEF) relay should have voltage pickup proportional to the frequency.
- A pickup setting of 5 –15 V secondary for the 59N element is typical because a setting in this range provides a balance between sensitivity to earth fault and stability for external earth faults outside of the generator zone.
- The 59N will not detect faults in the first 4.2 percent of the winding, yielding a coverage of 95 percent, therefore it is coined as 95% SEF Protection.
- Due to the sensitivity of the 59N relay, a ground fault inside VT or a ground fault on the secondary side of the VT could very likely cause the 59N element to operate. To avoid tripping the unit for these cases, care must be taken to coordinate the 59N element with the operating time of the VT's high-voltage (F1) and low-voltage (F2) fuses.





Summary – Stator Earth Fault Protection

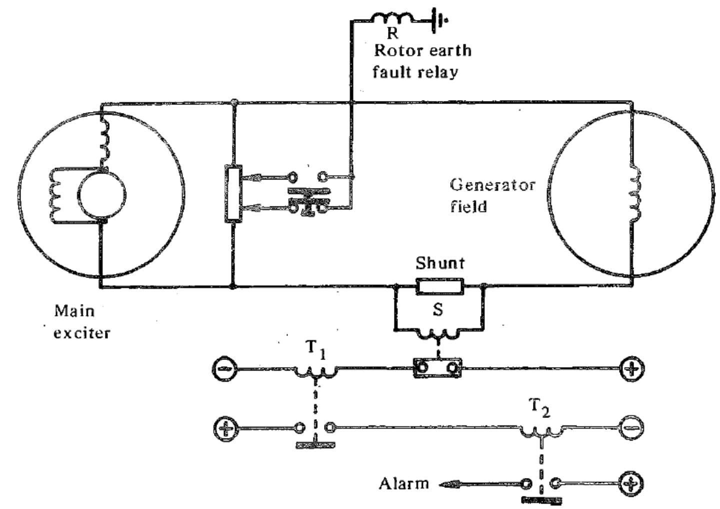
Protection Scheme	Description
59N	• Simple operating principle covering most of the stator winding. • Simple setting (Security to most winding vs Stability to external fault, i.e. HV fault at GSU)
27N3	• Protect the portion of stator winding left for 59N • Require additional supplement at low load and offline condition • Sensitive to available third harmonics source in grid • Not required additional VT at stator terminal
59D3	• Insensitive to variation as it depends on impedance ratio and voltage change. • Additional grounded-wye VT required at stator terminal • Simple setting with calculable coverage
64S	• Active detection by measuring shunt impedance of the stator. • Only disadvantage is injection set required. • Coverage independent on fault location, generator frequency and voltage, loading. • Works equally well when the machine is online, offline, starting and standstill.



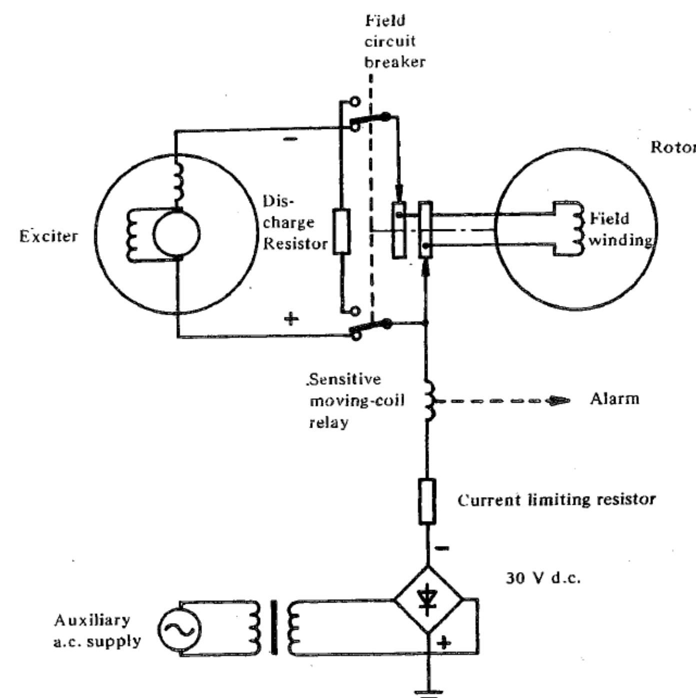
Rotor Earth Fault Detection

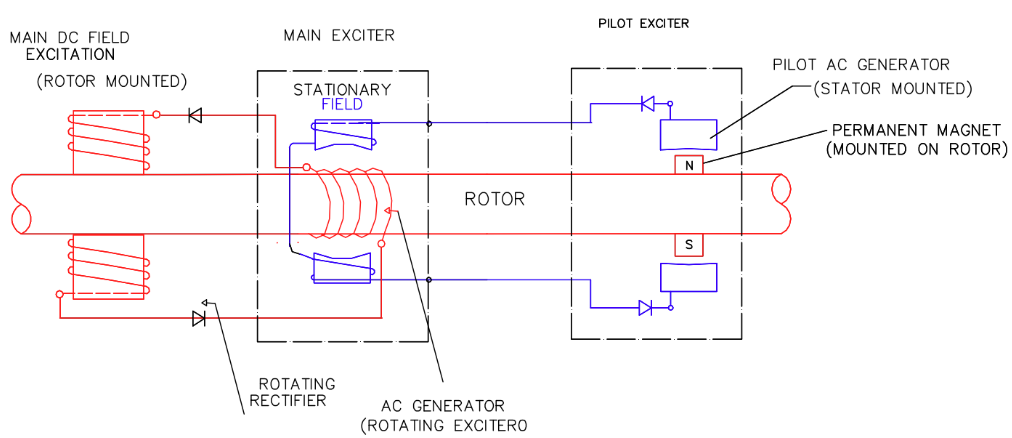
- Rotor is often designed to be floated to avoid interference to field applied to generator during stator fault.
- To detect earth fault at rotor field circuit, it is to either connect the rotor circuit to earth through a resistor and earth fault relay, or apply a DC voltage to the field winding. With such incomplete circuit, there is no current flowing through and hence the relay is maintained stable.
- For Sensitive Relay design, the blind spot is at the centre point of field winding, and a tapping switch is provided to select a different point to drive the rotor E/F circuit, or a nonlinear resistor can be applied.
- The earth return path is through the rotor body. The contact between the stator and rotor is insulating bearing oil film. It is essential to earth the rotor shaft by an additional earthed brush.

