Generator Grounding
IEEE San Francisco
11/16/2010
Quick primer

- Power resistors aren’t color-coded
- Resistors have no polarity
- Know your system before ordering
- Resistors get hot

IEEE Std 32

Time Rating and Permissible Temperature Rise for Neutral Grounding Resistors

<table>
<thead>
<tr>
<th>Time Rating (On Time)</th>
<th>Temp Rise (deg C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ten Seconds (Short Time)</td>
<td>760°C</td>
</tr>
<tr>
<td>One Minute (Short Time)</td>
<td>760°C</td>
</tr>
<tr>
<td>Ten Minutes (Short Time)</td>
<td>610°C</td>
</tr>
<tr>
<td>Extended Time</td>
<td>610°C</td>
</tr>
<tr>
<td>Continuous</td>
<td>385°C</td>
</tr>
</tbody>
</table>
Advantages of Neutral Grounding

- Greater safety for personnel and equipment
- Increased service reliability
- Lower operating and maintenance expense
- Reduced magnitude voltage transients
- Simplified ground-fault location
IEEE Std 242-2001 (Buff Book)

12.4 Generator Grounding

Generators are not often operated ungrounded. While this approach greatly limits damage to the machine, it can produce high transient overvoltages during faults and also makes it difficult to locate the fault.
NEMA Std MG 1-2003  Motors and Generators

32.34 Neutral Grounding

- For safety of personnel and to reduce over-voltages to ground, the generator neutral is often either grounded solidly or grounded through a resistor or reactor.
- The neutral may be grounded through a resistor or reactor with no special considerations required in the generator design or selection unless the generator is to be operated in parallel with other power supplies.
- The neutral of a generator should not be solidly grounded unless the generator has been specifically designed for such operation.
Objectives of Generator Grounding

- Minimize the damage for internal ground faults
- Limit mechanical stress in the generator from external ground faults
- Provide a means of system ground fault detection
- Coordinate with other system/equipment requirements
Solidly Grounded Systems

- Best suited for LV 3Ø, 4W systems
- Generator must be rated for use as solidly grounded
- System trips on first fault
- Coordinated relay scheme may be difficult
Three Pole Transfer Switch

- Generator neutral unbonded from case ground
- Single neutral to ground connection
- Not considered separately derived systems
IEEE Std. 142-1991 (Green Book)

1.8.1 Discussion of Generator Characteristics

- Unlike the transformer, the three sequence reactances of a generator are not equal. The zero-sequence reactance has the lowest value, and the positive sequence reactance varies as a function of time. Thus, a generator will usually have higher initial ground-fault current than a three-phase fault current if the generator is solidly grounded. According to NEMA, the generator is required to withstand only the three-phase current level unless it is otherwise specified...

A generator can develop a significant third-harmonic voltage when loaded. A solidly grounded neutral and lack of external impedance to third harmonic current will allow flow of this third-harmonic current, whose value may approach rated current. If the winding is designed with a two-thirds pitch, this third-harmonic voltage will be suppressed but zero-sequence impedance will be lowered, increasing the ground-fault current...

Internal ground faults in solidly grounded generators can produce large fault currents. These currents can damage the laminated core, adding significantly to the time and cost of repair...Both magnitude and duration of these currents should be limited whenever possible.
## Generator Impedance Example

<table>
<thead>
<tr>
<th>Frame/# of brgs</th>
<th>691/2</th>
<th>692/2</th>
<th>693/2</th>
<th>695/1</th>
<th>696/1</th>
<th>697/1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volts</td>
<td>480</td>
<td>480</td>
<td>480</td>
<td>480</td>
<td>480</td>
<td>480</td>
</tr>
<tr>
<td>Arrt. Number</td>
<td>144-1748</td>
<td>166-2664</td>
<td>144-1754</td>
<td>166-2680</td>
<td>166-2692</td>
<td>166-2698</td>
</tr>
<tr>
<td>Ratings</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>120° C Rise</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ekW</td>
<td>900</td>
<td>1000</td>
<td>1100</td>
<td>1250</td>
<td>1400</td>
<td>1500</td>
</tr>
<tr>
<td>kVA</td>
<td>1125</td>
<td>1250</td>
<td>1375</td>
<td>1563</td>
<td>1750</td>
<td>1875</td>
</tr>
<tr>
<td>Motor Starting Capability at 30% Voltage Dip</td>
<td>2100</td>
<td>2050</td>
<td>2477</td>
<td>3018</td>
<td>3222</td>
<td>2661</td>
</tr>
<tr>
<td>Pitch</td>
<td>0.7142</td>
<td>0.7142</td>
<td>0.7222</td>
<td>0.7333</td>
<td>0.6666</td>
<td>0.7333</td>
</tr>
<tr>
<td>Efficiency (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100%</td>
<td>94.4</td>
<td>94.4</td>
<td>95</td>
<td>95.4</td>
<td>95.7</td>
<td>95.8</td>
</tr>
<tr>
<td>75%</td>
<td>94.8</td>
<td>94.9</td>
<td>95.4</td>
<td>95.7</td>
<td>96.0</td>
<td>96.1</td>
</tr>
<tr>
<td>50%</td>
<td>94.7</td>
<td>94.9</td>
<td>95.2</td>
<td>95.5</td>
<td>95.8</td>
<td>96.0</td>
</tr>
</tbody>
</table>

