The Importance of the Neutral-Grounding Resistor

Presented by: Jeff Glenney, P.Eng. and Don Selkirk, E.I.T.
• What is high-resistance grounding (HRG)?
• What is the purpose of HRG?
• Why is the neutral-grounding resistor (NGR) so important – Why monitor the NGR?
• Code requirements
• Summary
• Case studies
High-Resistance Grounding of an electrical power system, is the grounding of the system neutral through a resistance which limits ground-fault current to a value equal to, or slightly greater than the capacitive charging current of that system.
What is High-Resistance Grounding?

The Neutral-Grounding Resistor is the connection between the system neutral and ground. It provides a path for ground-fault current to return to the transformer neutral.
What is High-Resistance Grounding?

A properly designed high-resistance-grounded system:

• Combines the benefits of ungrounded and solidly grounded systems:
  • Allows the user to run with a single ground fault on the system, or shut down in an orderly manner
  • Prevents transient overvoltages and limits voltage fluctuation at the neutral during a ground fault
  • Facilitates the location of ground faults
• Minimizes the risk of arc flash and arc blast on the first ground fault
• Limits energy available to a ground-fault fault
• Provides current to current-sensing ground-fault protection
Wire Wound NGR
Edge Wound NGR
NGR in Vented Enclosure
What is the importance of the NGR? – Why Monitor the NGR

What are the consequences of an NGR failure?
Why Monitor the NGR

Load

Ground-Fault Relay
Why Monitor the NGR? – False Sense of Security

Ground-Fault Relay

Load
UNGROUNDED SYSTEM:
NORMAL OPERATION & FAULTED OPERATION

Neutral point established by distributed capacitance

- Phase C at ground potential
- No fault current (no return path to source)

Normal operation

Ground fault on phase C
UNGROUNDED (DELTA) SYSTEM: FAULTED OPERATION WITH TRANSIENT OVERVOLTAGE

- A & B phases are:
  - Line-line voltage above ground
- Phase C > ground voltage
- Intermittent fault current
- Personnel danger

Normal operation

Intermittent ground fault on phase C
WHY MONITOR THE NGR? – False Sense of Security

Ungrounded Wye – Open NGR

Ungrounded Delta
Why Monitor the NGR?

- During a ground-fault the NGR is a critical component.
- Without the NGR current sensing ground-fault protection does not operate on a ground fault.
- Does this really matter?
### Failure Mode

<table>
<thead>
<tr>
<th>Failure Mode</th>
<th>Percentage of Failures</th>
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<tbody>
<tr>
<td>1. Line-to-ground</td>
<td>98 %</td>
</tr>
<tr>
<td>2. Phase-to-phase</td>
<td>&lt; 1.5 %</td>
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<tr>
<td>3. Three-phase</td>
<td>&lt; 0.5 %</td>
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</table>

Most three phase faults are man-made: i.e. accidents caused by improper operating procedure.
For a Resistance-Grounded System:

In 98 out of every 100 electrical faults the protection system will not operate as designed without the NGR.
Each ground-fault relay has a redundant back up plus the adjacent two main buses and bus tie section zones are protected by full bus differential relays and backed up by partial bus differential protection.

“Feeder units have two redundant relays. The relays are different models with different CT inputs, but perform the same functions and send simultaneous trips to the feeder circuit breaker.”
Ground Protection – Single Line
Ground Protection – Single Line
NGR Monitoring Methods

• Does not monitor NGR continuity, only measures neutral-point voltage and current

• Active only when GF present

• This is back-up ground-fault protection, not NGR monitoring
A Superior Method

Monitoring Device

- Monitors ground current
- Monitors Voltage at the neutral
- Continuously monitors the NGR continuity
- The monitor provides indication of the NGR continuity whether there is a ground-fault or not
- Isolates the monitor from line-to-neutral voltage
- Detects NGR failure without an energized load
Code Requirements for NGR Monitoring

NGR Monitoring – US and Canadian Code References
• Where is resistance grounding required?
• Where is monitoring required?
Ground-fault detection and relaying shall be provided to automatically de-energize any high-voltage system component that has developed a ground fault. The continuity of the equipment grounding conductor shall be continuously monitored so as to de-energize automatically the high-voltage circuit to the portable or mobile equipment upon loss of continuity of the equipment grounding conductor.
US Regulations - 30 CFR Section 18.47 – Gassy Mines or Tunnels

