Improving System Protection
Reliability and Security

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Introduction

• Summarize conclusions from NERC 2013 Reliability Report
• Analyze Generator Differential Protection Misoperation
• Analyze 27TN Misoperation
  (3rd Harmonic Neutral Undervoltage)
• Analyze Incorrect Phase Rotation Settings
• Corrective Actions
• Conclusions
Introduction

NERC released an official report in 2013 that featured statistics for misoperations across the entire country.
As of June 18, 2007, the U.S. Federal Energy Regulatory Commission (FERC) granted NERC legal authority to enforce Reliability Standards with all U.S. users, owners, and operators of the bulk power system, and made compliance with those standards mandatory and enforceable.

NERC assesses and reports on the reliability and adequacy of the North American bulk power system, which is divided into several assessment areas within **eight** Regional Entity boundaries, as shown in the map and corresponding table.

The users, owners, and operators of the bulk power system within these areas account for virtually all the electricity supplied in the United States, Canada, and a portion of Baja California Norte, México.
Major Events Ranked > 10
NERC Daily Severity Risk Index
(Benchmarks)

• 1989 Quebec Solar Flare (3)
• 1996 Western Disturbance (7)
• 2003 Eastern Interconnection Blackout (8)
# Events (2012)

- **Misoperations** - 33 events *(more than one third)*
- Equipment failures - 27 events
- Individual human performance - 11 events
- Management | Organizational issues - 26 events
Misoperations primarily resulted from:
- Incorrect settings/logic/design errors
- Communication failure
- Relay failure or malfunction

These events include **Human Error** during **testing** and maintenance activities.

**Human Error** during **testing** and **maintenance** resulting in protection system activation has contributed to large disturbance events.
Misoperations in 2012

Most of these misoperations contribute to increasing Security Risk Index (SRI) and indicate that the number of transmission element outages is increasing.
Corrective Actions (1)

Applications requiring coordination of functionally different relay elements should be avoided.

This type of coordination is virtually problematic and is the cause of numerous misoperations reported in the study period.
Corrective Actions (2)

Misoperations due to setting errors can be reduced – several techniques include:

- Peer **reviews**
- Increased training
- **More extensive fault studies**
- **Standard setting templates** for standard schemes
- Periodic **review** of existing settings when there is a change in system topography

**Greater Complexity = Greater Risk of Misoperation**
Misoperation Analysis
Generator Differential

\[ \text{DIFF}_A = |I_A - I_a| \]
\[ \text{DIFF}_B = |I_B - I_b| \]
\[ \text{DIFF}_C = |I_C - I_c| \]
Misoperation Analysis
Generator Differential

Utility has two misoperations during external events. **First event** occurred when DC current passed through line side and neutral side CTs – most pronounced in C-Phase.
Generator Differential

Line Side (C)

Neutral Side (c)
Generator Differential

Line Side (C)

Neutral Side (c)

Differential (C)

0.578 amps
Generator Differential

Excitation Characteristics for Neutral Side CTs (A and C Phases)

A-Phase

C-Phase
(lower knee point voltage)

$V_{\text{knee}} < 100 \text{ volts}$
Second event occurred during high magnitude external three-phase fault.

Figure shows high level of dc offset in C-Phase. Current is completely offset for several cycles (worst case). DC offset is leading cause of CT saturation.
If there is a large DC offset present, current transformers can saturate with restraint current significantly less than two times nominal relay current. DC offset shown was greater than 10 amps secondary.
Myth – Digital Fourier Transform (DFT) removes DC offset

DC offset present in fault current exponentially decays as shown. DFT cannot fully reject it.
DC offset present in fault current exponentially decays as shown. DFT cannot fully reject it.
Generator Differential
(Murphy’s Law is always in effect!)

87T Curve

Phase Differential Operating Characteristic at Time of Trip

Blue Triangle = C-Phase Operating Point

NOTE: Misoperation due to CT saturation typically occurs when fault current is coming out of saturation.
Generator Differential

Detailed technical analysis revealed the following:

**MAIN 1** Minimum Pickup = 0.4 amps secondary

**MAIN 2** Minimum Pickup = 0.4\( \cdot \)\( I_{\text{nom}} \) = 1.2 amps secondary
\( (I_{\text{nom}} = 3 \text{ amps secondary}) \)

**MAIN 1** Generator Phase Differential protection **3 times** as sensitive!

*Utility copied settings directly from an arbitrary example in instruction book for main 2 minimum pickup.*

**Settings Error** - Main 1 and Main 2 Minimum Pickup should be equal.
Generator Differential

BEST PRACTICE

If DC offset from transformer inrush (e.g., black start) or fault condition can cause CT saturation, then following are appropriate for generator phase differential protection settings:

- Minimum pickup up to 0.5 amps secondary
- Slope of 20 percent
- Time delay up to 5 – 8 cycles

Detailed calculations are necessary for generator differential protection to determine if CTs can saturate.