Generator Field Failure by Sensitive Relay



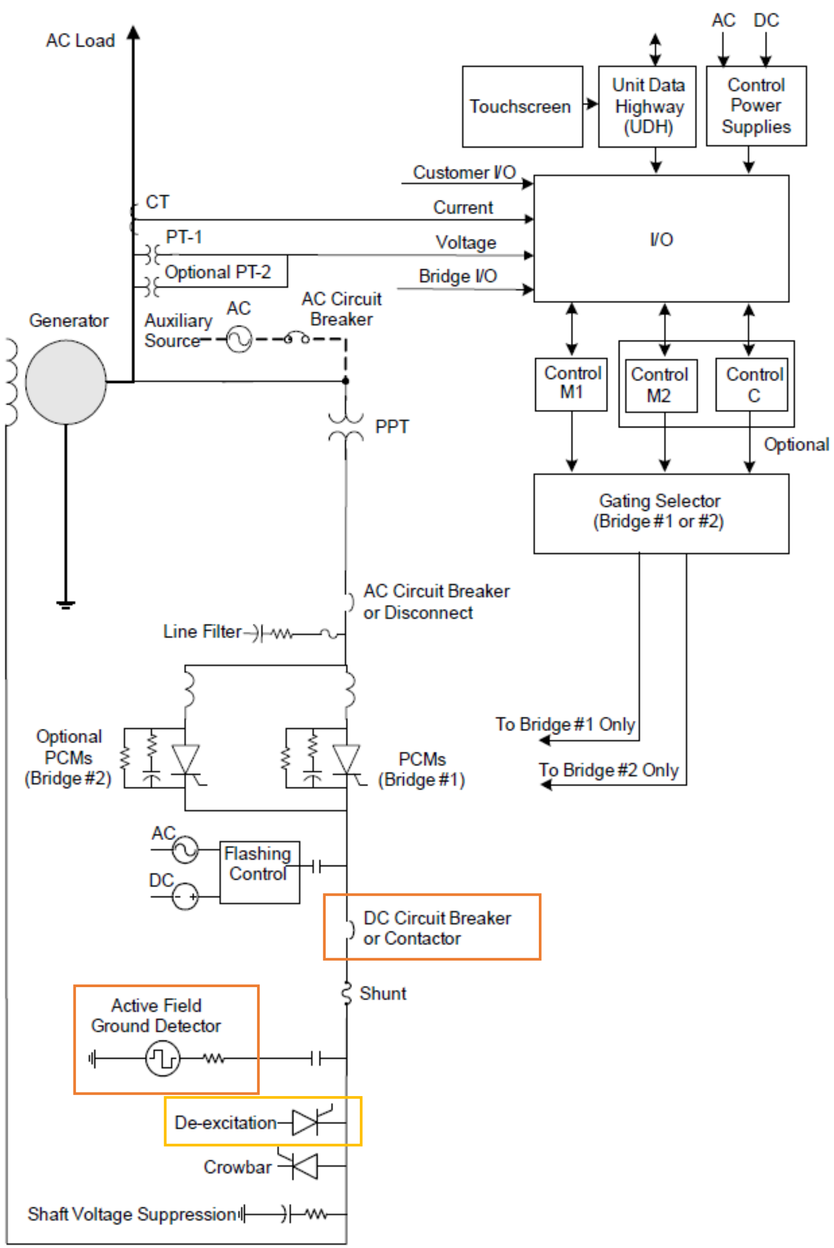
Negative Potential Biasing for Rotor E/F Detection





Brushless Exciter

Rotor Earth Fault Detection – Exciter Control Check from GBG (for C2)



Ex2100e Check at C2 side on 21/04/2024

- Supply DC voltage (600V$_{DC}$)
- EDEX Card (Exciter De-Excitation) output voltage
- DC CB Aux Contact

Reminder –

Before disconnecting DC supply from protection panel, make sure the exciter Ex2100e has been switched off to avoid any failure in electronic device.

What does it imply?

- Field Failure circuit does obtain the DC CB Aux Contact and DC CB trip signal.
- It could be triggered by field ground detector, thyristors fuse burnt off, missing gate pulse and open / shorted thyristor bridge.
- EDEX Card may have possible condition to short the DC path to earth.
- After disconnecting DC supply from protection panel, it is possible to have exciter DC output returning to protection panel through grounding.
  [Note – the closest ground to rotor circuit is the shaft, separated with insulating oil films, and monitored with shaft voltage suppression.]

400kV SIDE:

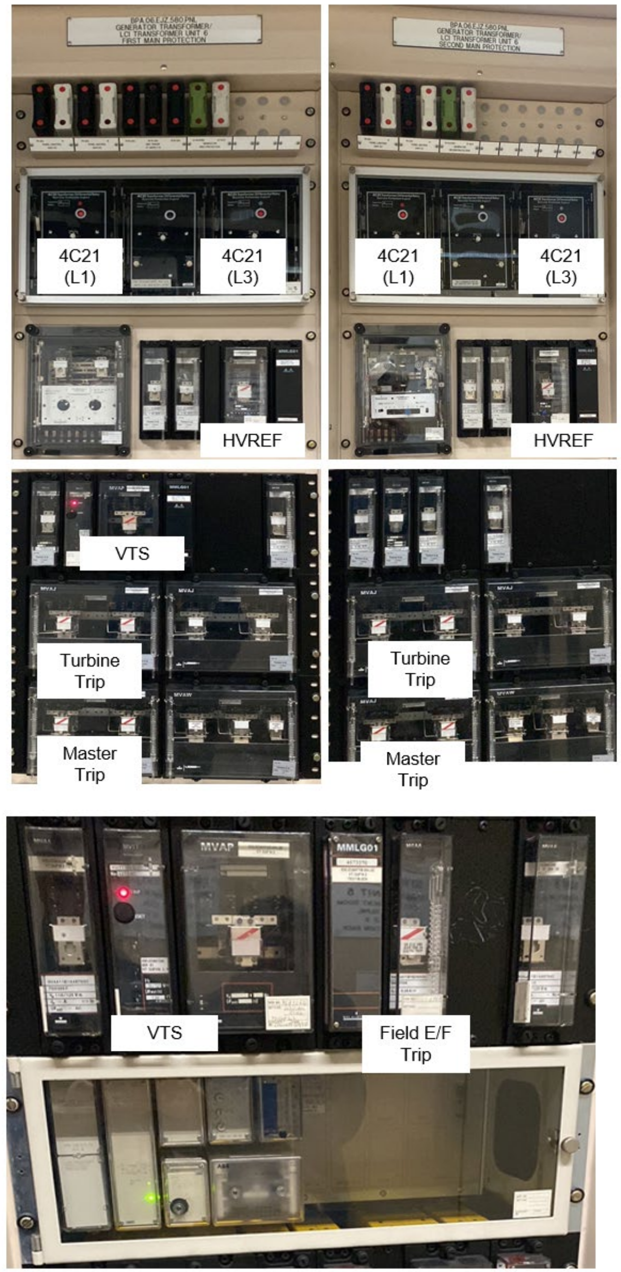
Only 1st and 2nd Intertrip Receive Operated
For both C5 and C6