Electric motor-driven mine equipment and accessories

30 CFR 18.47 Voltage Limitation

(2) A continuously monitored, failsafe grounding system is provided that will maintain the frame of the equipment and the frames of all accessory equipment at ground potential. Also, the equipment, including its controls and portable (trailing) cable, will be deenergized automatically upon the occurrence of an incipient ground fault. The ground-fault-tripping current shall be limited by grounding resistor(s) to that necessary for dependable relaying. The maximum ground-fault-tripping current shall not exceed 25 amperes.
Testing grounding systems.
Continuity and resistance of grounding systems shall be tested immediately after installation, repair, and modification; and annually thereafter. A record of the resistance measured during the most recent tests shall be made available on a request by the Secretary or his duly authorized representative.
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30 CFR 75.801 – Grounding Resistors

The grounding resistor, where required, shall be of the proper ohmic value to limit the voltage drop in the grounding circuit external to the resistor to not more than 100 volts under fault conditions. The grounding resistor shall be rated for maximum fault current continuously and insulated from ground for a voltage equal to the phase-to-phase voltage of the system.
Mandatory safety standards, surface coal mines and surface work areas of underground coal mines

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30 CFR 75.814(3) – Electrical Protection

3) Ground-fault currents must be limited by a neutral grounding resistor to not more than--

i. 6.5 amperes when the nominal voltage of the power circuit is 2,400 volts or less; or

ii. 3.75 amperes when the nominal voltage of the power circuit exceeds 2,400 volts.
4) High-voltage circuits extending from the section power center must be provided with--

i. Ground-fault protection set to cause deenergization at not more than 40 percent of the rating of the neutral grounding resistor

ii. A backup ground-fault detection device to cause deenergization when a ground fault occurs with the neutral grounding resistor open; and

iii. Thermal protection for the grounding resistor that will deenergize the longwall power center if the resistor is subjected to a sustained ground fault. The thermal protection must operate at either 50 percent of the maximum temperature rise of the grounding resistor, or 150 deg. C (302 deg. F), whichever is less, and must open the ground-wire monitor circuit for the high-voltage circuit supplying the section power center. The thermal protection must not be dependent upon control power and may consist of a current transformer and overcurrent relay.
Mandatory safety standards--underground coal mines

30 CFR 75.1719-2 – Lighting fixtures; requirements.

(2) Alternating current circuits supplying power to stationary lighting fixtures shall contain conductors energized at voltages not greater than 70 volts to ground. Alternating current circuits, energized at 100 volts or more and used to supply power to stationary lighting fixtures, shall originate at a transformer having a center or neutral tap grounded to earth through a proper resistor, which shall be designed to limit fault current to not more than 5 amperes. A grounding circuit in accordance with §75.701-4 shall originate at the grounded terminal of the grounding resistor and extend along with the power conductors and serve as a grounding conductor for the frames of all equipment receiving power from the circuit.
Mine Power Substation - The area containing electrical switchgear (circuit breakers, fuses, switches, and/or transformers), used for the purpose of controlling power from the surface power system to the underground mine power transmission.

I. Alternating current installations shall include A through M.

G. Secondary or mine feeder circuit breaker with:

4. Automatic tripping of circuit breakers by protective relays and shall provide as a minimum tripping by:

f. Ground fault-current limiting resistor protection and monitoring by current and potential transformer relaying.
Load Center

13. Main breaker tripping devices, which must include:

   a. Overload and short circuit protection

   b. Ground fault by current protector.

   c. Ground fault by potential protector in the event of an open ground resistor.

   d. Continuous monitoring of the ground resistor is acceptable in lieu of potential protector.

   e. Time delay tripping for coordination of tripping is allowed.
10-1102 Use

(1) – Should read “Neutral grounding devices shall be permitted to be used only on systems where all neutral conductors are insulated to the nominal system voltage.”

