WSU Hands-On Generator Protection Track Overview

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Chuck is an active 20-year member of the IEEE Power System Relay Committee (PSRC) and is the past chairman of the Rotating Machinery Subcommittee. He is active in the IEEE IAS I&CPS, PCIC and PPIC committees, which address industrial system protection. He is a former U.S. representative to the CIGRE Study Committee 34 on System Protection and has chaired a CIGRE working group on generator protection. He also chaired the IEEE task force that produced the tutorial “The Protection of Synchronous Generators,” which won the PSRC’s 1997 Outstanding Working Group Award. Chuck is the 1993 recipient of the Power System Relay Committee’s Career Service Award and he recently received the 2002 IAS I&CPS Ralph Lee Prize Paper Award. His papers have been republished in the IAS Industrial Applications Magazine.

Chuck has a Bachelor of Science in Electrical Engineering from Purdue University and is a graduate of the eight month GE Power System Engineering Course. He has authored a number of papers and magazine articles on protective relaying. He has over 25 years of experience as a protection engineer at Centerior Energy, a major investor-owned utility in Cleveland, Ohio where he was the Manager of the System Protection Section. He is also a former instructor in the Graduate School of Electrical Engineering at Cleveland State University as well as a registered Professional Engineer in the state of Ohio.
A major US manufacturer of:

- Digital multifunction generator, interconnection and transformer protection
- Generator synchronizing and bus transfer equipment
- Voltage control devices for LTC transformer, regulators, and capacitor banks
- Packaged systems using Beckwith products
Introduction

- Contrary to popular belief, generators do experience shorts and abnormal electrical conditions.
- Proper protection can mitigate damage to the machine in many cases.
- Generator Protection Areas:
  - Short Circuits in the generator itself
  - Abnormal electrical conditions may be caused by the generator or the system.
Generator Protection

- **Internal Faults**
  - Stator Phase
  - Stator and Field Ground

- **System Back Up for Faults**
  - Phase and Ground

- **Abnormal Operating Conditions**
  - Overvoltage
  - Overexcitation
  - Load Unbalance
  - Loss of Field
  - Loss of Synchronism
  - Frequency
  - Loss of prime mover
  - Inadvertent Energizing
  - Compromised potential source (blown fuse)
  - Open trip circuit
IEEE Standards

- Latest developments reflected in:
  - Std. 242: IAS Buff Book
  - C37.102: IEEE Guide for Generator Protection
  - C37.101: IEEE Guide for AC Generator Ground Protection
  - C37.106: IEEE Guide for Abnormal Frequency Protection for Power Generating Plants

*These are created/maintained by the IEEE PSRC & IAS
They are updated every 5 years*
C37.102-2006
Updated Version
now available which
has significant
changes and
additions.
IEEE TUTORIAL ON THE PROTECTION OF SYNCHRONOUS GENERATORS


Special Publication of the IEEE Power System Relaying Committee
FUNDAMENTALS
- Basic Synchronous Generators
- Connections to the system
- Short Circuits
- Generator Grounding
- IEEE Guidelines
- Device Numbers
Generator Excitation & AVR Control

- Generator Field
- AVR
- Static Exciter
- CT
- VT
- Generator Step-up Transformer
- Excitation Transformer
GENERATOR-TYPE: TLRI 93/33-36

RATED GENERATOR OUTPUT $S_r = 125,000$ MVA
RATED ARMATURE VOLTAGE $U_a = 13,400$ kV
RATED ARMATURE CURRENT $I_a = 5,230$ kA
RATED FREQUENCY $f_r = 60.0$ Hz
POWER FACTOR $P.F. = 0.85$
COLD AIR TEMPERATURE $T_z = 40.00$ C&deg;

V84.2 Generator Data
Frame Size TLRI 93/33-36
0.85 P.F. Insulation Class B
Synchronous Generator Types

- Round Rotor
- Salient-Pole
Direct Connected Generator
Unit Connected Generator to Power System
GENERATOR CURRENT DECAY
Symmetrical Trace of a Generator
Generator Short-Circuit Currents Phase

