

# NERC

NORTH AMERICAN ELECTRIC  
RELIABILITY CORPORATION

## Power Plant and Transmission System Protection Coordination

### GSU Phase Overcurrent (51T), GSU Ground Overcurrent (51TG), and Breaker Failure (50BF) Protection

NERC Protection Coordination Webinar Series  
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to ensure  
the reliability of the  
bulk power system

- Technical Reference Document Overview
- Objectives
- Description of Protection Functions
- Time-Current Coordination
- Discuss and Describe System Events that Could Create Conditions that Would Cause Operation of These Functions

- Detailed Coordination Information
  - Function 51T – GSU Phase Overcurrent
  - Function 51TG – GSU Ground Overcurrent
  - Function 50BF – Breaker Failure
- What is Important to Coordination
  - Settings that Protect the Generator
  - Coordination Margin
- Question and Answer

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- Introduction and Background – Blackout Recommendation TR-22
  - SPCS’s Assignment
- The Need for this Technical Reference Document - History and Background:
  - August 14, 2003 Blackout
  - Subsequent Events
  - Specific Concerns Regarding Generator and Power Plant Protection

- Support of PRC Standards
- Benefits of Coordination:
  - To the Generator Owner
  - To the Transmission Owner
  - To the Planning Coordinator
- Reliability of the Bulk Electric System and Power Delivery to the Customer



- Increase knowledge of recommended protection for GSU Phase Overcurrent, GSU Ground Overcurrent, and Breaker Failure protection.
- Facilitate improved coordination between power plant and transmission system protection for these specific protection functions.

- Focus is on the reliability of the Bulk Electric System.
- This Technical Reference Document is applicable to all generators, but concentrates on synchronous generators connected at 100-kV and above.
- Distributed Generation (DG) facilities connected to distribution systems are outside the scope of this document.



# The Need for GSU Phase Overcurrent Protection – Function 51T

- Neither IEEE C37.91 nor IEEE C37.102 supports the use of a phase overcurrent function for backup protection for faults in both the GSU and generator, or for system faults.
- IEEE C37.102 provides the following information concerning phase overcurrent backup protection:
  - *“In general, a simple time-overcurrent relay cannot be properly set to provide adequate backup protection. The pickup setting of this type of relay would normally have to be set from 1.5 to 2 times the maximum generator rated full-load current in order to prevent unnecessary tripping of the generator during some emergency overload condition.*
  - *With this pickup setting and with time delays exceeding 0.5 s, the simple time-overcurrent relay may never operate since the generator fault current may have decayed below relay pickup.”*

IEEE C37.102-2006 – Guide for AC  
Generator Protection, Section 4.6.1.2

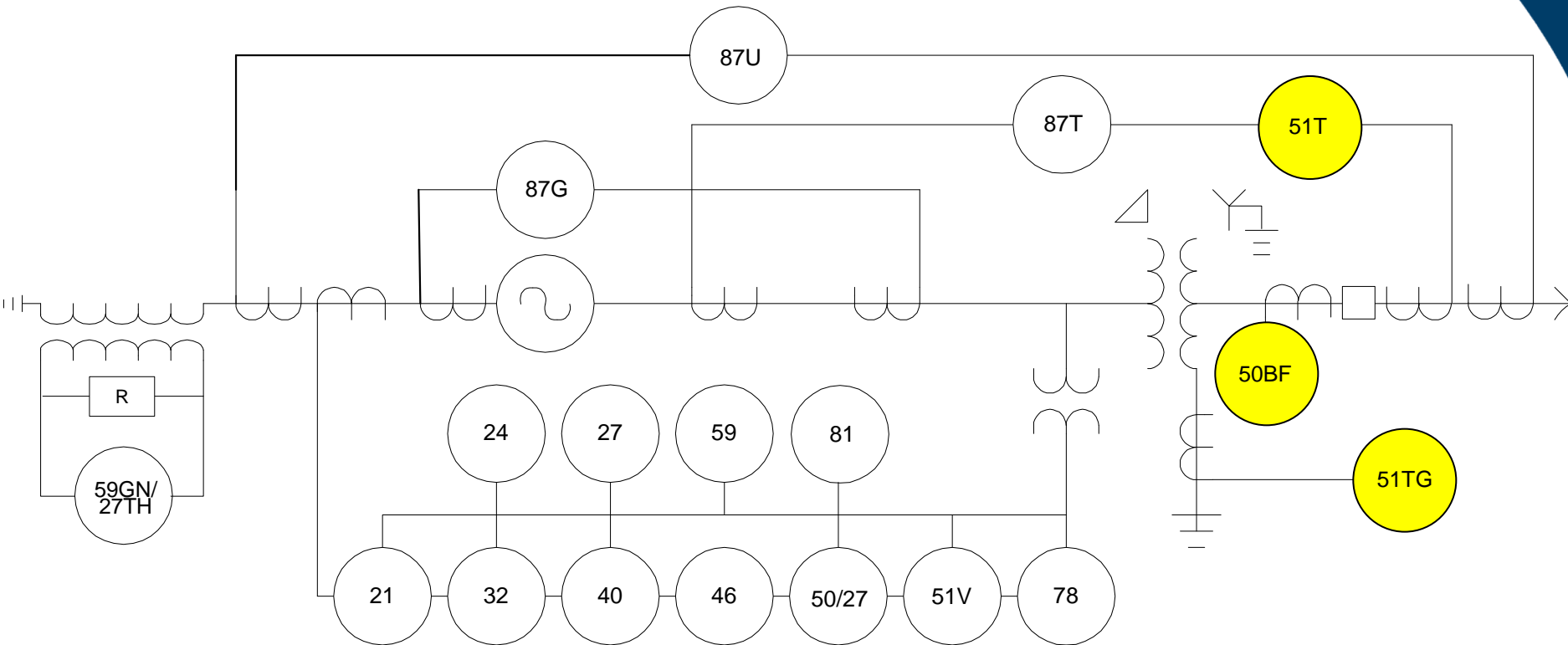
# The Need for GSU Ground Overcurrent Protection – Function 51TG

