Steve Schoenherr – Minnesota Power **Roger Hedding – ABB Inc.**

100% Stator Ground Fault Detection Implementation at the Hibbard Renewable Energy Center

Minnesota Power

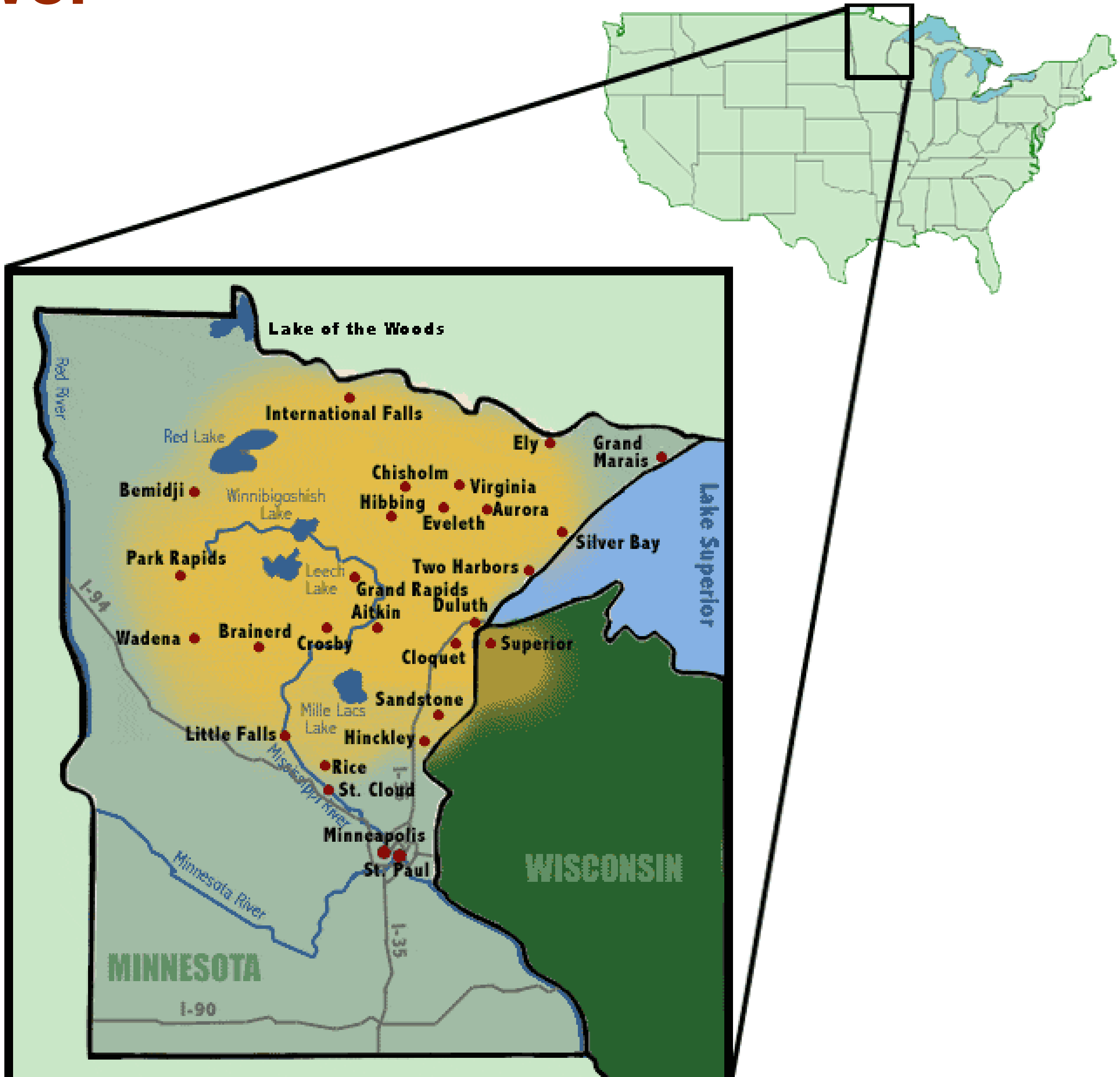
143,000 retail customers

Serve 16 municipalities

5 thermal plants

11 Hydro stations

1500 Megawatts net



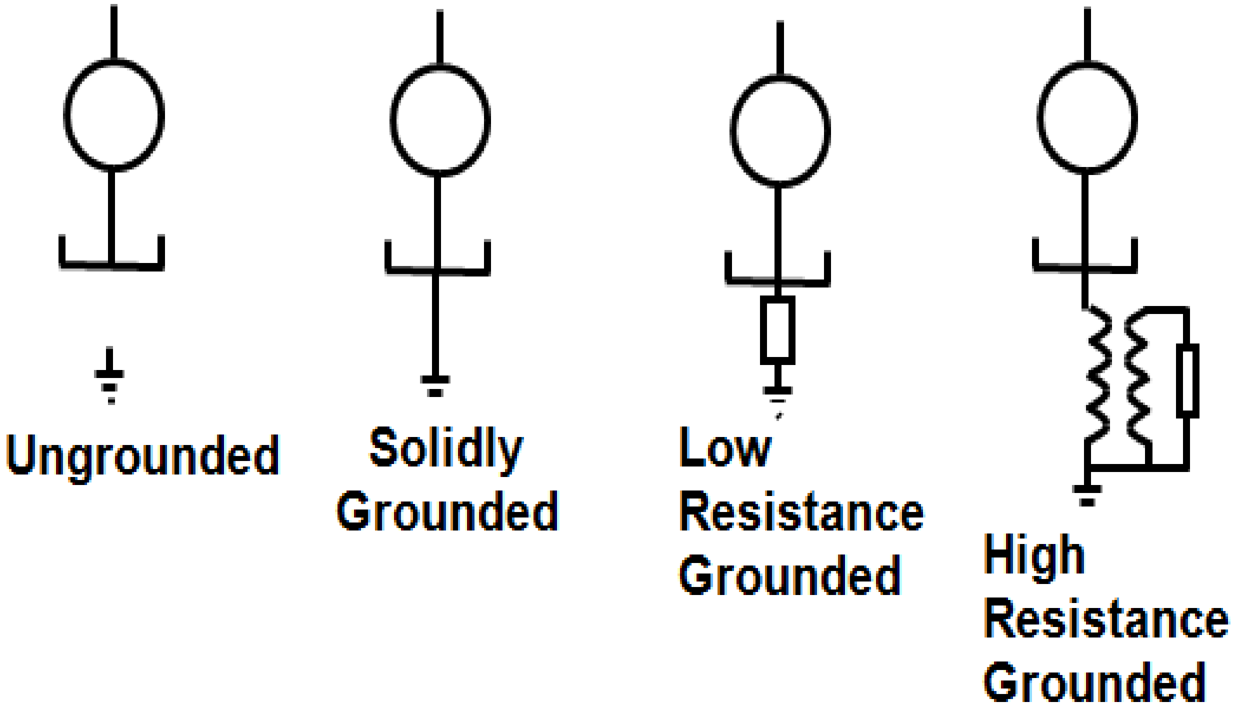
Minnesota Power generator protection upgrade

- Upgrading Protection at Power plants
- Changing grounding from low impedance to high impedance
- Normally used neutral overvoltage and third harmonic voltage to detect stator ground faults
- Found not to be reliable on Laskin Energy Center Units 1 and 2
- Since Hibbard Units 3 and 4 are similar design chose to use another method of 100% stator ground fault protection

Outline for Presentation

- Introduction
- Generator Grounding
- Types of Ground fault protection
- Stator Ground fault protection at Hibbard
- Commissioning
- Conclusions

Types of Generator Grounding



Ungrounded

- Generator grounded through winding and cable capacitance
- Fault current negligible
- Rarely used
- Neutral must be insulated for full phase to phase voltage