D-C Component

Time
Generator Terminal Fault Current
Accumulation of damage over time:

Most of the damage occurs in the period after the generator breaker opens.
Multi-Phase Generator Fault Oscillograph

- High Side of Generator Breaker Currents
- Generator Neutral Terminal Currents
- Fault Inception
- High Side Breaker Opens
Low Impedance Grounding

- Generator Windings
- Resistor or Reactor
- Low Impedance
  - Usually a good ground source
  - Generator still likely to be damaged on internal ground fault
    - Ground fault current typically 200-400 A
    - This Level of Ground Current Can Cause unacceptable damage
Low Impedance Grounding Generators
Bussed Together
High Impedance Grounding
Oscillograph of STATOR Ground Fault

- Generator Neutral Voltage
- Fault Inception
- Breaker Opens
- Generator Phase Currents
- Trip Command
Types of Generator Grounds

- High Impedance
  - Moderately expensive
  - Used when generators are unit connected
  - System ground source obtained from generator grounding transformer
  - Generator damage minimized or mitigated from ground fault
  - Ground fault current typically <=10A
- Pictures of stator damage after an internal ground fault
- This generator was high impedance grounded, with the fault current less than 10A
- Some iron burning occurs, but the damage is repairable vs. low impedance grounded machines where the damage is typically severe.
Dual (Hybrid) Grounding

Generator Windings

High speed switch capable of interrupting LRG Current

LRG 200-400 A

HRG Less Than 10 A
HYBRID GROUNDING

Converts from low to high Impedance Grounding if internal generator fault is detected.
<table>
<thead>
<tr>
<th>Device</th>
<th>Function</th>
<th>Discussed in Tutorial Section</th>
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<td>Volts/Hz protection for generator overexcitation.</td>
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<td>Loss-of-field protection.</td>
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<td>Device</td>
<td>Function</td>
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<td>Stator Thermal Protection.</td>
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<td>51GN</td>
<td>Time overcurrent ground relay.</td>
<td>4 &amp; 11</td>
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<td>51TN</td>
<td>Backup for ground faults.</td>
<td>4 &amp; 11</td>
</tr>
<tr>
<td>51V</td>
<td>Voltage-controlled or voltage-restrained time overcurrent relay. Backup for system and generator phase faults.</td>
<td>11</td>
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<tr>
<td>59</td>
<td>Overvoltage protection.</td>
<td>6</td>
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<td>59GN</td>
<td>Overvoltage relay. Stator ground fault protection for a generator.</td>
<td>4</td>
</tr>
<tr>
<td>Device</td>
<td>Function</td>
<td>Discussed in Tutorial Section</td>
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<td>Loss-of-synchronism protection.</td>
<td>9</td>
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<td>Frequency relay. Both underfrequency protection.</td>
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<td>Hand-reset lockout auxiliary relay.</td>
<td>14</td>
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<td>87G</td>
<td>Differential relay. Primary phase-fault protection for the generator.</td>
<td>2</td>
</tr>
<tr>
<td>87N</td>
<td>Stator ground fault differential .</td>
<td>4</td>
</tr>
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<td>87T</td>
<td>Differential relay. Primary protection for the transformer.</td>
<td>2</td>
</tr>
<tr>
<td>87U</td>
<td>Differential relay for overall generator and transformer protection.</td>
<td>2</td>
</tr>
</tbody>
</table>
FROM IEEE C37.102

Unit Connected, High Z Grounded
NERC PROTECTION SYSTEM MAINTENANCE REQUIREMENTS
NERC REGIONAL RELIABILITY ORGANIZATIONS (RROs)

Regional Entities

- Florida Reliability Coordinating Council (FRCC)
- Midwest Reliability Organization (MRO)
- Northeast Power Coordinating Council (NPCC)
- ReliabilityFirst Corporation (RFC)
- SERC Reliability Corporation (SERC)
- Southwest Power Pool, Inc. (SPP)
- Texas Regional Entity (TRE)
- Western Electricity Coordinating Council (WECC)
NERC RELIABILITY STANDARDS
TRANSMISSION SYSTEM - GENERATOR MAINTENANCE AND TESTING:

PRC-005-1 TRANSMISSION AND GENERATION PROTECTION SYSTEM MAINTENANCE AND TESTING

R1. Each Transmission Owner and any Distribution Provider that owns a transmission Protection System and each Generator Owner that owns a generation Protection System shall have a Protection System maintenance and testing program for Protection Systems that affect the reliability of the BES. The program shall include:

R1.1 Maintenance and testing intervals and their basis
R1.2 Summary of maintenance and testing procedures
NERC RELIABILITY STANDARDS
TRANSMISSION SYSTEM - GENERATOR MAINTENANCE AND TESTING:

PRC-005-1 EVIDENCE OF COMPLIANCE

R2.1 Evidence Protection System devices were maintained and tested within the defined intervals.

R2.2 Date each Protection System device was last tested/maintained.
NERC RELIABILITY STANDARDS
TRANSMISSION SYSTEM - GENERATOR MAINTENANCE AND TESTING:

NERC PROTECTION SYSTEM DEFINED:

CT & VT → RELAY → TRIP CONTROL LOGIC → GEN. SHUTDOWN
DC → TRIP CONTROL LOGIC → CIRCUIT BREAKER
NERC RELIABILITY STANDARDS
TRANSMISSION SYSTEM - GENERATOR MAINTENANCE AND TESTING:

CATEGORIES OF PROTECTION SYSTEMS:

**UNMONITORED** – -------------- Electromechanical and Solid State (no self-testing)

**PARTIALLY MONITORED** --- Digital Relays with Failure Alarms Send to a Manned Location (Relay Self-Testing)

**THOROUGHLY MONITORED** – Same as Above Monitoring, Plus Additional Monitoring of Alarms and Performance Measured Values

**FULLY MONITORED**  - --------- Same as Above, Plus Continuous Monitoring of all Components of the Protection System
NERC RELIABILITY STANDARDS TRANSMISSION SYSTEM - GENERATOR MAINTENANCE AND TESTING:

<table>
<thead>
<tr>
<th>Category</th>
<th>Component</th>
<th>Maximum Verification Interval</th>
<th>Verification Activities</th>
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<tr>
<td></td>
<td></td>
<td>Un-monitored</td>
<td>Partial Monitoring</td>
</tr>
<tr>
<td>Reference</td>
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<td>Figure 1</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>1.</td>
<td>Testing and calibration of protective relays.</td>
<td>5 years</td>
<td>7 years</td>
</tr>
<tr>
<td>2.</td>
<td>Verification of instrument transformer outputs and correctness of connections to protection system.</td>
<td>7 years</td>
<td>7 years</td>
</tr>
<tr>
<td>3.</td>
<td>Verification of protection system tripping including circuit breaker tripping, auxiliary tripping relays and devices, lockout relays, telecommunications-assisted tripping schemes, and circuit breaker status indication required for correct operation of protection system.</td>
<td>5 years</td>
<td>7 years</td>
</tr>
<tr>
<td>4.</td>
<td>Station battery supply</td>
<td>1 month</td>
<td>7 years</td>
</tr>
</tbody>
</table>
APPLICATION OF MULTIFUNCTION DIGITAL GENERATOR PROTECTION
Evolution of Technology in Generator Protection

- Single Function Electromechanical
- Single Function Static
- Single Function Microprocessor-Based
- Multifunction Digital Relays
  - Almost all new generating facilities use this technology
  - All generator protection functions in on hardware platform
Multifunction Digital Relay

- Targets (Optional)
- Integral HMI (Optional)
- Metering
- Waveform Capture
- IRIG-B
- Front RS-232 Communication
- Rear Ethernet Port (Optional)
- Rear RS-485 Communication
- Multiple Setting Groups
- Programmable I/O
- Self Diagnostics
- Dual Power Supply (Optional)
- Breaker Monitoring
- Trip Circuit Monitoring

High-impedance Grounding with Third Harmonic 100% Ground Fault Protection

Low-impedance Grounding with Overcurrent Stator Ground Fault Protection
Multifunction Digital Relay
I/O M-3425A