(3) Where line-to-neutral loads are served, provision shall be made to automatically de-energize the system on the occurrence of

(a) a ground fault;

(b) a grounded neutral on the load side of the neutral grounding device; or

(c) a lack of continuity of the conductor connecting the neutral grounding device from the neutral point through the neutral grounding device to the system grounding electrode.
Where ground-fault protection is used, the supply shall be

(a) Grounded through a neutral-grounding device that limits ground-fault voltage to 100 V or less; and

(b) de-energized in less than 1 s if ground-fault current exceeds 20% of the prospective ground-fault current
Canadian Regulations – CSA M421-00 Section 3.6.2

General – Grounding – Neutral-Grounding Devices

A neutral-grounding device shall be

(a) Continuously rated, except when ground-fault tripping is provided:

(b) Monitored so as to de-energize the supply in less than 60s if the neutral-grounding device opens; and

(c) Connected as close as practical to the supply neutral.
A circuit supplying movable equipment shall be grounded through a neutral-grounding device that limits ground potential rise at the movable equipment to 100 V or less.
Where on-board, three-phase power transformers larger than 20 kVA and operating at voltages in excess of 300 V are used, the following requirements shall apply:

(a) Except as permitted by Item (g), either a direct or derived neutral shall be grounded through a resistor at the power source to limit the prospective ground-fault current to 25 A or less (see Appendix A).
Mobile electrical equipment operating at voltages in excess of 150 V shall be supplied by a system wherein

(a) the neutral is grounded through a neutral-grounding device that limits ground-fault voltage at the mobile equipment to 50 V or less;

(b) ground-fault protection is provided; and

(c) ground-conductor monitoring is employed.
Systems operating at voltages-to-ground in excess of 150 V shall be
(a) grounded through a neutral resistance; and
(b) provided with ground fault protection.
• Definition of HRG
• Benefits of HGR
• Consequences of an NGR failure
  – Ground-fault relaying doesn’t operate
  – Transient over voltages
• Real world example of install and forget
• Continuous monitoring vs. back up ground fault protection
  – An NGR monitor usually meets the requirements of back up ground-fault protection as well
Presentation Review

Why monitor the neutral-grounding resistor (NGR)?

• In 98% of faults in industrial power systems the NGR is a critical system component
• Without it all current-sensing ground-fault protection does not function
• The NGR is no more resistant to failure than any other system component
• Minimize the risk of transient overvoltages
• Back up protection or monitoring required by various codes
**Code Summary - US**

<table>
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<th>Comment</th>
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<tr>
<td>NEC 250.188</td>
<td>High Voltage - Can not be met with an open NGR.</td>
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| 30 CFR 18.47 | Gassy Mines or Tunnels  
  • Continuously monitored grounding system. Could be interpreted to include the NGR.  
  • Maintain the frame of the equipment and the frames of all accessory equipment at ground potential. Can not be met with an open NGR. |
| 30 CFR 56.12028, 57.12028 | Metal and Non-Metal – Surface and Underground  
  • NGR continuity has to be confirmed after installation or repair and annually. Records must be available |
| 30 CFR 75.814(3) | Underground Coal  
  • Back up ground fault protection required in the event of fault with open NGR |
# Code Summary - US

## Pennsylvania Bureau of Mine Safety

<table>
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<tr>
<td>Mine Power Substation</td>
<td>• Ground fault-current limiting resistor protection</td>
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<td>Load Center</td>
<td>• Ground fault by potential protector in the event of an open ground resistor</td>
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<td>• Continuous monitoring of the ground resistor is acceptable in lieu of potential protector</td>
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### Code Summary - Canada

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<tr>
<td>C22.1-06 10-1102.3</td>
<td>Where line to neutral loads are served continuous NGR monitoring required.</td>
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| CSA M421-00 Section 3.5.5 | Where ground-fault protection is used, the supply shall be:  
  • Grounded through a neutral-grounding device that limits ground-fault voltage to 100 V or less |
| CSA M421-00 Section 3.6.2 | General – Grounding – Neutral-Grounding Devices  
  • Continuous monitoring is required on any NGR  
  • De-energize supply in less than 60 s if NGR opens |

In Mining in Canada it is clearer:  
• Any where ground-fault protection is used high-resistance grounding is required.  
• Any where high-resistance grounding is used the NGR must be continuously monitored.
MONITORING NEUTRAL-GROUNDING RESISTORS

Case Studies
NGR MONITORING: CASE STUDY I

Situation:

• In 1952 Henry Post was tasked with reducing the high failure rate of ungrounded 3 Phase, 440 Vac oil-field pumping motors, at Humble Oil.
• Evidence pointed to failure of the stator windings due to over voltage caused by phase-to-ground faults.