Solidly Grounded

- Generator neutral directly tied to ground
- High magnitude of fault current unacceptable because of extreme damage to generator
- Tripping generator breaker, field, and prime mover does not cause fault current to immediately go to zero due to trapped flux in field.
- Not commonly used

Low impedance grounding

- The resistor or reactor is chosen such that the fault current for a single line to ground fault is limited to between 200 amps and 150% of rated load current.
- Phase differential relays can provide some ground fault protection for higher level faults, but added protection is required.

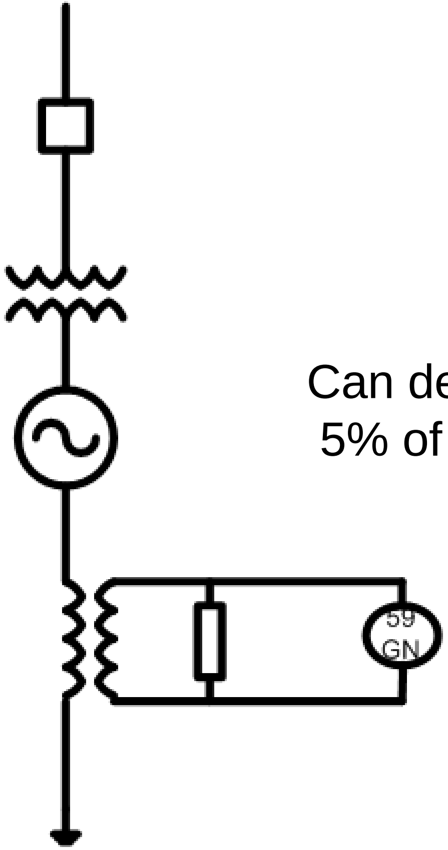
High Impedance grounding

- Mainly used on unit connected generators
- Distribution transformer is used for grounding with a resistor placed on the secondary to limit the ground fault current to 3 – 25 amps.
- Distribution transformer primary voltage chosen to be slightly greater than the line to neutral voltage of the generator.
- The secondary rating is either 120 or 240 v.
- Ground fault level too low for generator differential to detect.