- The ground overcurrent function provides generator and GSU ground backup overcurrent protection for uncleared system ground faults.
- The ground overcurrent function is connected to detect the ground current provided by the GSU transformer when connected as a ground source.

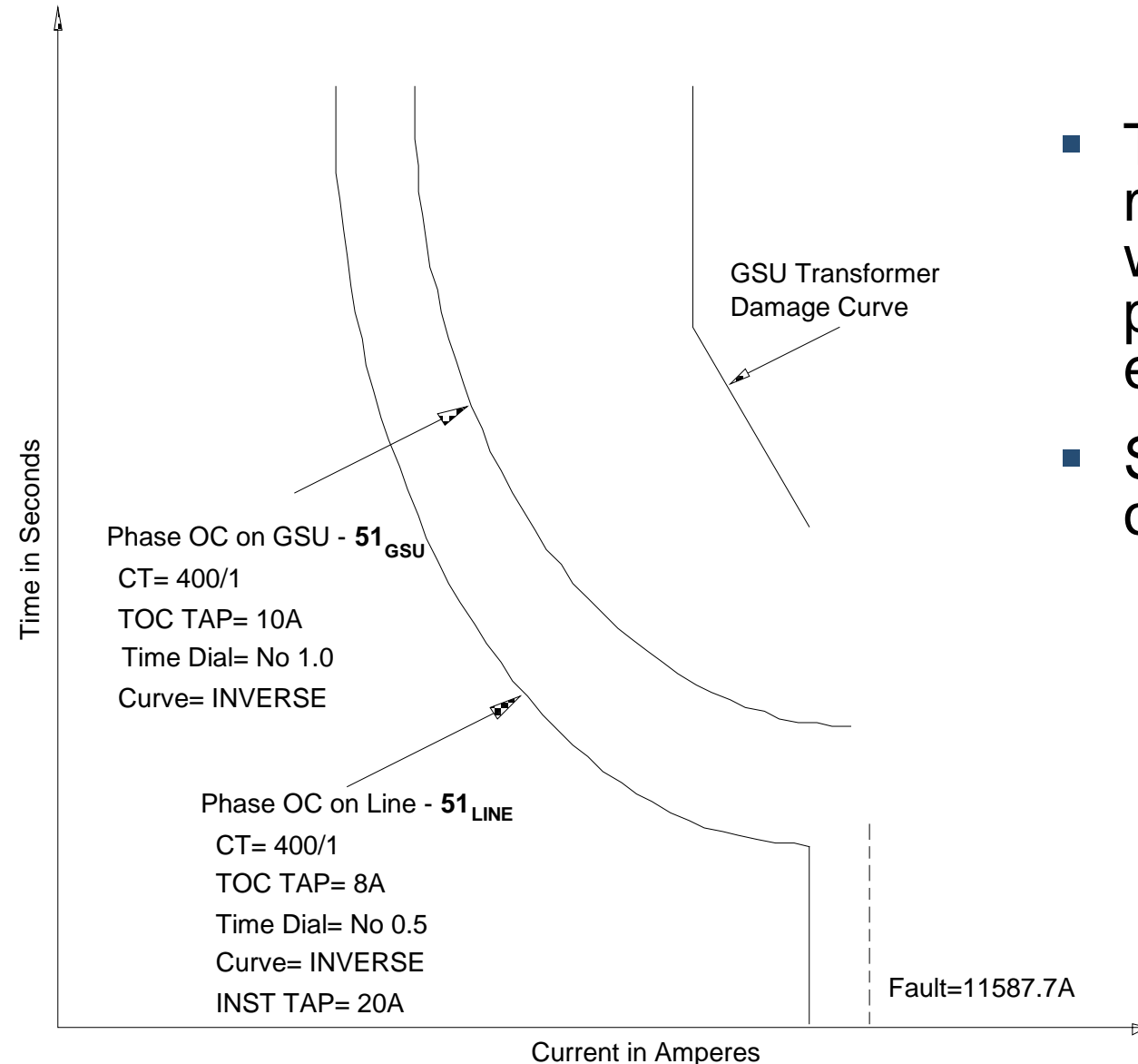
# The Need for Breaker Failure Protection – Function 50BF

- Breaker failure protection provides isolation of the generator in the event its breakers fail to open subsequent to receiving a signal to trip.
- When a generator unit breaker fails, the breaker failure function is required to initiate the tripping of backup breaker to isolate the failed breaker.