### Reactances (per unit)

<table>
<thead>
<tr>
<th>Subtransient Direct Axis</th>
<th>X’d</th>
<th>X’q</th>
<th>0.1723</th>
<th>0.1988</th>
<th>0.179</th>
<th>0.1662</th>
<th>0.1783</th>
<th>0.2346</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subtransient Quadrature Axis</td>
<td>X’d</td>
<td>X’q</td>
<td>0.2027</td>
<td>0.233</td>
<td>0.2174</td>
<td>0.2027</td>
<td>0.2209</td>
<td>0.292</td>
</tr>
<tr>
<td>Transient Saturation</td>
<td>X’d</td>
<td>X’q</td>
<td>0.2492</td>
<td>0.2833</td>
<td>0.2583</td>
<td>0.2405</td>
<td>0.2529</td>
<td>0.3273</td>
</tr>
<tr>
<td>Synchronous Direct Axis</td>
<td>Xd</td>
<td>Xq</td>
<td>3.522</td>
<td>3.89</td>
<td>3.6277</td>
<td>3.4137</td>
<td>3.4743</td>
<td>4.4266</td>
</tr>
<tr>
<td>Synchronous Quadrature Axis</td>
<td>Xd</td>
<td>Xq</td>
<td>1.7443</td>
<td>1.9287</td>
<td>1.7979</td>
<td>1.6941</td>
<td>1.7266</td>
<td>2.2033</td>
</tr>
<tr>
<td>Negative Sequence</td>
<td>X2</td>
<td>Xq</td>
<td>0.1875</td>
<td>0.2159</td>
<td>0.1982</td>
<td>0.1845</td>
<td>0.1996</td>
<td>0.2633</td>
</tr>
<tr>
<td>Zero Sequence</td>
<td>Xo</td>
<td>Xq</td>
<td>0.0328</td>
<td>0.0367</td>
<td>0.0413</td>
<td>0.0482</td>
<td>0.004</td>
<td>0.0681</td>
</tr>
</tbody>
</table>
Resistance Grounding

**High Resistance**
- More often at LV than MV
- Less than 10 amps continuously
- Avoid shutdowns
- Least damage

**Low Resistance**
- More often at MV than LV
- Less than 1000 amps for ten seconds
- Safely shutdown
- Less damage than solidly grounded

[Diagram of resistance grounded circuit]
Four Pole Transfer Switch

- Allows multiple layers of GFP, different grounding methods, multiple generators
MV HRG Schematics

Medium Voltage Wye (Four-Wire) Connected Neutral Grounding Resistor
Single Phase GTR

- Usually paired with resistor to give HRG at MV
- Using line to neutral rated resistor not size/cost efficient
- Current normally less than 15A
- Voltage equal to system line to neutral voltage
- Secondary typically 240 V
System Capacitance

A capacitor is an electrical device that can store energy in the electric field between a pair of closely spaced conductors

(Thank you, Wikipedia)

- Capacitance re-charges during an arcing fault, creating a larger overvoltage
- Overvoltage stresses insulation, leading to further faults
In ungrounded systems, a voltage is held on the system capacitance after a fault. In an arcing or intermittent fault, this can lead to a significant voltage build-up.

In a high resistance grounded system, the resistance must be low enough to allow the system capacitance to discharge relatively quickly.
System Charging Current

Only discharges if \( R_o < X_{co} \), so \( I_r > I_{xco} \)
( per IEEE142–1991 1.4.3)

- That is, \textit{resistor current} must be greater than \textit{capacitive charging current}.