Stator Ground fault detection methods

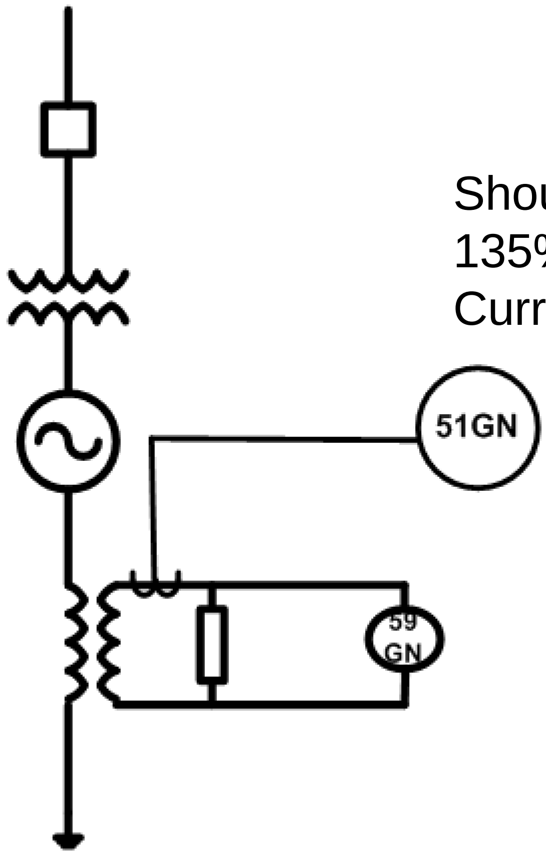
- Classical neutral overvoltage
- Neutral time overcurrent
- Third harmonic undervoltage
- Third harmonic residual voltage
- Third harmonic comparator
- Voltage/current injection

Neutral Overvoltage (59GN)



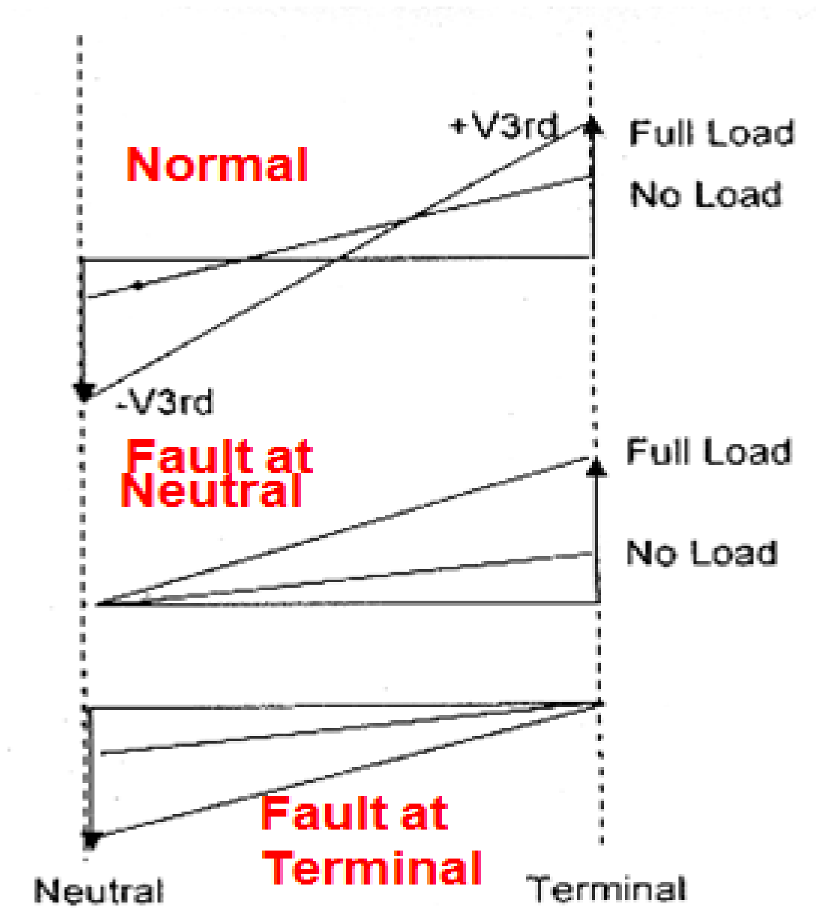
Can detect faults down to within
5% of the generator neutral

Neutral time overcurrent (51GN)