# Relay One-Line Showing All Generator Protection and Identifying Function 51T, 51TG, and 50BF



# Time-Current Coordination



- These protections must be coordinated with system fault protection and the equipment capability
- Sensitivity and timing of the relaying must:
  - Result in tripping of proper system elements
  - Permit the generator to stay on line during system stressed conditions

# System Events that Could Cause Undesired Operation of These Protection Functions

- **Fault Conditions**
  - Miscoordination with system protection during a system fault

# General Data Exchange Requirements – Generator Owner Data and Information

- The following general information must be exchanged in addition to relay settings to facilitate coordination, where applicable:
  - Relay scheme descriptions
  - Generator off nominal frequency operating limits
  - CT and VT/CCVT configurations
  - Main transformer connection configuration
  - Main transformer tap position(s) and impedance (positive and zero sequence) and neutral grounding impedances
  - High voltage transmission line impedances (positive and zero sequence) and mutual coupled impedances (zero sequence)
  - Generator impedances (saturated and unsaturated reactances that include direct and quadrature axis, negative and zero sequence impedances and their associated time constants)
  - Documentation showing the function of all protective elements listed above



- The following general information must be exchanged in addition to relay settings to facilitate coordination, where applicable:
  - Relay scheme descriptions
  - Regional Reliability Organization's off-nominal frequency plan
  - CT and VT/CCVT configurations
  - Any transformer connection configuration with transformer tap position(s) and impedance (positive and zero sequence) and neutral grounding impedances
  - High voltage transmission line impedances (positive and zero sequence) and mutual coupled impedances (zero sequence)
  - Documentation showing the function of all protective elements
  - Results of fault study or short circuit model
  - Results of stability study
  - Communication-aided schemes

# Detailed Coordination Information for Functions 51T, 51TG, and 50BF

- Detailed coordination information is presented under seven headings, as appropriate, for each function in the document.
- The following slides present a section-by-section summary for Functions 51T, 51TG, and 50BF.

# Document Format – Seven Sub-Sections for Each Protection Function

- Purpose
- Coordination of Generator and Transmission System
  - Faults
  - Loadability
  - Other Conditions, Where Applicable
- Considerations and Issues
- Coordination Procedure
  - Test Procedure for Validation
  - Setting Considerations
- Examples
  - Proper Coordination
  - Improper Coordination
- Summary of Detailed Data Required for Coordination of the Protection Function
- Table of Data and Information that Must be Exchanged

# Purpose – Functions 51T and 51TG

- Provide generator and GSU phase and ground backup protection for uncleared system phase and ground faults.