- ‘Rule of thumb’ numbers for 480V system

<table>
<thead>
<tr>
<th>Transformer (kVA)</th>
<th>Charging Current (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>0.2 – 0.6</td>
</tr>
<tr>
<td>1500</td>
<td>0.3 – 0.9</td>
</tr>
<tr>
<td>2000</td>
<td>0.4 – 1.2</td>
</tr>
<tr>
<td>2500</td>
<td>0.5 – 1.5</td>
</tr>
</tbody>
</table>
Chosing resistor setting

- Chose fault current higher than capacitive charging current
- Ex. If charging current is determined to be 1.9 A, chose at least 3 A of fault current
Hybrid Grounding

- Low resistance grounding overcomes capacitive charging current
- After generator is isolated the LRG is removed, limiting fault current to 5 A
Ground Fault Detection

- Source Ground – monitors current flow in system grounding conductor connected between neutral and ground

- Zero Sequence – detects vector unbalance of current sum in each phase

- Residual Connected – uses multiple CT’s and relays, indicating any leakage to ground
Excessive Neutral Current

- Neutral current includes ground fault current and harmonics/noise
- Cumulative current may be sufficient to alarm/trip
- Use filter/tuned relay to avoid nuisance alarms

\[ I_{\text{total}} = I_{\text{fault}} + I_{3\text{rd}} + I_{5\text{th}} + I_{7\text{th}} \cdots \]
Communication with Feeder relays

- Faulted feeder has one phase \( \sim 0 \) V
- Zero Sequence CT detects fault current
- Integration of HRG (via Ethernet or RS-485) allows for selective tripping
Alternative for Residual Current

- Less sensitive than ZSCT
- Less costly than ZSCT
- Effective for feeder identification
Paralleled Generators

- Easy if all generators are same design and pitch, always operated at equal loading and are not switched with three pole transfer switch

*IEEE Std. 142-1991 (Green Book)*
1.7.3 Paralleled Generators in an Isolated System
• Collecting neutrals and solidly grounding them collectively creates a path for excessive 3\textsuperscript{rd} harmonic current

• Collecting neutrals through a single grounding resistor may exceed the continuous duty of the resistor
## AWG Stranded Copper Wire Resistance

<table>
<thead>
<tr>
<th>Size</th>
<th>Diameter</th>
<th>Resistance @ 77°F</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>inch</td>
<td>mm</td>
</tr>
<tr>
<td>18</td>
<td>0.0465</td>
<td>1.182</td>
</tr>
<tr>
<td>14</td>
<td>0.0740</td>
<td>1.880</td>
</tr>
<tr>
<td>12</td>
<td>0.0933</td>
<td>2.371</td>
</tr>
<tr>
<td>10</td>
<td>0.1177</td>
<td>2.989</td>
</tr>
<tr>
<td>8</td>
<td>0.1484</td>
<td>3.770</td>
</tr>
<tr>
<td>6</td>
<td>0.1871</td>
<td>4.753</td>
</tr>
<tr>
<td>4</td>
<td>0.2360</td>
<td>5.994</td>
</tr>
<tr>
<td>0</td>
<td>0.3752</td>
<td>9.530</td>
</tr>
</tbody>
</table>

**NEC 250.36**

In no case shall the ground system conductor be smaller than 8 AWG copper or 6 AWG aluminum or copper-clad aluminum.
Separate Grounding Paths

- Separately grounding prevents circulating 3rd harmonic current
- Must have means of disconnecting neutral if generator is being serviced
- Multiple NGR’s has cumulative effect on ground fault current
• A neutral deriving transformer holds the fault current on the main bus to a consistent current rating

• Each generator is protected against internal faults by HRG
Neutral Deriving Transformer

- Creates a neutral point in a 3 wire system
- Rated for system voltage, expected current and duty cycle
- Two methods to establish a neutral
Zig–Zag Transformer

- High impedance to normal phase currents
- Low impedance to fault current
- Duty cycle same as resistor
Wye Delta Grounding Transformer

- Uses 3 industrial control transformers
- Connect to create neutral
- Low voltage resistor
Recommendation

- Solidly ground only at LV when generator permits, loads are non-critical and primarily single phase
- HRG at LV
- LRG at MV or where charging current is excessive