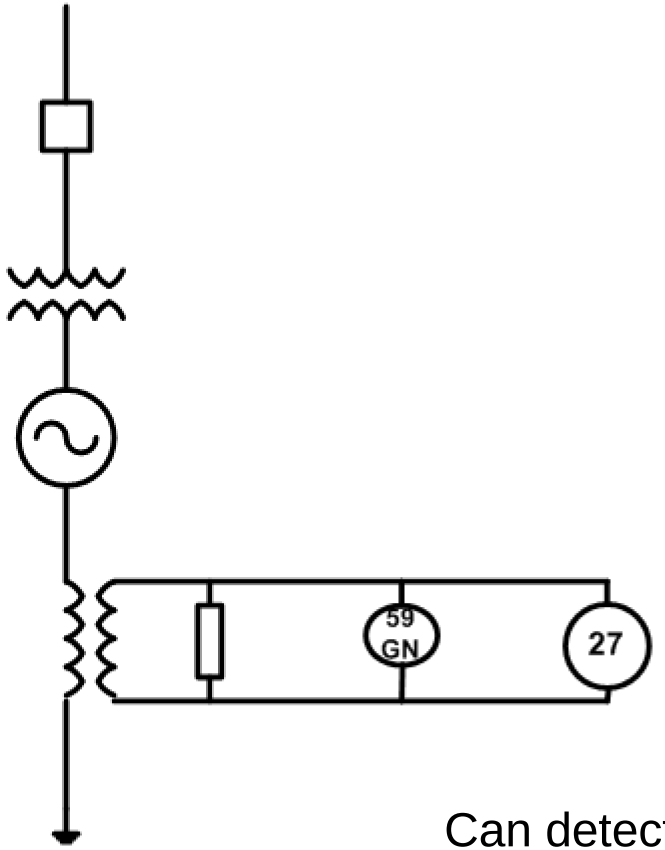


Should be set greater than
135% of the maximum neutral
Current under non fault conditions

Third Harmonic Voltage Profile



Third Harmonic Undervoltage



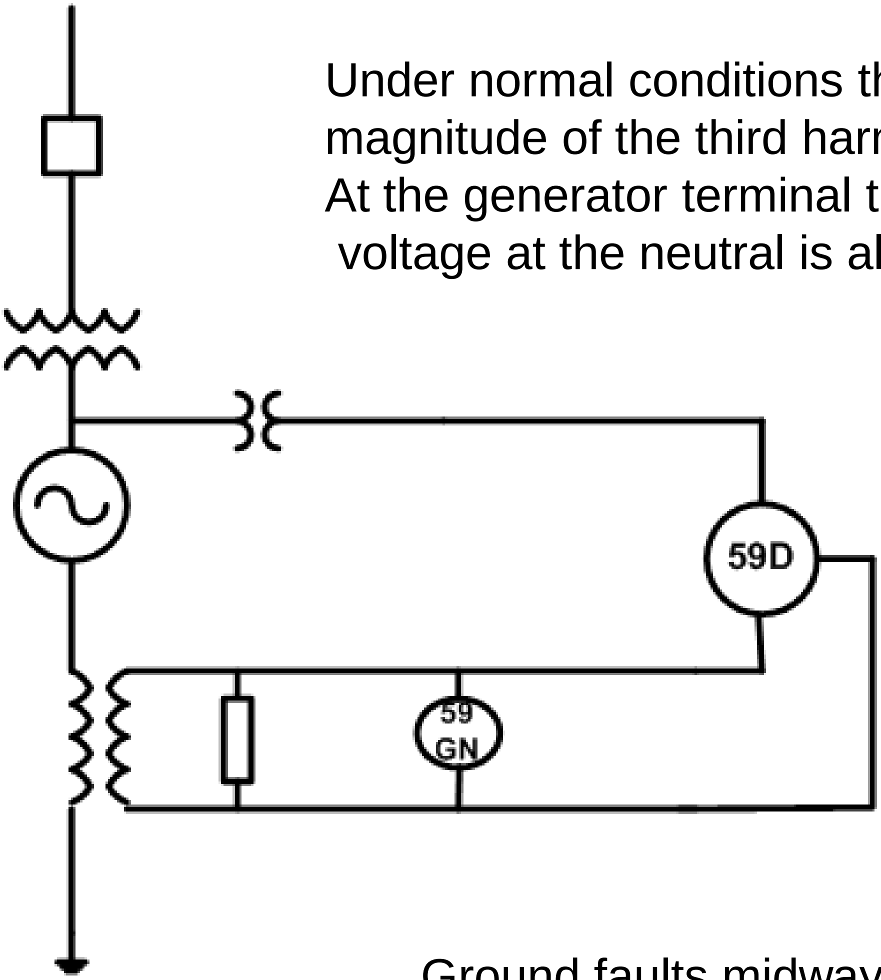
Tuned to 180HZ

Can detect fault from 0 – 30%
Of the stator winding

Third Harmonic Residual voltage

- Third Harmonic generator terminal voltage increases as ground fault approaches the neutral.
- Residual voltage at generator terminals supplied by wye grounded – broken delta potential transformer
- Overvoltage relay tuned to 180HZ.
- For faults near generator terminal not enough third harmonic voltage to operate relay.
- Must use with 59GN.