Higher C class CTs can help to mitigate saturation.
Generator Differential

\[ V_{CT}^{MAX} = 2 \cdot (R_{CT} + 2 \cdot R_{lead} + R_{burden}) \]

2x accounts for a fully offset current waveform
Misoperation Analysis

27TN Third Harmonic Neutral Undervoltage

Neutral Overvoltage (59N) can only see stator ground faults up to 90-95 percent of the winding with respect to the terminals.

27TN sees stator ground faults close to the machine neutral.

Overlap

59N

equivalent

equivalent

0%

100%

stator winding

Overlap

27TN

5-15%

neutral

neutral
If the voltage magnitude drops below the pickup, then a trip occurs after time delay.
27TN Third Harmonic Neutral Undervoltage

Utility had experienced several misoperations when system voltage was low. However, the trip shown occurred when machine was under excited and drawing vars from system.

\[ P_{nom} = 746.5 \text{ watts secondary} \]

\[ 25 \text{ watts} + 139 \text{ vars secondary} \]
27TN Third Harmonic Neutral Undervoltage

Third harmonic neutral voltage changes as a function of load. *Pickup setting is typically set equal to one-half of minimum value measured during normal operation.*

![Image of software interface showing settings for 27TN Third Harmonic Undervoltage, Neutral]

- $V_{N_{\text{min}}} = 1 \text{ volt}$
- Input 1 = 52b
27TN Third Harmonic Neutral Undervoltage

Solution is to block on low forward power as this is prevailing system condition when nuisance trip occurs.

**Drawback**: No protection for stator ground faults close to neutral during this operating condition.
27TN Third Harmonic Neutral Undervoltage

Customer is strongly considering installation of 100 percent stator ground fault protection using sub-harmonic voltage injection (64S).
27TN Third Harmonic Neutral Undervoltage

Conventional protection (59N) cannot detect grounds in last 5 to 10 percent of stator winding.

27TN is not always reliable and may have to be blocked during specific operating conditions.

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

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

Each of four failures caused massive damage to generator and collectively had total cost, including repair and loss of generation, close to $500,000,000. This demonstrates that failure of stator windings in last five percent of winding is not uncommon.
27TN Third Harmonic Neutral Undervoltage

Catastrophic Damage - Stator Grounds in last 5% of Winding

Winding Damage: Broken Stator Winding Conductor

Core and Winding Damage: Burned Open Bar in a Slot

Burned Away Copper: Fractured Connection Ring
27TN Third Harmonic Neutral Undervoltage

64S provides all the following:

- Detect stator ground when winding insulation first starts to break down and trip unit before catastrophic damage occurs.
- Trip in order of cycles since 20 Hz signal is decoupled from 60 Hz power system.
- Detect grounds close to machine neutral or even right at neutral thus providing 100 percent coverage of stator windings.
- Detect grounds when machine is starting up or offline.
- Reliably operate with generator in various operating modes (such as a synchronous condenser) and at all levels of real and reactive power output.
27TN Third Harmonic Neutral Undervoltage

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

Numerical Generator Relay 20 Hz Metering
Incorrect Phase Rotation Settings

Generator Protection
Numerical protection relays require a setting to determine the correct phase rotation.

ABC Phase Rotation
Some power systems have ACB phase rotation.
Incorrect Phase Rotation Settings

40 Loss-of-Field Protection

- 40 operates on \( Z_1 \) (positive-sequence impedance).
- 40 measures incorrect impedance due to **wrong phase rotation setting**
- 40 trips each time customer attempts to synch the generator to the grid

How did this get past commissioning?
Incorrect Phase Rotation Settings

78 Out-of-Step Protection

• 78 operates on $Z_1$ (positive-sequence impedance)
• 78 measures incorrect impedance due to wrong phase rotation setting
• 78 tripped during external event

Steady state impedance measurement

How did this get past commissioning?
Incorrect Phase Rotation Settings

Both elements (40 and 78) were effectively operating on $Z_2$ (negative-sequence impedance) due to the incorrect phase rotation settings.

- Modern numerical relays have built-in tools provided to determine the phase rotation.
- Phase rotation can quickly be checked.

How did these get past commissioning?
Conclusions

2013 NERC reported Misoperations - 33 events ( > one third of total)
• Due to incorrect settings, logic, testing and design errors

Simplified software for complex applications and visualization tools can aid in enhancing proper relay settings and operation.

Corrective actions include the following:
• Peer reviews
• Training
• Analysis
• Standard settings templates
• Periodic reviews

Examples given illustrate why these types of misoperations occur and how to avoid them.
Questions ?

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