Note – Generator BU OC Remain Stable
OC: 1.25A, 0.7 (Not Operated)

Item	Protection Type	Relay Type
100	GEN PROT	
111	1ST GEN/TX DIFF PROT	
121	2ND GEN/TX DIFF PROT	
200	GEN INTERTRIP PROT	
211	1ST I/T RECEIVE	MVAW02
221	1ST I/T PSS	MVAX12
231	2ND I/T RECEIVE	MVAW02
241	2ND I/T PSS	MVAX12
300	GEN BACK-UP PROT	
311	OC	2TJM10 x3
321	1ST BACKUP TRIP	MVAJ54
331	1ST BACKUP PSS	MVAX12
341	2ND BACKUP TRIP	MVAJ54
351	2ND BACKUP PSS	MVAX12
400	TRIP RLY AUTO RESET	
411	AUTO RESET TIMER	MVTT14
451	AUTO RESET SUPP SUPV	MVAX12
711	INSTRUMENT	

GENERATOR C5

GENERATOR C6



GEN C5

GEN Tx: Duo Bias (4C21) L1, L3
(First & Second)
HVREF
(First & Second)
Leading to 1st Turbine Trip

GEN LF Stator E/F
Field E/F Trip 1
Leading to 1st Master Trip
U/T 1st LV Trip

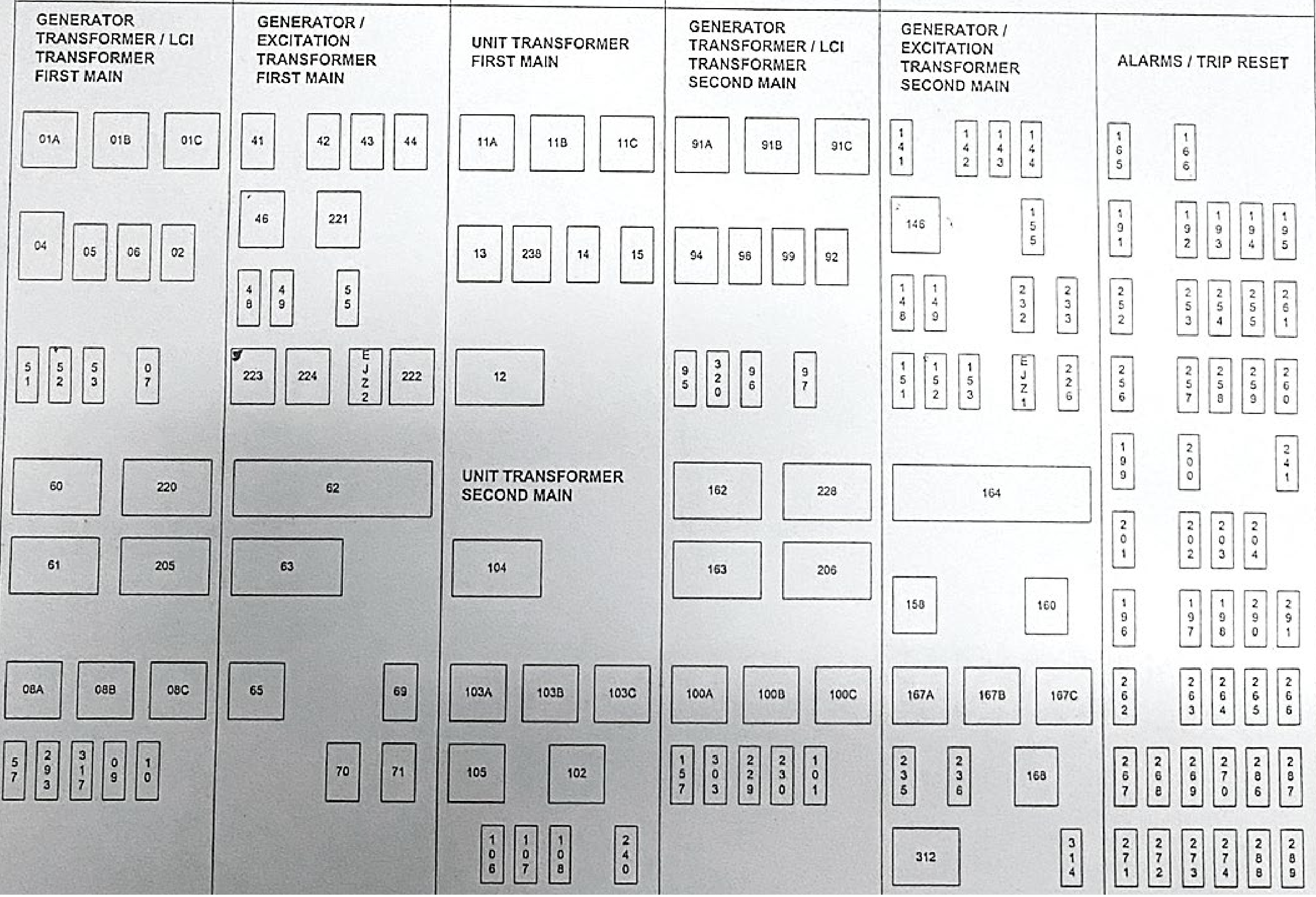
GEN C6

GEN Tx: Duo Bias (4C21) L1, L3
(First & Second)
HVREF
(First & Second)
Leading to 1st Turbine Trip

~~GEN LF Stator E/F~~
Field E/F Trip 1
Leading to 1st Master Trip
U/T 1st LV Trip