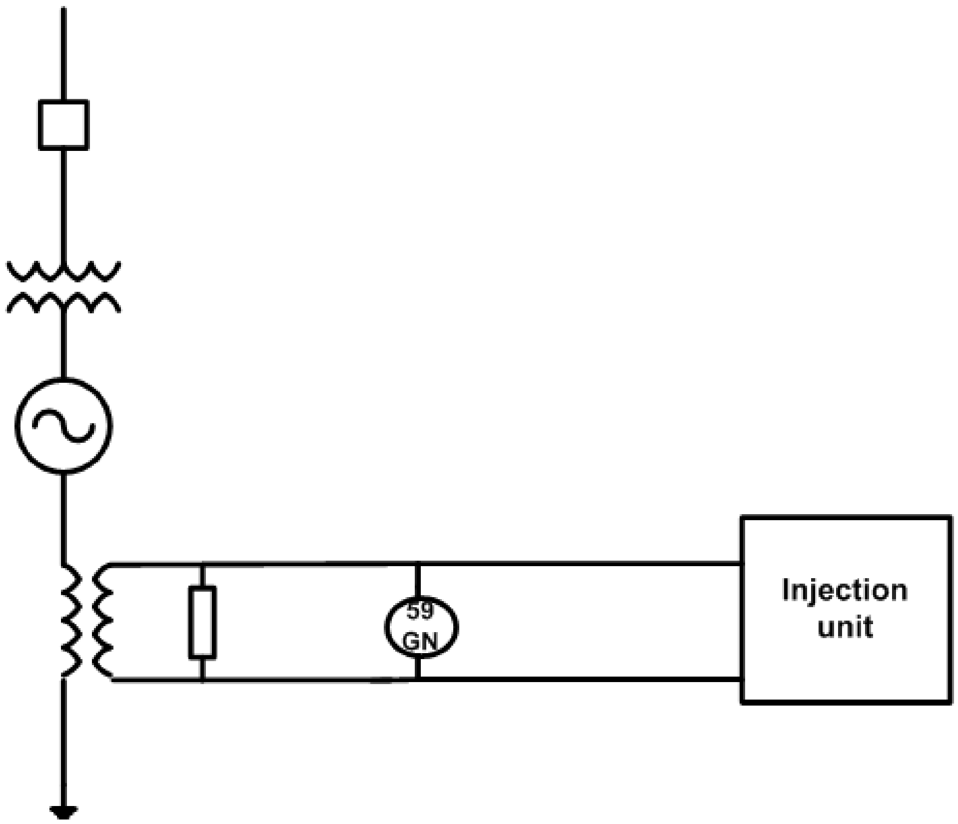
Third Harmonic Comparator



Under normal conditions the ratio of the magnitude of the third harmonic voltage
At the generator terminal to the third harmonic voltage at the neutral is almost constant.

Ground faults midway in stator winding are Detected by 59GN.

Voltage injection



Independent signal with a
certain frequency is injected
Into stator circuit

Measured current and
voltage used to calculate
The stator winding resistance
To ground.

Not influenced by generator
Operating conditions

Grounding upgrade at Hibbard

- Existing grounding of unit 3 & 4 was low impedance
- Upgrade to high impedance
- Transformer