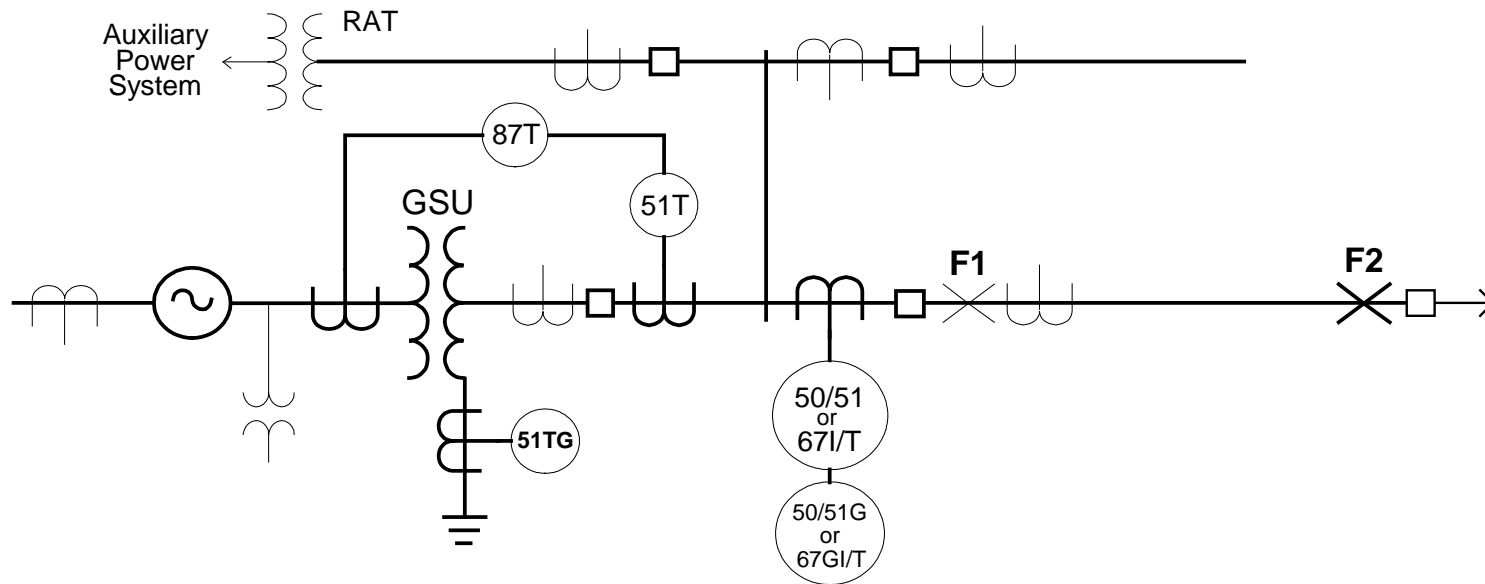


Figure 3.9.1 — Phase & Ground Backup Overcurrent Relays on GSU Transformer

## Caution:

- Use of a GSU phase overcurrent element (51T) for backup protection is strongly discouraged.
- The distance function (21) and the voltage supervised overcurrent protection function (51V) are better suited for this purpose.
  - The Technical Reference Document describes the use and application of these functions to provide the best phase backup protection that can be coordinated between the protective relaying of a Generator Owner and Transmission Owner.
  - For completeness the issues required to utilize the 51T backup overcurrent protection function are presented.
- When used, the 51T function and associated settings need to consider the following:

## ■ Faults

- The 51T and 51TG must meet the following considerations for fault coordination:
  - Pickup for the worst-case backup fault on the transmission system based on the application.
  - Have sufficient time delay with adequate margin to coordinate with the worst-case clearing time of the transmission protection with breaker failure clearing times included.
  - Be set such that the generator has the ability to produce the fault current long enough to complete the overcurrent backup function without causing any misoperation.
    - This requires great care in determining the sensitivity (pickup value) and selectivity (time to operate value).

- **Loadability**
  - The 51T function must be set to accommodate a minimum loading of 200 percent of the generator MVA rating at rated power factor.
    - The above requirement allows a generator to remain online through extreme operating system events, by allowing a generator to utilize its full capability of field forcing.
    - Note: Any 51 function utilized from the generator or GSU multi-functional protective relays must meet the above loadability requirement.
  - The 51TG function must accommodate the greatest system unbalance anticipated at the GSU, with margin.



- Protective functions other than 51T are available to provide backup protection for phase faults while providing better coordination with the transmission and generator protections.
- The 51TG backup overcurrent provides backup and time delayed protection for ground faults when primary relaying or equipment does not operate properly.
- Refer to IEEE C37.102 section 4.6 for recommendations on setting the 21, 51V, and 51TG relays, and refer to the references in IEEE C37.102 that discourage the use of the 51T.

# Coordination Procedure

## – Function 51T and 51TG

- **Coordination of Function 51T**
  - The 51T must have a minimum pickup of twice the generator MVA rating at rated power factor.
  - The 51T must operate slower, with margin, than the slowest transmission protection system that it must coordinate with based on protection design including breaker failure time.
  - The 51T must sense the required fault based on the transmission protection design with the fault current available from the generator in the time frame that it is set to operate.
  - The Generator Owner must determine that the setting for the 51T that coordinates with the transmission protection will also coordinate with the generator protection systems for the fault current available from the transmission system.

- **Coordination of Function 51TG**
  - The 51TG must have a pickup with margin greater than the largest non-fault system unbalance anticipated based on system design.
  - The 51TG must operate slower with margin than the slowest transmission protection system that it must coordinate with based on protection design including breaker failure time.

# Example - Proper Coordination

## – Function 51T and 51TG

- Settings for Function 51T
  - Step 1 — Rated current = = 1,778 A, primary =  $(1,778\text{A}/400) = 4.445 \text{ A}$ , secondary
  - Step 2 — Select a relay characteristic curve. [Note: Curve is typically chosen to match the curve used by the Transmission Owner i.e. a Very-Inverse Curve.]
  - Step 3 — Tap Setting of 51T =  $2 \times I \text{ rated} = (4.445\text{A}) \times (2) = 8.89\text{A}$ ; choose Tap = 9.0A
  - Step 4 — From short-circuit studies; obtain the 3 $\phi$  through-fault current for the fault located on the generator bus shown as F1 in the diagram.  $I_{3\phi}=11,587\text{-A}$ , primary through-fault current on GSU transformer. Relay current = 11,587 A, primary/400 = 28.96 A, secondary
  - Step 5 — Multiple =  $(\text{relay current}) / (\text{Tap}) = 28.96\text{A}/9.0\text{A} = 3.21$ , choose a Time Dial such that a time equal to approximate 30 cycles more than the slowest transmission overcurrent setting.
  - Step 6 — Ensure coordination with all appropriate transmission system protection elements.
  - Step 7 — The Generator Owner takes the information concerning the 51T in the plot and determines that it will coordinate with the other generator protection for the available transmission system fault current for GSU and generator faults.