BLACK POINT POWER STATION
GENERATION PROTECTION CUBICLES RELAY

UNIT	DATE	TIME	NAME & SIGN	REMARKS



BLACK POINT POWER STATION
GENERATION PROTECTION CUBICLES RELAY

UNIT	DATE	TIME	NAME & SIGN	REMARKS

GENERATOR TRANSFORMER / LCI TRANSFORMER FIRST MAIN

- 01A - G/Tx first bias differential relay
- 01B - G/Tx first bias differential
- 01C - G/Tx first bias differential
- 02 - G/Tx HV restricted earth fault
- 04 - G/Tx overfluxing relay
- 05 - G/Tx buchholz surge trip relay
- 06 - G/Tx HV winding temp trip relay
- 07 - G/Tx OLTC surge trip relay
- 08A - LCI Tx bias differential relay
- 08B - LCI Tx bias differential relay
- 08C - LCI Tx bias differential relay
- 09 - LCI Tx buchholz surge trip relay
- 10 - LCI Tx winding temp trip relay
- 51 - G/Tx VT supervision time delay 1 auxiliary relay
- 52 - G/Tx voltage supervision 1 relay
- 53 - G/Tx VT voltage supervision 1 relay
- 57 - LCI disconnector auxiliary contact repeat (B1-stable) relay
- 60 - first main protection turbine trip 1 relay (TT1 A)
- 61 - first main protection master trip relay (MT1)
- 205 - 400kV switchgear intertrip receive trip / follower relay (PS1/ TR1)
- 220 - first main protection turbine trip 2 relay (TT1 B)
- 293 - alarm relay for LCI disconnector repeat relay faulty
- 317 - LCI disconnector auxiliary contact repeat relay

GENERATOR / EXCITATION TRANSFORMER FIRST MAIN

- 41 - first main protection supply supervision relay
- 42 - generator first differential protection relay
- 43 - generator first differential protection relay
- 44 - generator first differential protection relay
- 46 - generator reverse power 1 relay
- 48 - generator CB breaker fail 1 time delay relay
- 49 - generator CB breaker fail 1 protection relay
- 55 - generator field failure protection relay
- 62 - gen low frequency stator E/F 1 relay
- 63 - generator underfrequency relay (4 stages)
- 65 - generator LCI DC link earth fault 1 relay
- 69 - generator LCI DC link E/F trip 1 relay
- 70 - excitation tx. buchholz surge trip relay
- 71 - excitation tx. winding temp trip relay
- 221 - Stator earth fault relay
- 222 - generator VT supervision time delay 1 auxiliary relay
- 223 - generator VT supervision time delay 1 relay
- 224 - generator VT supervision 1 relay
- EJZ2 - Excitation Field Earth Fault Trip

UNIT TRANSFORMER FIRST AND SECOND MAIN

- 11A - U/Tx bias differential relay
- 11B - U/Tx bias differential relay
- 11C - U/Tx bias differential relay
- 12 - U/Tx first LV trip relay (UT1)
- 13 - U/Tx LV standby earth fault 1 relay
- 14 - U/Tx buchholz surge trip relay
- 15 - U/Tx LV winding temp trip relay
- 102 - U/Tx HV high set overcurrent protection relay
- 103A - UTx HV overcurrent protection relay R phase
- 103B - UTx HV overcurrent protection relay W phase
- 103C - UTx HV overcurrent protection relay B phase
- 104 - U/Tx second LV trip relay (UT2)
- 105 - U/Tx LV standby earth fault 2 relay
- 106 - U/Tx pressure relief trip relay
- 107 - U/Tx oil temp trip relay
- 108 - U/Tx LV restricted earth fault relay
- 109 - test terminal block U/Tx LV ref.
- 238 - U/Tx LV standby earth fault 1 repeat relay
- 240 - U/Tx overcurrent repeat relay

GENERATOR TRANSFORMER / LCI TRANSFORMER SECOND MAIN

- 91A - G/Tx second bias differential relay
- 91B - G/Tx second bias differential relay
- 91C - G/Tx second bias differential relay
- 92 - G/Tx HV restricted earth relay
- 94 - G/Tx HV standby earth fault relay
- 95 - G/Tx HV pressure relief trip relay
- 96 - G/Tx LV winding temp trip relay
- 97 - G/Tx oil temp trip relay
- 98 - G/Tx OLTC pressure relief trip relay
- 99 - G/Tx OLTC DC pressure relief trip relay
- 100A - LCI Tx HV overcurrent protection relay R phase
- 100B - LCI Tx HV overcurrent protection relay W phase
- 100C - LCI Tx HV overcurrent protection relay B phase
- 101 - LCI Tx HV overcurrent protection relay
- 157 - LCI disconnector auxiliary contact repeat 1 (B1-stable) relay
- 162 - second main protection turbine trip 1 relay (TT2 A)
- 163 - second main protection master trip relay (MT2)
- 206 - 400kV switchgear intertrip receive trip / follower relay (PS2/ TR2)
- 228 - second main protection turbine trip 2 relay (TT2 B)
- 229 - LCI Tx pressure relief device trip relay
- 230 - LCI Tx oil temp trip relay
- 303 - LCI disconnector repeat relay faulty alarm relay
- 320 - LCI disconnector auxiliary contact repeat 2 relay

GENERATOR / EXCITATION TRANSFORMER SECOND MAIN

- 141 - second main protection supply supervision relay
- 142 - generator second differential protection relay
- 143 - generator second differential protection relay
- 144 - generator second differential protection relay
- 146 - gen. reverse power 2 relay
- 148 - generator CB breaker fail 2 time delay relay
- 149 - generator CB breaker fail 2 protection relay
- 151 - VT supervision generator time delay 2 auxiliary
- 152 - generator voltage supervision time delay 2 relay
- 153 - generator VT voltage supervision 2 relay
- 155 - generator connections earth fault relay
- 158 - gen under impedance relay
- 160 - generator negative phase sequence relay
- 164 - generator low frequency stator E/F 2 relay
- 167A - excitation Tx HV overcurrent protection relay R phase
- 167B - excitation Tx HV overcurrent protection relay W phase
- 167C - excitation Tx HV overcurrent protection relay B phase
- 168 - excitation Tx. HV overcurrent protection relay
- 226 - gen circuit breaker repeat relay
- 232 - generator connections earth fault stage 2 relay
- 233 - generator connections earth fault stage 1 relay
- 235 - excitation Tx. pressure relief device trip relay
- 236 - excitation Tx. oil temp trip relay
- 312 - generator LCI DC link earth fault trip 2 relay
- 314 - gen LCI DC link earth fault trip 2 relay
- **EJZ1 - Excitation External Trip Relay**