    13,800 v Primary

    240 v secondary

Resistor

    1.664 ohms, 8154w

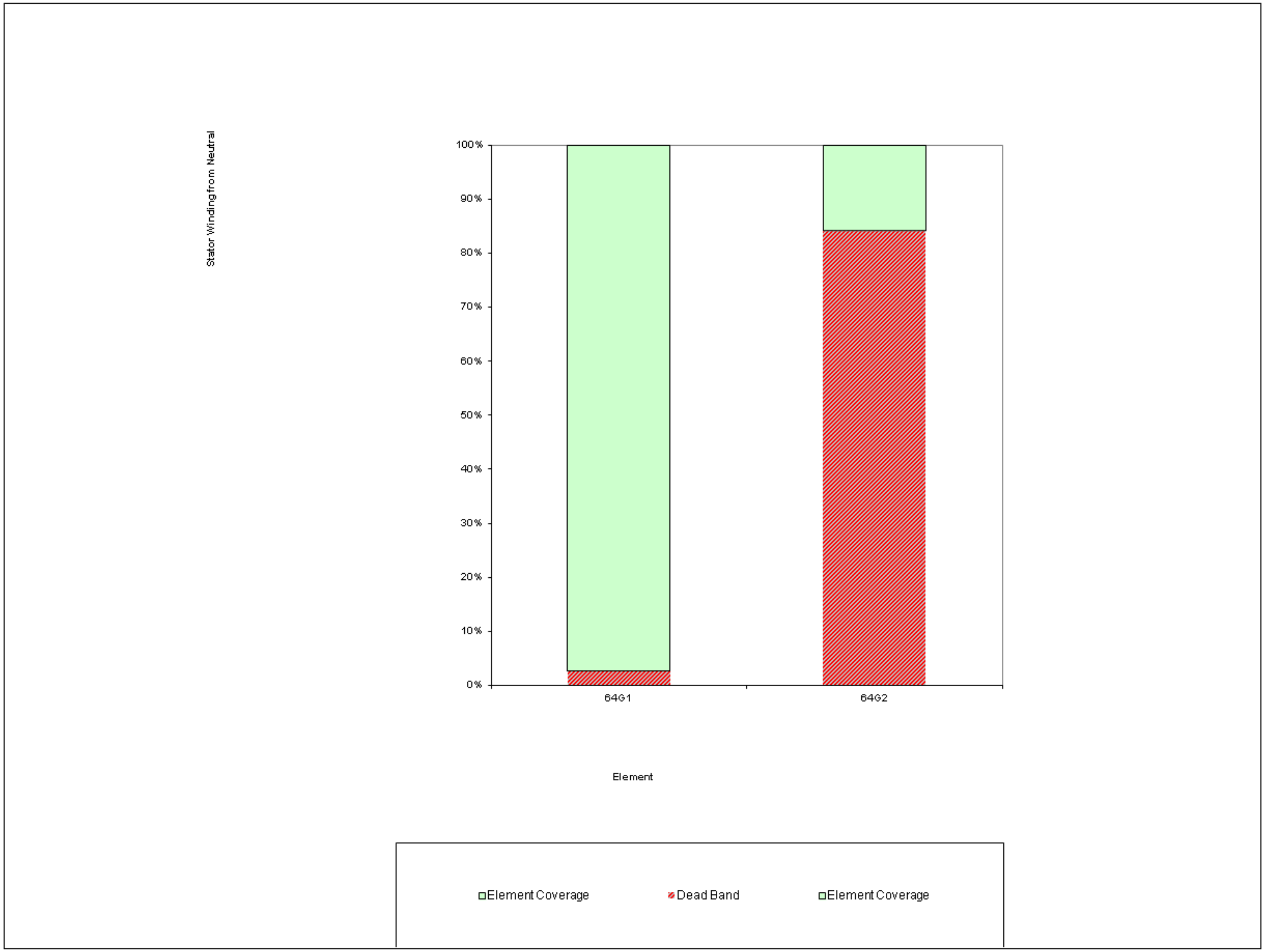
Limit ground fault current to 6 amp

Stator Ground protection at Hibbard

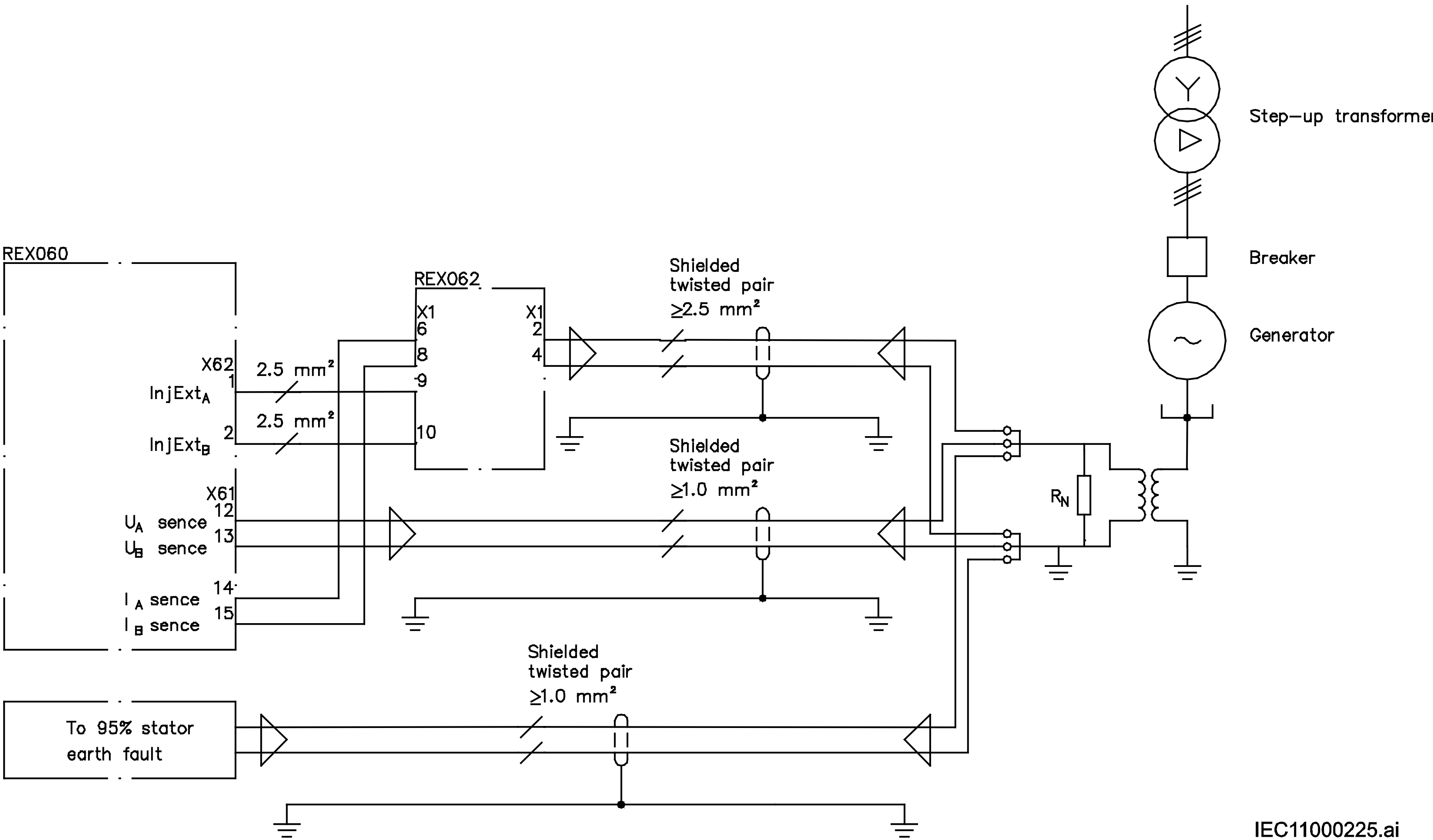
- Third harmonic voltage readings from Unit 3 after new relays installed did not produce sufficient third harmonic voltage for third harmonic comparator scheme