# Example - Proper Coordination

## – Function 51T and 51TG

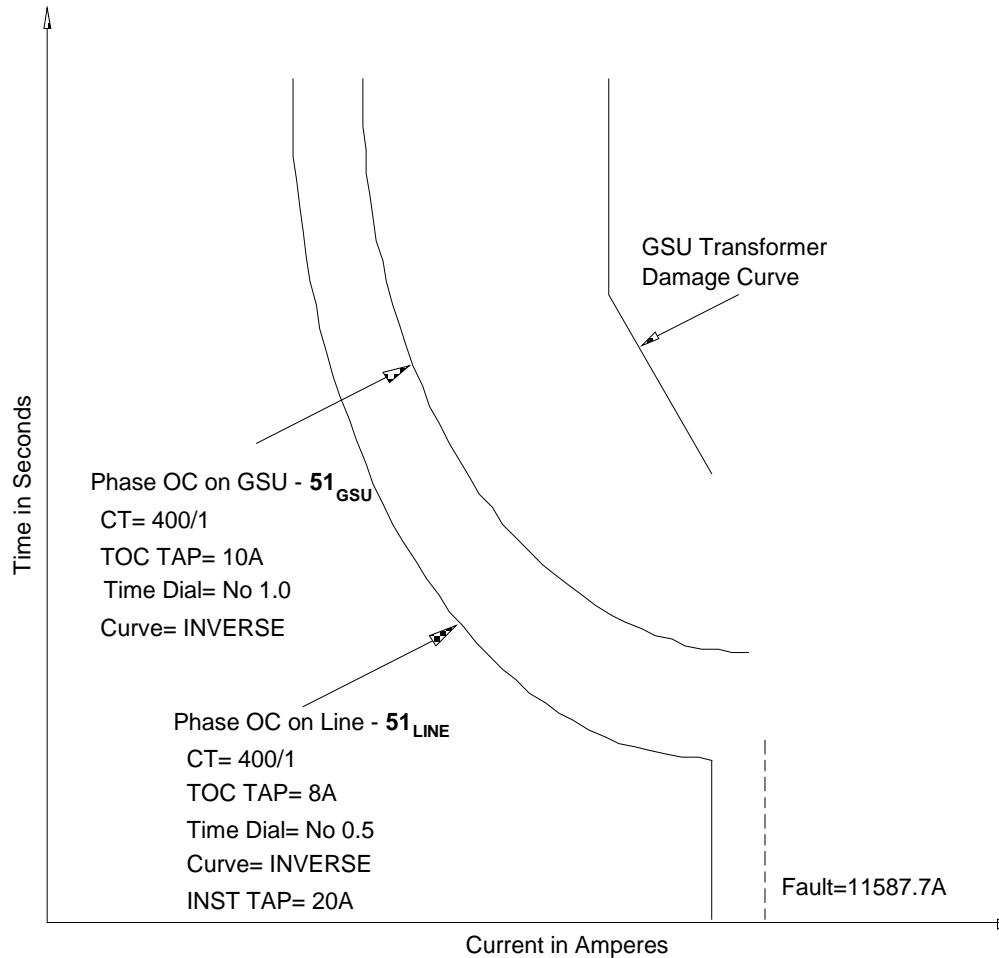


Figure 3.9.3 — Function 51TGSU & 51LINE (G or N) Overcurrent Relay Coordination Curves

# Example - Proper Coordination

## – Function 51T and 51TG

- Setting for the 51TG
  - Assumption: current transformer ratio (CTR) for the neutral CT on the GSU transformer is 1-600/5A (CTR=120:1), multi-ratio.
  - Step 1 — Obtain  $3I_0$  current from short-circuit studies for fault location F2 (the primary minimum fault current provided from the neutral of the GSU that must be detected by 51TG). F2 = 1930 Amperes primary.
  - Step 2 — Select a relay characteristic curve. [Note: Curve is typically chosen to match the curve used by the Transmission Owner, i.e. a very-inverse curve.]
  - Step 3 — Tap Setting of 51TG [Note: Tap is typically selected based on available minimum short-circuit current (F2) and current transformer ratio on the neutral of GSU transformer (120:1) such that two or higher times pickup is available for the fault that represents the minimum ground current that the 51TG is suppose to provide backup protection for a fault at F2, while providing for the worst case system unbalance.]. 51TG tap setting =  $(F2)/(2.0 \text{ margin} * \text{CTR}) = 1930 \text{ Amp} / (2.0 * 120) = 8.04$ , choose 8.0 tap.
  - Step 4 — From short-circuit studies; obtain the  $3I_0$  through-fault current for the fault located on the generator bus shown as F1 in the diagram.  $3I_0 = 7,556 \text{ A}$ , primary from the neutral of GSU transformer. Relay current =  $7,556\text{A}/120 = 62.96\text{A}$ , secondary
  - Step 5 — Multiple =  $(\text{relay current}) / (\text{Tap}) = 62.96/8\text{A} = 7.87$ , choose a Time Dial equal to approximate 30 cycles or more than the slowest transmission overcurrent setting. The time delay setting with margin will result in a time setting in the 60 – 90 cycles range. The 30 cycle margin will accommodate breaker failure clearing timers up to 20 cycles with margin.