ALARMS / TRIP RESET

- 165 - trip relay reset supply supervision relay
- 166 - trip relay reset time delay relay
- 191 - G/T buchholz alarm / oil temp alarm relay
- 192 - G/T HV/LV winding temp / conservator oil level alarm relay
- 193 - G/T cooling unit failure / spare alarm relay
- 194 - G/T OLTC incomplete / OLTC faulty alarm relay
- 195 - G/T spare dehydrating breather (future) alarm relay
- 196 - U/T buchholz alarm oil temp alarm relay
- 197 - U/T LV winding temp / conservator oil level alarm relay
- 198 - U/T spare / spare alarm relay
- 199 - gen circuit breaker trip circuit 1 supervision relay
- 200 - gen circuit breaker trip circuit 2 supervision relay
- 201 - gen CB SF6 pressure low / SF6 lockout alarm relay
- 202 - gen CB air pressure low / compressor faulty alarm relay
- 203 - gen CB air pressure open lockout / air pressure close lockout alarm relay
- 204 - gen CB compressor excessive running / spare alarm relay
- 241 - alarm supply supervision relay
- 252 - alarm relay for G/Tx restricted earth fault 2
- 253 - alarm relay for G/Tx standby earth fault
- 254 - alarm relay for IPB earth fault 2
- 255 - alarm relay for gen stator earth fault
- 256 - alarm relay for gen field failure
- 257 - alarm relay for gen differential R phase
- 258 - alarm relay for gen differential W phase
- 259 - alarm relay for gen differential B phase
- 260 - alarm relay for gen reverse power 1
- 261 - alarm relay for gen reverse power 2
- 262 - alarm relay for U/Tx standby earth fault 2
- 263 - alarm relay for U/Tx HV overcurrent R phase
- 264 - alarm relay for U/Tx HV overcurrent W phase
- 265 - alarm relay for U/Tx HV overcurrent B phase
- 266 - alarm relay for U/Tx HV high set overcurrent R phase
- 267 - alarm relay for excitation Tx HV overcurrent R phase
- 268 - alarm relay for excitation Tx HV overcurrent W phase
- 269 - alarm relay for excitation Tx HV overcurrent B phase
- 270 - alarm relay for excitation Tx HV high set overcurrent R phase
- 271 - alarm relay for LCI Tx HV overcurrent R phase
- 272 - alarm relay for LCI Tx HV overcurrent W phase
- 273 - alarm relay for LCI Tx HV overcurrent B phase
- 274 - alarm relay for excitation Tx HV high set overcurrent R phase
- 286 - alarm relay for excitation Tx HV high set overcurrent W phase
- 287 - alarm relay for excitation Tx HV high set overcurrent B phase
- 288 - alarm relay for LCI Tx HV high set overcurrent W phase
- 289 - alarm relay for LCI Tx HV high set overcurrent B phase
- 290 - alarm relay for U/Tx HV high set overcurrent W phase
- 291 - alarm relay for U/Tx HV high set overcurrent B phase

Immediate Relay Integrity Proof under Alarm Handling

C5 FIRST

4C21

	R	W	B
HV	0.189 A	0.181 A	0.185 A
LV	0.187 A	0.181 A	0.186 A
DC	16.71 V	16.30 V	16.50 V

HVREF (Setting : 125V)

V_2	I_2
123.8 V	19mA

SECOND

4C21

	R	W	B
HV	0.196A	0.193 A	0.180A
LV	0.190A	0.191 A	0.181 A
DC	18.40 V	16.00 V	16.71 V

HVREF (Setting: 75mA)

V_2	I_2
11.85V	76mA

C6 First

4C21

		R	W	B
	HV	0.182A	0.185A	0.193A
	LV	0.181A	0.185A	0.193A
2A inject.	DC	17.20 V	15.90 V	18.58 V

HVREF (Setting : 125V)

V_2	I_2
121.5V	19mA

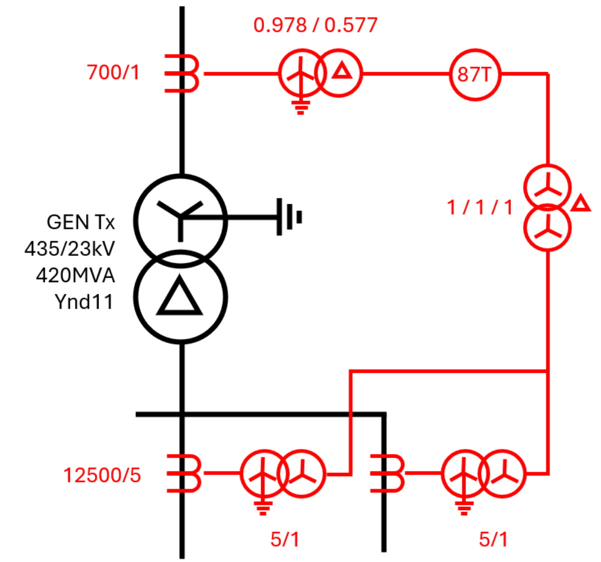
Second

4C21

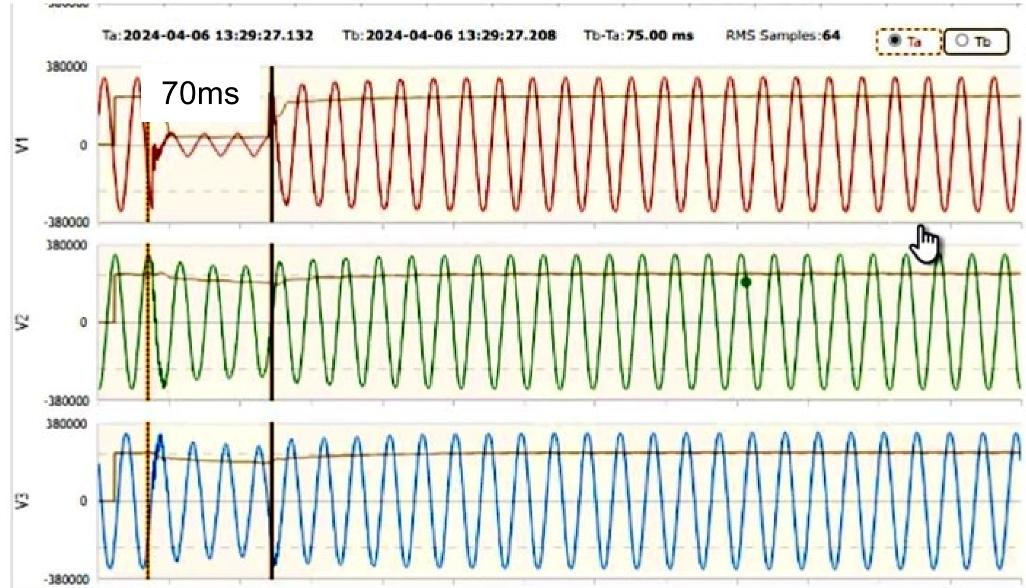
		R	W	B
	HV	0.185A	0.188A	0.182A
	LV	0.184A	0.188A	0.181A
2A inject	DC	18.38 V	17.31 V	17.56 V