GENREATOR LOAD	3RD HARMONIC SECONDARY VOLTAGE TERMINAL SIDE	3RD HARMONIC SECONDARY VOLTAGE NEUTRAL SIDE
Off Line	1.753V	2.010V
0.364 MW	1.865V	2.154V
1.052 MW	1.943V	2.249V
5.163 MW	2.960V	3.609
8.679 MW	3.914V	4.801V

Stator fault coverage



100% Stator Ground Implementation



100% Stator Ground fault Protection elements

Three Main Parts of Stator Ground Protection

- Generator Protection Relay
- Injection unit
- Shunt Resistor

Injection unit

- Injects square wave into secondary side of grounding transformer
- Frequency of 106HZ
- Measures the resulting 106HZ current
- Generator relay uses these values to calculate a reference resistance from winding to ground
- This value compared to value set during commissioning

Shunt Resistor

- Installed to protect Injection unit
- Injection unit designed to handle 120v not 240v as present on secondary of grounding transformer

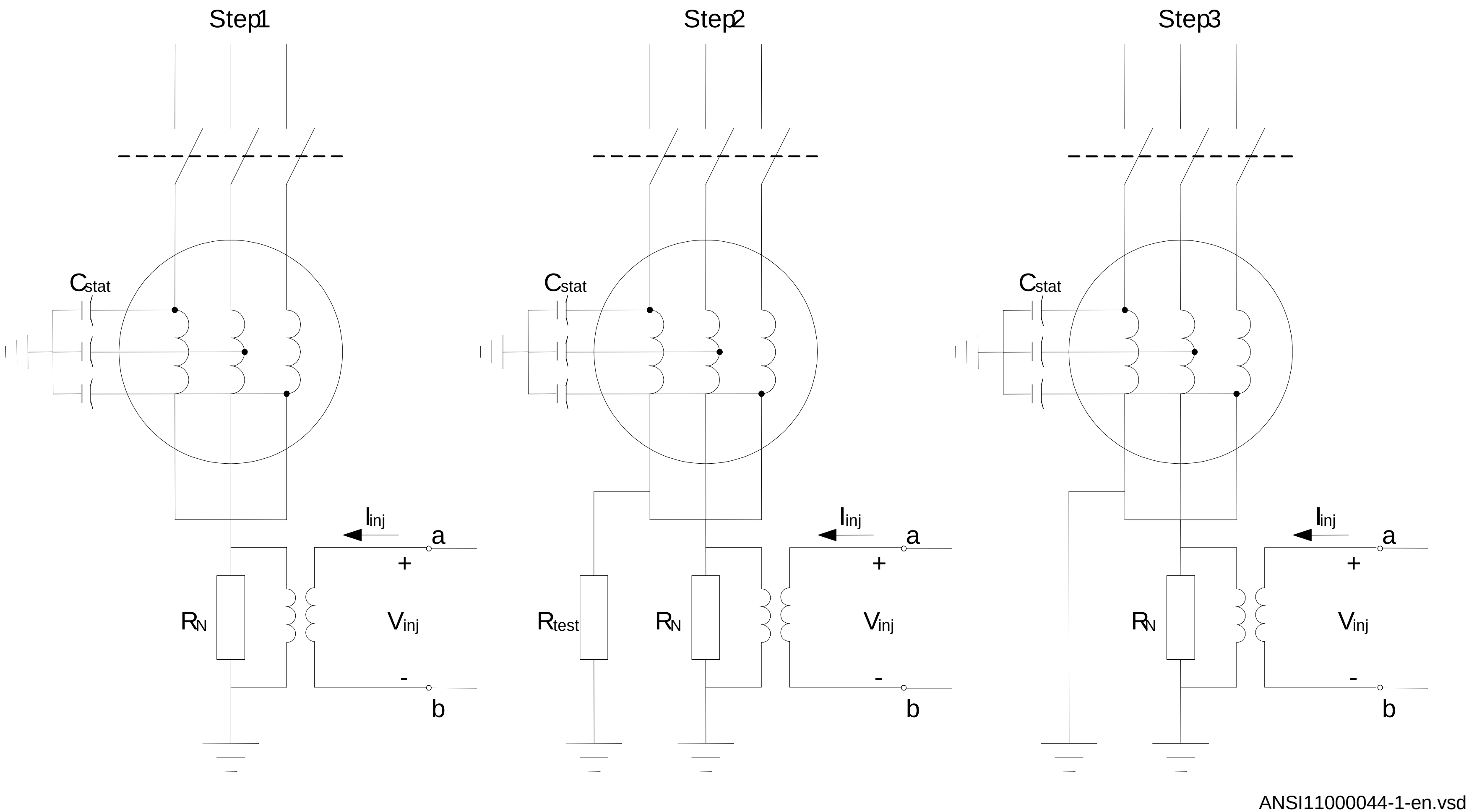
Commissioning

- Injection unit needs to be calibrated
- Resistance of the stator is being measured at the generator protection relay which led to approximately 250’ of cable to the grounding transformer of the generator
- Calibration accounts for the resistance of this cable.