# Example - Proper Coordination – Function 51T and 51TG

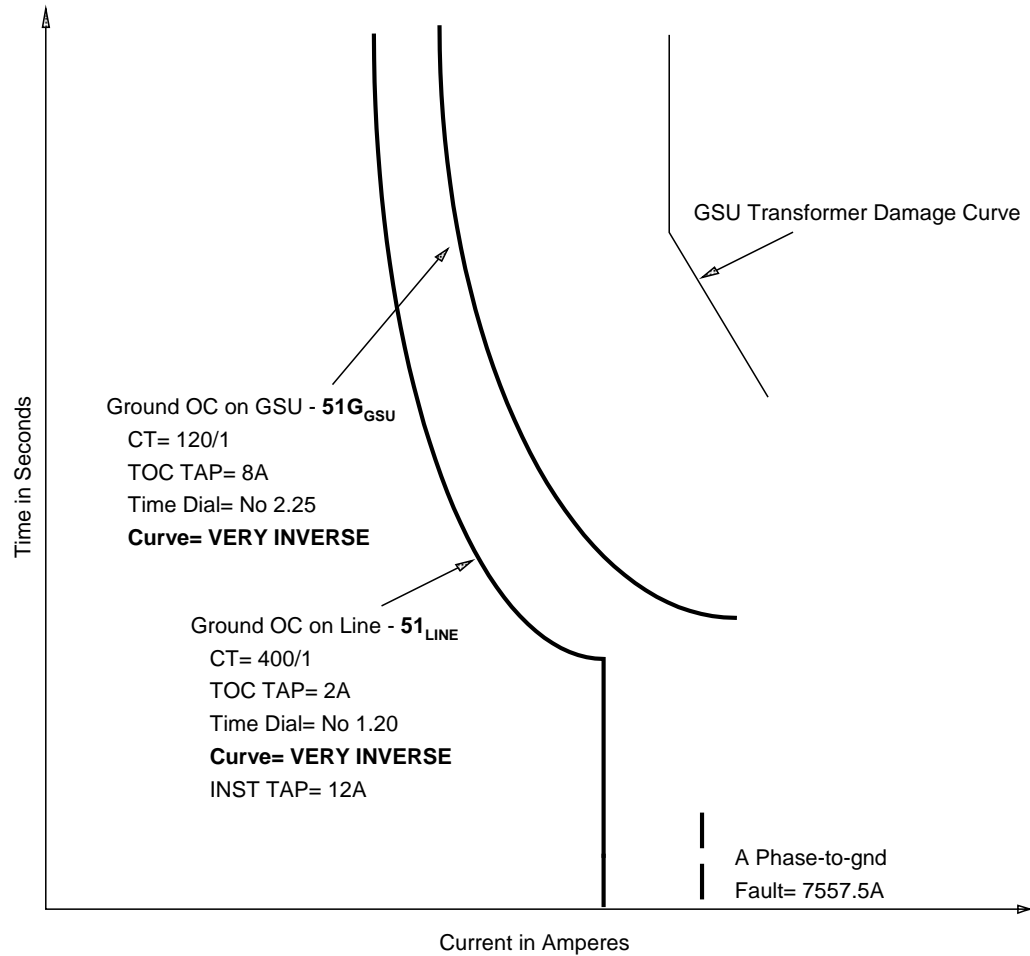


Figure 3.9.4 — Function 51TG Overcurrent Relay Characteristic Curve



# Summary of Protection Functions Required for Coordination – Function 51T and 51TG

Table 2 Excerpt — Functions 51T / 51TG Protection Coordination Data Exchange Requirements		
Generator Protection Function	Transmission System Protection Functions	System Concerns
<p>51T — Phase fault backup overcurrent</p> <p>51TG — Ground fault backup overcurrent</p>	<p>51</p> <p>67</p> <p>51G</p> <p>51N</p> <p>67N</p>	<ul style="list-style-type: none"> <li>• Must have adequate margin over GSU protection and nameplate rating</li> <li>• 51T not recommended, especially when the Transmission Owner uses distance line protection functions</li> <li>• Open phase, single-pole tripping and reclosing</li> <li>• Generator Owners(s) needs to get Relay Data (functions 51, 67, 67N, etc) and Single line diagram (including CT and PT arrangement and ratings) from Transmission Owner(s) for function 51T coordination studies</li> </ul>