HVREF (Setting: 75mA)

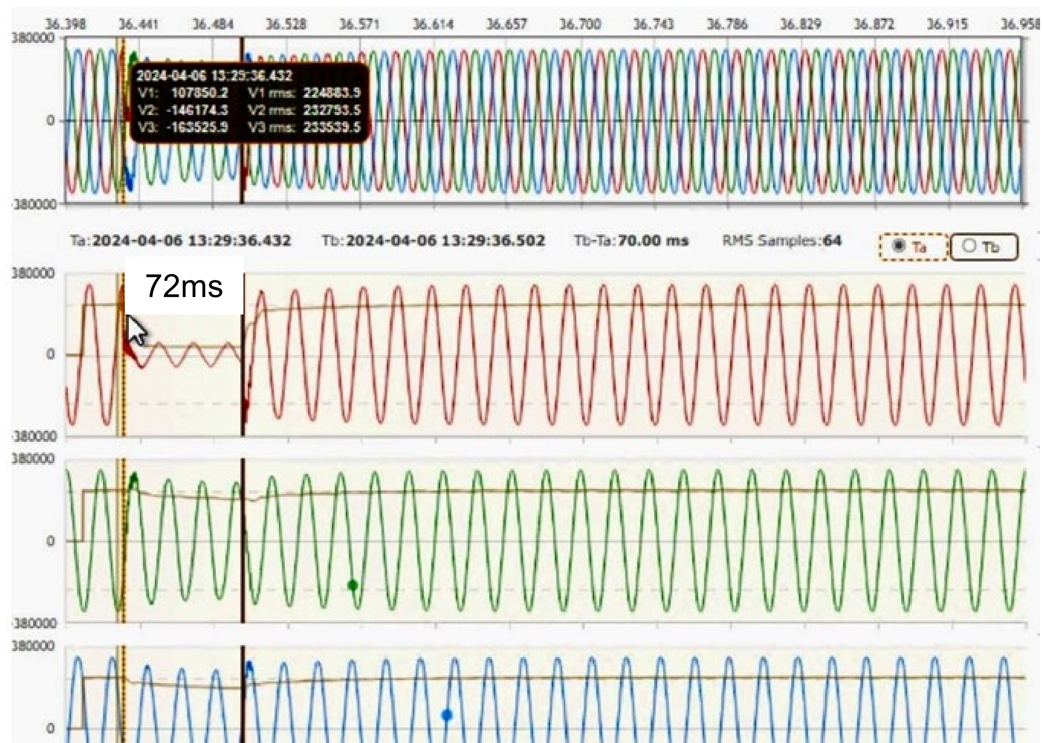
V_2	I_2
11.55V	76mA



Voltage Dip at 13:29:**27**.132

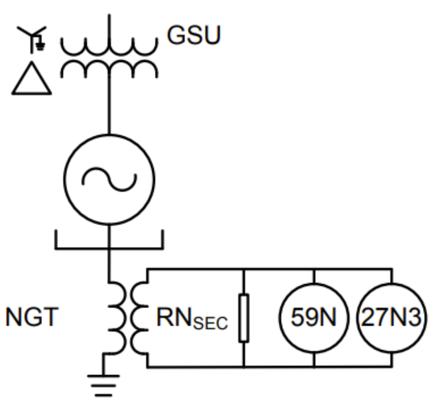


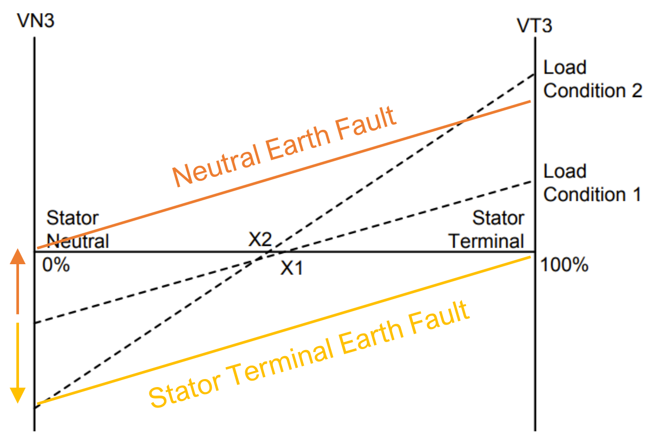
Voltage Dip at 13:29:**36**.432

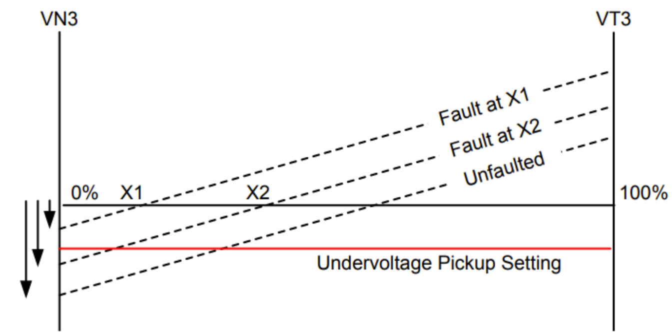


Third Harmonics Under-Voltage 27N3 Element for 100% Stator Earth Fault Protection

1. **Triplen Harmonics Voltage** are generated during normal operation of generators due to physical limitations in their design. These harmonics are in equal magnitude and phase on all three phases, resulting in zero-sequence voltages, with the third-harmonic voltage being the largest.
2. **Voltage Divider Circuit**: The stator capacitance, system capacitance, and grounding resistance create a voltage divider circuit in the zero-sequence network. The neutral grounding resistor (NGR, or NGT) are selected to have similar third-harmonic voltage the stator windings.
3. **Third-Harmonic Voltage Magnitude**: The magnitude of third-harmonic voltage at the generator neutral varies widely from generator to generator, depending on factors such as generator construction, loading conditions, and system configuration.
4. **Voltage Distribution**: A linear load dependent third-harmonics voltage distribution across stator is assumed.
5. **Faulted Conditions**: A ground fault at the neutral creates an upward shift in the curve, while a ground fault at the terminals creates a downward shift.
6. **Fault Detection**: A third-harmonic undervoltage element across the grounding resistor (VN3) can be used to detect ground faults near the neutral of the generator due to the shift.



