64S Protection Guide—
Theory, Application and Commissioning of Generator 100% Stator Ground Fault Protection Using Low Frequency Injection

Steve Turner
Senior Applications Engineer

BECKWITH ELECTRIC COMPANY, INC.
TRADITIONAL APPROACHES

Prior
• Neutral Overvoltage Scheme (only 90-95%)

Late 70’s
• 100% 3rd Harmonic Neutral Undervoltage Scheme Introduced

Early 80’s
• 100% 3rd Harmonic Ratio Scheme Introduced
• 100% Sub-Harmonic Injection Schemes used in Europe
Stator Ground Faults Close to the Neutral Do Occur!

- 210 MW Generator (commissioned in 1991)
  - Stator – water cooled
  - Rotor – hydrogen cooled
- 3x 84 MVA GSU (252 MVA)
  - 240/15.75 kV
  - Isolated Phase Bus Conductor

- Total of six 64S operations
- Stator was replaced in 2011 due to core looseness and partial deterioration
- 6th stator ground fault occurred within 10 percent of the neutral following the replacement which was detected by 64S

Other examples will be shown.
Catastrophic Damage - Stator Grounds in last 5% of the Winding

A generator trip will not typically occur if a failure occurs in a lower voltage portion of the winding near the neutral, until some other relay protection detects there is a problem, (e.g., arcing becomes so widespread that other portions of the winding become involved).

There has been recent experience with four such failures in large generators that demonstrate the lack of proper protection can be disastrous.

Each of the four failures caused massive damage to the generator and collectively had a total cost, including repair and loss of generation, close to $500,000,000. **This demonstrates that failure of stator windings in the last five percent of the winding is not uncommon.**
Catastrophic Damage - Stator Grounds in last 5% of the Winding

Winding Damage:  
Broken Stator Winding Conductor

Core and Winding Damage:  
Burned Open Bar in a Slot

Burned Away Copper:  
Fractured Connection Ring
59N Neutral Overvoltage Protection

Fault Position

Voltage at Neutral (60 Hz)

<table>
<thead>
<tr>
<th>%</th>
<th>Voltage (pu)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>0</td>
</tr>
<tr>
<td>50%</td>
<td>0.5</td>
</tr>
<tr>
<td>100%</td>
<td>1.0</td>
</tr>
</tbody>
</table>

90-95%
59N Coordination Issues

NOTE:
20 Hz injection scheme is decoupled from 50|60 Hz system so it can be set with much less time delay

F1 – TRANSMISSION SYSTEM GROUND FAULT
F2 – VT SECONDARY GROUND FAULT
3rd Harmonic Neutral Undervoltage Scheme
Overlap 59N and 27TN: Provides 100% Stator Ground Fault Coverage
3rd Harmonic Undervoltage Scheme Disadvantages

- Requires Extensive Field Testing to Determine Minimum 3rd Harmonic (must run generator at various levels of load)
- May Have to be Blocked during some Operating Conditions
- Will not Work at all if 3rd Harmonic is Low (otherwise can false trip)

More Security = Less Reliability
3rd Harmonic Ratio Scheme

\[ \text{Ratio} = \frac{V_{\text{terminal}}}{V_{\text{neutral}}} \]
3rd Harmonic Ratio Scheme Disadvantages

• Requires Measurement of 3rd Harmonic Terminal Voltage

• Requires Wye Grounded Primary VT with Broken Delta Secondary

• Requires Extensive Field Testing to Determine Maximum 3rd Harmonic Ratio

• Will Not Work at all if 3rd Harmonic is Low (*But No False Tripping*)
3rd Harmonic Scheme Limitations at Hydro Plants

• False Tripping during Load Rejection

• Synchronous Condenser Operation

• Performance of Third Harmonic Scheme on Parallel Generators
64S

20 Hz SUB-HARMONIC VOLTAGE INJECTION
20 Hz Voltage Injection Scheme
Coupling Filter and Voltage Injector
Band Pass Filter (Hardware)