# Protection Function Data and Information Exchange Required for Coordination – Functions 51T and 51TG

Table 3 Excerpt — Functions 51T / 51TG Data to be Exchanged Between Entities		
Generator Owner	Transmission Owner	Planning Coordinator
<p><b>Function 51T</b> — Phase fault backup overcurrent</p> <p><b>Function 51TG</b> — Ground fault backup overcurrent</p>	One line diagram of the transmission system up to one bus away from the generator high-side bus	None
Relay timer settings.	Impedances of all transmission elements connected to the generator high-side bus	
Total clearing times for the generator breakers	Relay settings on all transmission elements connected to the generator high-side bus	
	Total clearing times for all transmission elements connected to the generator high-side bus	
	Total clearing times for breaker failure, for all transmission elements connected to the generator high-side bus	

## Purpose — Function 50BF

- Breaker failure protection provides isolation of the generator in the event its breakers fail to open subsequent to receiving a signal to trip.
- When a generator unit breaker fails, the breaker failure function is required to initiate the tripping of backup breaker(s) for isolation of the failed breaker.

- **Faults**
  - Breaker failure and generator unit protection are required to coordinate with protective relays on the next zone of protection including breaker failure relaying time.
  
- **Loadability**
  - There are no coordination issues related to loadability for this function.

- All upstream (next level) protection settings and systems must be considered when evaluating the performance of breaker failure functions associated with generators.
- Total clearing time, which includes breaker failure time, of each breaker in the generation station switchyard should coordinate with the critical clearing times associated with unit stability.

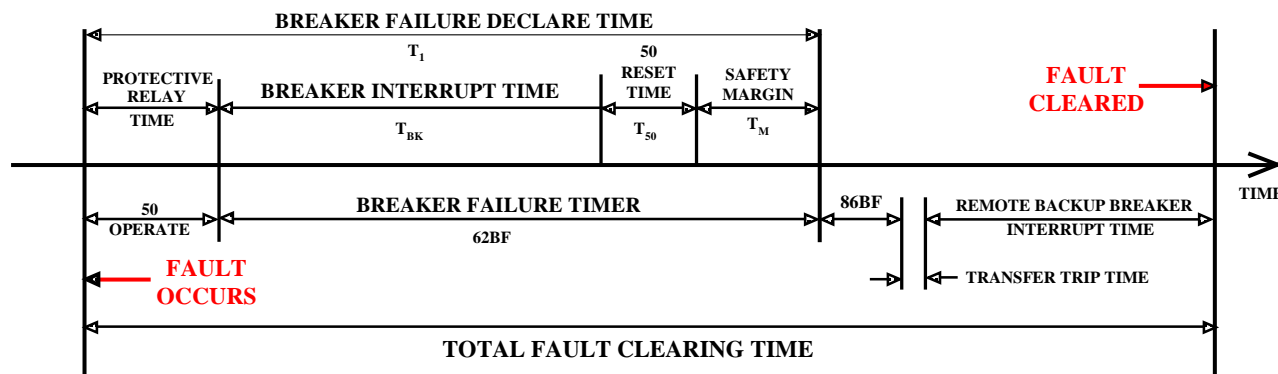
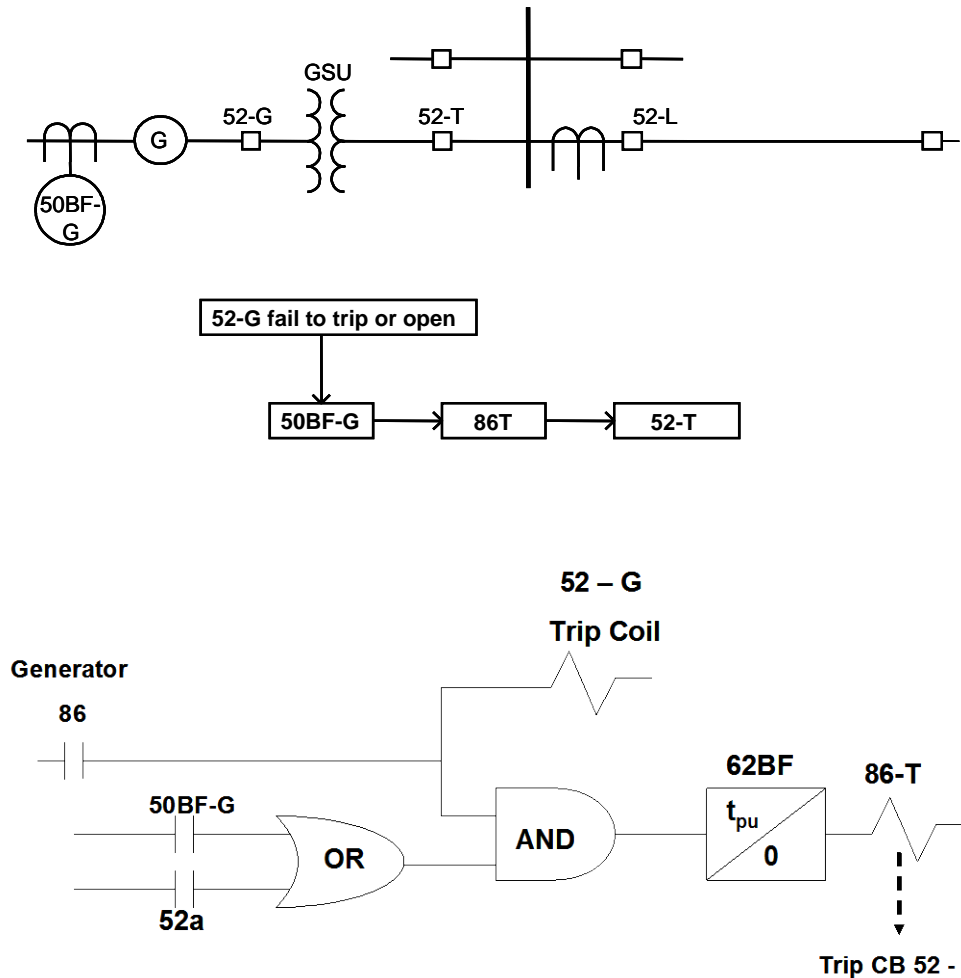