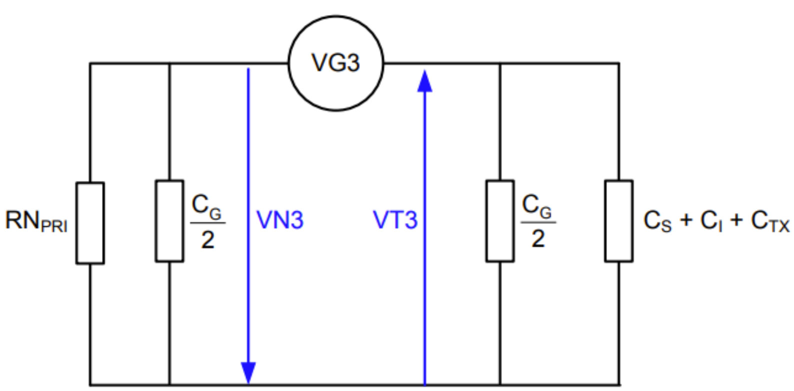


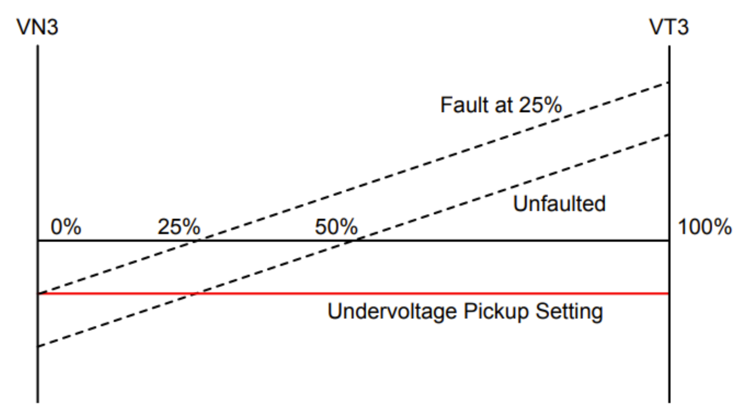


Third Harmonics Under-Voltage 27N3 Element for 100% Stator Earth Fault Protection

Setting

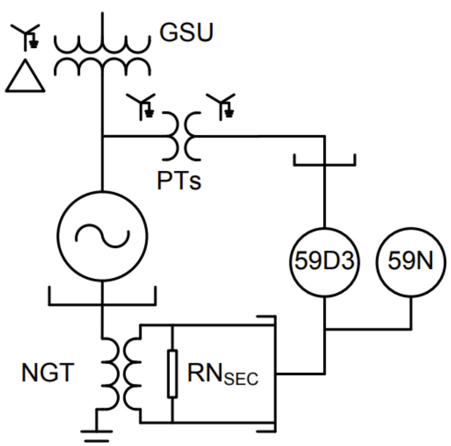
- **Low enough** to remain security with minimum third-harmonic voltage for unfaulted generator.
- **High enough** to detect ground faults across the required range.
- $pickup_{27N3} = VN3_{MIN} /2$, where $VN3_{MIN}$ is the lowest value of VN3 observed during test
- During low load condition, the observed third harmonics voltage is small. the element could be supplemented with torque-controlled low forward power element, allowing a higher undervoltage setting to be applied.
- Sensitivity of 27N3 element is dependent on the *voltage characteristics* of the machine.
- Third harmonic generated by the machine is expected to vary with the fundamental terminal voltage. During generator starting with reduced frequency, this element is not expected to provide coverage in case the setting is not frequency dependent.
- Neutral third harmonic might change significantly when the generator is offline, especially in the case of a synchronizing breaker on the low-voltage side of the GSU.

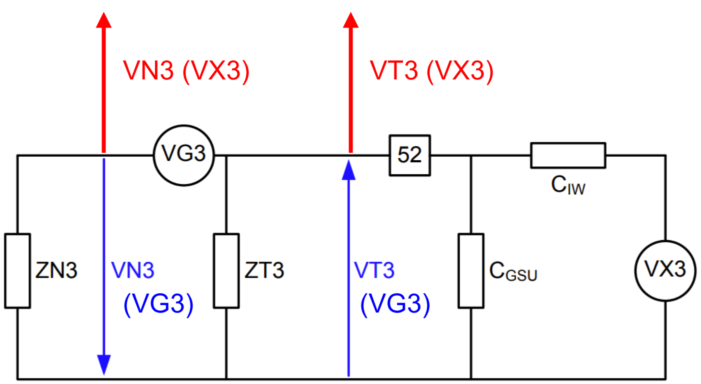




Voltage Differential Scheme 59D3 Element for 100% Stator Earth Fault Protection

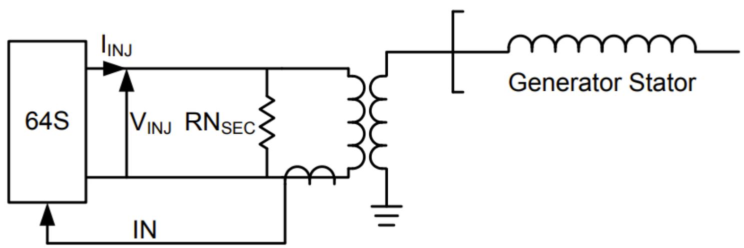
- **Third harmonic undervoltage 27N3** is difficult to set and determine its actual coverage.
- Although generator 3rd harmonics varies significantly, the ratio of the voltage drop VT3 and VN3 relies mainly on the ratio ZN3 / ZT3, which is a constant during normal operation.
- A voltage differential scheme requires an additional grounded wye VT at the terminal to measure VT3. An open delta is required for EM relay, while internal summation of line-to-neutral voltage at digital relay is needed.
- OP = ||VN3| - RAT |VT3|| > PKP
  where RAT is the ratio setting to make operating quantity OP = 0 during normal operation,
  and PKP is the pickup setting.
- It is recommended to carry a survey on VN3 and VT3 with MW and MVAR varies.
- Ideally, the ratio is constant over the operating range of the machine. Yet, the GSU itself can be an external source of third harmonics, e.g. due to coupling with interwinding capacitance C_{IW}. The ratio is heavily affected when the generator third harmonics drops to low magnitude at low load condition.
- When the generator CB (52) is opened, the GSU capacitance is no longer parallel with other terminal impedance, and the scheme does not respond to any external third-harmonic source. In such case, offline and online mode of operation should employ different setting.