Standard

Expanded
Multifunction Digital Relays

Advantages

- Advance technology: reduced maintenance
- Reduced panel space: more economical, lower price per function, more complete protection on smaller generators
- Flexibility
- Communication capability
- System integration
- Self-diagnostics: reduced maintenance
- Oscillographic capability
- System Integration (Input to DCS Systems)
Hardware Block Diagram

VTs & CTs

Anti-Aliasing Low-Pass Filters (LPF)

Analog Multiplexer

Programmable Gain Amplifier

Analog-to-Digital Converter

RAM

Digital Signal Processor (DSP)

Dual-Ported RAM

Address/Data Bus

NMI Module

Target Module

RS232 and RS485 Communication ports

IRIG-B Time Code input

Relay Outputs

Contact Inputs

Power Supply

Character Liquid Crystal Display

RAM

Flash-Programmable ROM

Host Processor

EEPROM

Clock with battery backup
Single Relay
Levels of Redundancy

- **Strategy #1**
  - Use a single multifunction relay
  - If you have a relay failure:
    - Rely on self-test features to detect failure (MTBF Typically 100 years)
    - Remove generator from service
    - Install spare relay
    - Recommission
    - Return generator to service

- **Cost of Strategy #1**
  - No primary and backup
  - Production loss for generator during off period
  - Moderately sized utility generators (150MW) can result in production losses of over $100,000/day or more.
Dual Relay Approach
Levels of Redundancy

- **Strategy #2**
  - Use duel relay approach
  - Have defined primary and backup systems
  - If you have a relay failure:
    - Continue to run the generator
    - Replace the failed relay
    - Recommission
    - Place the new relay in service

- **Cost of Strategy #2**
  - Purchase and installation of a second relay
Level of Redundancy

- Most new generators are gas turbines or steam unit as part of a combined cycle plant
- On these projects - generator protection is “pre-packaged” by generator manufactures
- Standard offering by many generator manufactures is a single multifunction relay package
Multifunction Generator Protection Application Considerations

- **Level of Redundancy**
  - There is no remote backup protection for most generation fault/abnormal operation consideration
  - Utilities need to be aware that if more redundancy is desired - they need to ask for it before generator is ordered
Generator VT Connections

These major VT generator connections are widely used:

- line to line voltage
- line to ground
  - 4-wire
  - 3-wire
- line to ground VT connections have unique application considerations
Line to Line VT’s

- Common open delta VT connection
- Relay VT inputs connected line to line
Line to Ground VT’s

4 Wire Connection

- Relay VT input connected line to ground
Neutral Shift on Ground Fault:

High Impedance Grounded Generator

- A ground fault will cause LG connected phase elements through a 3Y-3Y VT to have undervoltage or overvoltage (depending on faulted phase)
Relay VT input connected line to ground

For stator ground fault neutral shift can result in false indication of overvoltage/overexcitation

Ideal solution is to supply voltage functions with phase to phase

If oscillograph monitors L-G voltage, it can be used to phase identify a stator and fault.
Voltage Inputs

3Y-3Y VT, secondary wired L-G (L-G to L-L selection)

Use of L-L Quantities for Phase Voltage-based elements

- The “Line-Ground to Line-Line” selection should be used when it is desired to provide the phase voltage-based elements (27, 59, 24 functions) with phase-to-phase voltages

- They will not operate for neutral shifts that can occur during stator ground faults on high impedance grounded generators

- The oscillograph in the relays will record line-ground voltage to provide stator ground fault phase identification
Line to Ground VT’s

- Relay VT input connected line to ground
- For stator ground fault neutral shift can result in false indication of overvoltage/overexcitation
- Ideal solution is to supply voltage functions with phase to phase
- If oscillograph monitors L-G voltage, it can be used to phase identify a stator and fault
- Need to coordinate 59N relay with VT secondary fuses to avoid unit trip for a VT secondary ground fault
Relay VT inputs connected line to line

This VT connection avoids the need to coordinate 59N with VT fusing

Can not phase identify stator ground faults
WSU Hands-On Generator Protection
Track Overview

THE END

????QUESTION ????