- The RLC series network is tuned to 20 Hz – any other frequency is rejected.
- If the total R is too high (including inductor winding losses) then the protection is unnecessarily desensitized.
- If the protection is compromised, it will fail to provide **early warning** when insulation is just starting to break down.
High Current Rejection (Hardware)

0.8 \times (240 \text{ V}) = 192 \text{ volts across } R_N

R_N = 0.125 \text{ ohms}

I_N(60 \text{ Hz}) = \frac{(192 \text{ V})}{(0.125 \text{ } \Omega)}/(400/5) = 19.2 \text{ amps}

High current can saturate low current input designed to measure in milli-amps
64S Settings

- **Total Current Pickup (|I_N|):**
  Backup protection for neutral faults (0 volt)
- **Real Component Pickup (Re[IN]):**
  Detect a ground as soon as insulation begins to break down (very sensitive)
Commissioning:
20 Hz Neutral Current Measurements

Open the High Side GSU Breaker While Testing
Commissioning:
Short Circuit at Machine Neutral

\[
\frac{25V}{8\text{ohms} \times 80} = 39 \text{ mA}
\]
Commissioning:
Fault Resistance at Machine Neutral
Calculation of 20 Hz Neutral Current
No Fault

Primary

Secondary

$\text{R}_{\text{Stator}} > 50 \text{ kilo-ohms}$

$X_{\text{CP}}$

$\text{R}_{\text{Filter}} = 8 \text{ Ohms}$

$\text{CT} = 400:5$

$25 \text{ V}$

$20 \text{ Hz}$

$\text{V}$
Main Sources of Ground Capacitance

Stator Windings

Iso-Phase Bus
Calculation of 20 Hz Neutral Current
No Fault

Generator/Bus/GSU

Injection System

\[ X_{CS}/N^2 \]

\[ R_S/N^2 \]

Secondary

\[ I_t \]

CT = 80:1

8 Ohms

25 V

20 Hz

CT = 80:1
Calculation of 20 Hz Neutral Current

*No Fault*

64S can be commissioned **in less than one hour** assuming there are no wiring errors.

*Numerical Generator Relay 20 Hz Metering*
20 Hz Neutral Current ($I_N$) during Ground Fault

$R_N = 0.5 \text{ ohms}$
20 Hz Neutral Current during Ground Fault

20 Hz Neutral Current as Function of Insulation Resistance

\[ R_N = 0.5 \text{ ohms} \]

MIN \( (R_s > 50 \text{ k-ohms}) \) \hspace{1cm} \text{MAX} \( (R_s = 1 \text{ k-ohm}) \)

\[ \boxed{R_N = 0.5 \text{ ohms}} \]
Real Component

\[ X_{cs} \sim \frac{1}{C_0} \]

As \( C_0 \) increases more current flows through \( X_{cs} \)

\[ \text{Current measurement is more sensitive and reliable as compared to an impedance measurement} \]
Pros

- Does Not Use 3rd Harmonic Voltage
- Independent of Generator MW and MVAR Loading
- Can Detect Stator Ground Fault When Generator is Off-Line
- Detects Stator Ground Faults Over the Entire Winding – *No Blind Spots*
CONCLUSIONS

- 100% Stator Ground Fault Protection Prevents Major Damage (for example, two simultaneous grounds close to neutral)
- If 3rd Harmonic Schemes are Being Considered
  *It is Important to First Determine Generator 3rd Harmonic “Signature”* (lots of metering data)
- 3rd Harmonic Schemes Have Many Limitations
- 20 Hz Injection is Superior
- 20 Hz Injection Scheme Detects Stator Grounds Over Entire Stator Winding
- 20 Hz Injection Scheme Detects Stator Grounds When Generator is Off-Line
64S Protection Guide—
Theory, Application and Commissioning of
Generator 100% Stator Ground Fault Protection
Using Low Frequency Injection

Steve Turner
Senior Applications Engineer
BECKWITH ELECTRIC COMPANY, INC.

QUESTIONS?