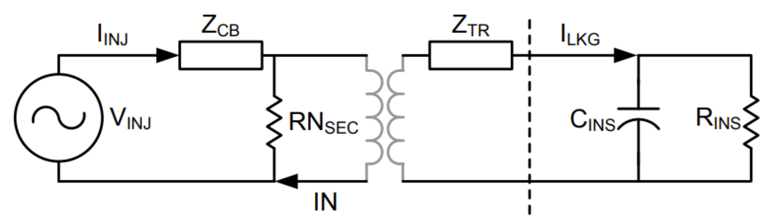




Subharmonic Injection Scheme 64S Element for 100% Stator Earth Fault Protection

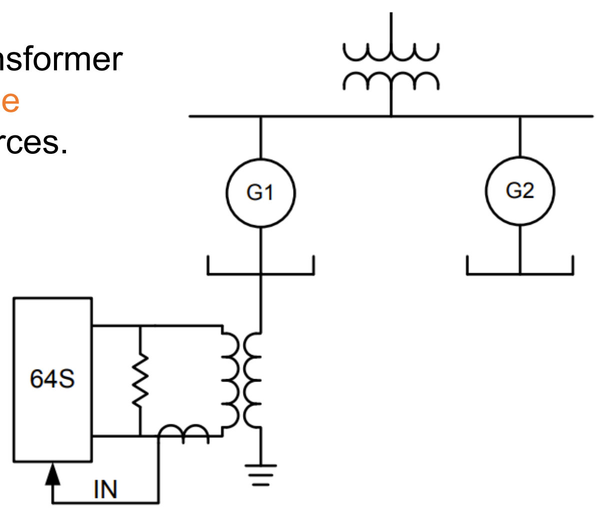
- A known voltage signal (multi-sine) is injected into stator through NGT and the resultant current is measured.
- The operating principle is to detect a change in measured stator leakage (insulation) resistance. V_{INJ} and I_{INJ} is used to calculate R_{INS} and C_{INS}. To improve the accuracy of calculated R_{INS}, the capacitance leakage current should be decreased by operating at a subharmonic frequency.
- The reason to make it a multi-sine is to reduce interference, especially during generator start-up with different rotor frequency. Each sine creates its sets of (R_{INS}, C_{INS}) and the multi-sets increase the reliability of protection scheme. Monitoring R_{INS} under normal operating condition provides an optimal setting.
- R_{INS} : detect possible insulation degradation; C_{INS} : detect grounding problems in stator circuits.

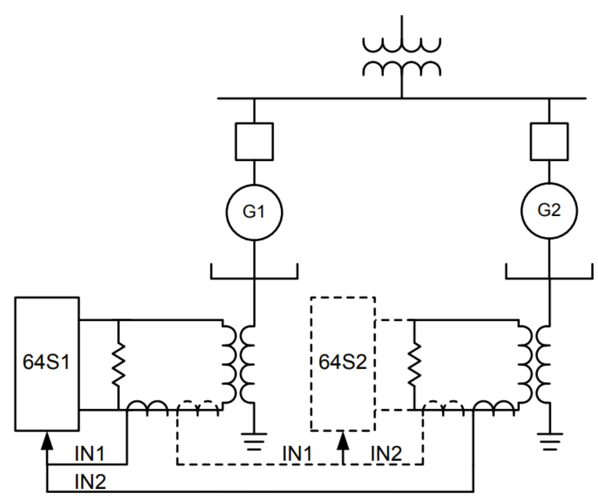


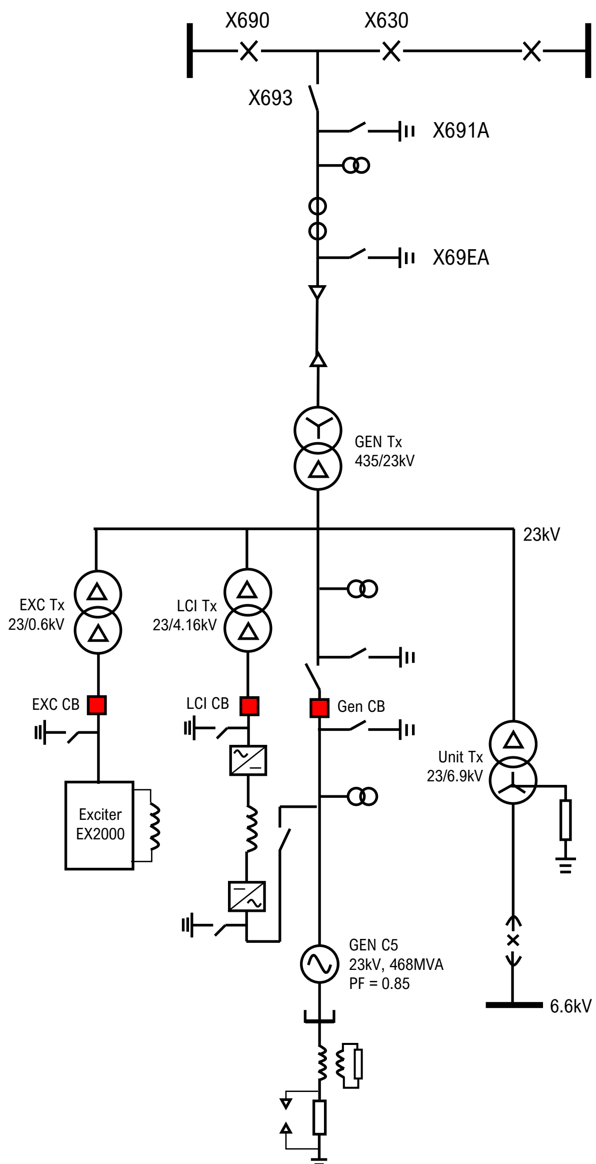


Parallel generators sharing same transformer often upset the passive neutral voltage protection as it presents external sources.

Neutral current at other generators should also be monitored to improve the accuracy of R_{INS} estimation.
It is also suggested to employ different frequency to avoid cross interference between 64S.







Follow-up Action on Turbine Trip and Master Trip due to GT HV Fault:

1. Isolate the fault with CBX690, X630, LCI CB, EXC CB, GEN CB and UTx LV CB Open.

2. Shaft Line tripped to cut off mechanical power input.
   If the shaft line is not tripped and mechanical power input is not stopped, with the power output cut-off with CBX690 and CBX630 opened, the mechanical power input accelerates the rotor and damage the shaft.

3. EXC CB Open to cut of excitation.
   If synchronous generator is loss of excitation, the generator will operate as an induction generator with reactive power (2 – 4 p.u. of rated load) taken from grid to build up field. It could lead to further voltage dip.