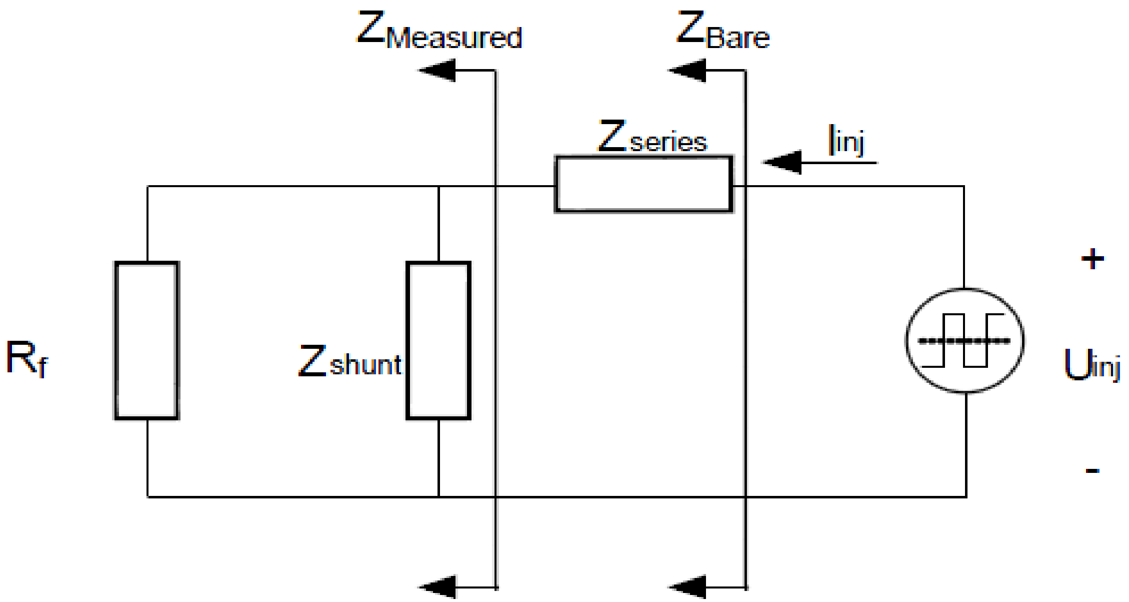
Three step calibration

- Measure with the injection circuit in its final configuration
- Injection with a known resistance from the neutral of the generator to ground.
- Injection with the neutral of the generator grounded

Calibration steps



K1 and K2 Values



$Z_{Bare} = V_{inj} / I_{inj}$... eq. 1

$Z_{measured} = Z_{Bare} \cdot K_1 + K2$ eq 2

Stator readings as unit is loaded

STATOR READINGS		
LOAD (MW)	REAL (OHM)	IMAGINARY (OHM)
VR OFF	1224.244	-945.448
VR ON OFF LINE	1313.83	-1020.388
3	1310.125	-1023
10	1299.284	-1022.067
15	1302.019	-1023.031
19.5	1294.789	-1024.84
27.7	1279.789	-1026.547
32.9	1277.404	-1028.37
37.5	1272.637	-1029.127

A setting of 1000 ohms was set for tripping the unit

Conclusion

- 100% stator ground fault protection is essential for generators
- Before implementing a protection method make sure there is adequate margin between operating quantities and fault quantities. In MP case there wasn’t sufficient third harmonic differential voltage for the scheme to work.
- The injection method was easy to apply, commission, and calibrate
- Applying high impedance grounding scheme also limits potential damage from ground faults