Action:

• Post had been working with the idea of Hi-R Neutral Grounding and decided to try it here.

Result:

• Problem solved, for a little while. When the failure rate increased again inspection of the NGR revealed failure due to corrosion.
NGR MONITORING: CASE STUDY II

Situation:
• In 2004 inspection of three NER’s at a stationary surface substation of an Anglo Coal mine in Australia reveals all three to be open.

Action:
• Startco suggests an SE-330 package for monitoring the NER’s.
• Anglo Coal presents the topic of NER monitoring at the 2004 Queensland Mine Electrical Conference.

Result:
• Anglo Coal is convinced that NER monitoring is beneficial.
• Another documented example of why we should monitor NGR’s is brought forward.
NGR MONITORING: OPEN NGR PHOTO
NGR MONITORING: CASE STUDY III

Situation:
• Shortly before they were about to be re-energized, inspection of eight NGR’s at one of P&G’s facilities revealed five NGR’s were left open after transformer testing.

Action:
• The NGR’s were reconnected.

But what if this had gone unnoticed?
NGR MONITORING: CASE STUDY IV

Situation:
• 2001 while visiting the processing plant at a mine in Northern MN. Physical damage was noticed on a grounding resistor.
• The resistor was mounted too close to the overhang of the building and an iceberg sized icicle had fallen on top of the screened enclosure.
• The enclosure and the resistor were both crushed by the impact.

Solution:
• Move to a warmer climate.
• This customer did not monitor his NGR but he may find the fault when he is looking for the reason he had so much damage caused by either a transient overvoltage or a phase-to-phase fault.
NGR MONITORING: CASE STUDY V

Situation:

• Assistant Maintenance Manager at Cargill Fertilizer, Inc in Bradley Junction Florida reported an SE-325 trip on a 5 year old installation.
• The grounding resistor was hit and burnt out by a lightning strike.

Problem:

Without continuous monitoring how long would the open resistor have gone undetected?
MSHA Fatality Report

UNITED STATES
DEPARTMENT OF LABOR
MINE SAFETY AND HEALTH ADMINISTRATION

District 5

ACCIDENT INVESTIGATION REPORT
(UNDERGROUND COAL MINE)

Fatal Electrical
Mine No. 2 (I.D. No. 44-68353)
Brent Coal Corporation
Big Rock, Buchanan County, Virginia

November 11, 1991

by

Luther T. Ward
Coal Mine Safety and Health Administration
6. The 601 section power center was designed to provide a resistance grounded, 3-phase, 480/550 volt source for the section electrical equipment.

7. The grounding resistor in the section power center was burned apart causing it to be inoperable. It had been spliced in two other locations. The investigation interview confirmed that there had been problems with the grounding resistor burning open or apart in the past. A balanced flux relaying method was provided as a means of grounded phase protection in all the 3-phase circuits in the 601 section power center. This relaying method could not function properly when the grounding resistor was open.

8. The three-phase 480 volt circuit and the 550 volt three-phase circuit were not electrically isolated. The 550 volt circuit was produced by an auto-transformer connection to the 480 volt wye connected transformer.

9. The trailing cable pulled apart at a splice. In an attempt to determine if the cable was energized, the victim brushed an exposed conductor with his hand and then struck it against the mine rib.

10. The eyewitness recognized when Taylor came into contact with electricity and started to push him. When he felt electricity in Taylor's clothes, he pulled his hand back and ran toward the power center yelling for help.
The grounding resistor in the section power center was burned apart causing it to be inoperable. It had been spliced in two other locations. The investigation interview confirmed that there had been problems with the grounding resistor burning open or apart in the past. A balanced flux relaying method was provided as a means of grounded phase protection in all the 3-phase circuits in the 001 section of the power center. This relaying method could not function properly when the grounding resistor was open.
NGR MONITORING: CONCLUSION

• NGR’s fail.
• Monitoring the NGR will help prevent the problems associated with an ungrounded system.
Thank You