Figure 3.8.3 — Example of Breaker Failure Timing Chart<sup>[1]</sup>

[1] This chart is excerpted from the IEEE Std. C37.119-2005 “Guide for Breaker Failure Protection of Power Circuit Breakers.”

# Consideration and Issues – Function 50BF



- Use of a 52a contact permits operation for low magnitude (e.g. turn-to-turn) faults and abnormal operating conditions
- Use of a fault detector permits operation when the 52a contact does not provide an accurate indication of the breaker status

Figure 3.8.1 — Unit Breaker Failure Logic Diagram

- The following is an example of Breaker Failure Timer Settings (62BF) of a Breaker Failure Scheme for typical three-cycle.
  - Breaker Failure Timer = Breaker Interrupting Time +50 Reset Time + Safety Margin
  - $62BF = TBK + T50 + TM = 3.0 + 1.55 + 5.0 = 9.55$  cycles or 159 milliseconds



- Transmission Owner and Generator Owner verify:
  - Breaker failure time is accounted for properly for each set of relay functions requiring coordination.
  - Appropriate backup breakers are tripped for breaker failure operation.
  - Total clearing time, which includes breaker failure time, of each breaker in the generation station switchyard coordinate with the critical clearing times associated with unit stability.

- To provide proper Breaker Failure (BF) protection, the following should be considered:
  - See C37.119 “IEEE Guide for Breaker Failure Protection of Power Circuit Breakers” for a well-designed breaker failure scheme.
  - Clearing time issues are addressed further in Sections 4.7 and A.2.11 of C37.102-2006 — Guide for AC Generator Protection.
  - Refer to Section 3.1 of the Technical Reference Document for coordination of upstream protective function 21 with the breaker failure scheme.



# Summary of Protection Functions Required for Coordination – Function 50BF

Table 2 Excerpt — Function 50BF Protection Coordination Considerations		
Generator Protection Function	Transmission System Protection Functions	System Concerns
50BF – Breaker failure on generator interconnection breaker(s)	50BF on line(s) and bus(es)	<ul style="list-style-type: none"> <li>• Check for single-points-of-failure</li> <li>• Overcurrent (fault detector) and 52a contact considerations</li> <li>• Critical clearing time</li> <li>• Coordination with zone 2 and zone 3 timers</li> <li>• Settings should be used for planning and system studies</li> <li>• Line relay reach and time delay settings with respect to each generator zone.</li> <li>• Bus differential relay (usually instantaneous) timing for HV bus faults including breaker failure on an adjacent bus.</li> <li>• Line and bus breaker failure timers and line zone 1 and zone 2 timers on all possible faults.</li> <li>• Single line diagram(s) including CTs and VTs arrangement</li> <li>• Power Circuit Breaker (PCB) test data (interrupting time)</li> </ul>

# Protection Function Data and Information Exchange Required for Coordination – Function 50BF

Table 3 Excerpt — Function 50BF Data to be Exchanged Between Entities		
Generator Owner	Transmission Owner	Planning Coordinator
Times to operate of generator protection Breaker failure relaying times	Times to operate, including timers, of transmission system protection Breaker failure relaying times	Provide critical clearing time or confirm total clearing time is less than critical clearing time

# What is Important to Coordination

- Settings that Protect the Generator
- Coordination Margin

# Settings that Protect the Generator

- The protection set-points for Functions 51T, 51TG, and 50BF are described in:
  - C37.102 “IEEE Guide for AC Generator Protection”
  - C37.91 “IEEE Guide for Transformer Protection”
  - C37.119 “IEEE Guide for Breaker Failure Protection of Power Circuit Breakers”
- The time-current characteristics, current detector level, and time delay are adjusted based on the specific generator, transformer, breakers, and system application.
- Examples of these were given in the presentation, but again, specific settings need to be determined and coordinated by the entities.

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# Question & Answer

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