NERC

NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

Power Plant and Transmission System Protection Coordination

Technical Reference Document Overview

System Protection and Control Subcommittee

Protection Coordination Workshop
Phoenix, AZ
March 17-18, 2010

to ensure the reliability of the bulk power system

A Technical Reference Document

What Is This Technical Reference Document?

- Power Plant and Transmission System Protection Coordination
  - Prepared by the NERC System Protection and Control Subcommittee (SPCS)
  - Approved by the NERC Planning Committee on December 8, 2009

Overview Presentation Description

What is This Session About?

- Addresses the NERC Power Plant and Transmission System Protection Coordination Technical Reference Document.
- An overview of the document and highlights of the structure and contents of the subsequent sessions.
- Given the extent and detail of the material presented in the Technical Reference Document, a series of presentations is required to accomplish this effort.

Agenda

- 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

Agenda

- Support of PRC Standards
  - PRC-001
  - PRC-006
  - PRC-023
  - PRC-024
- 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

Agenda

- Review of Technical Reference Table 2
- Review of Technical Reference Table 3
- Review of General Data Exchange
- General Discussion of the Document outline (Seven Sub-Sections for each Protection Function)
- Description and Introduction of Each of the Detailed Coordination Modules
- Session Summary
- Questions and Answers

Introduction and Background – Blackout Recommendation TR-22

- SPCS's Assignment:
  - **Recommendation TR–22** - "NERC should evaluate these protection schemes and their settings for appropriateness including coordination of protection and controls when operating within a coherent generation area (but weakly connected to an interconnection) or within an electrical island. Generators directly connected to the transmission system using a 51V should consider the use of an impedance relay instead."
  - The SPCS adopted a 0.85 per unit voltage at the system high-side of the generator step-up transformer as the stressed system voltage condition for an extreme system event in this document.

History and Concerns Driving the Effort

- The history and background of the issues and challenges driving this effort.
  - August 14, 2003 Blackout
  - Subsequent Events

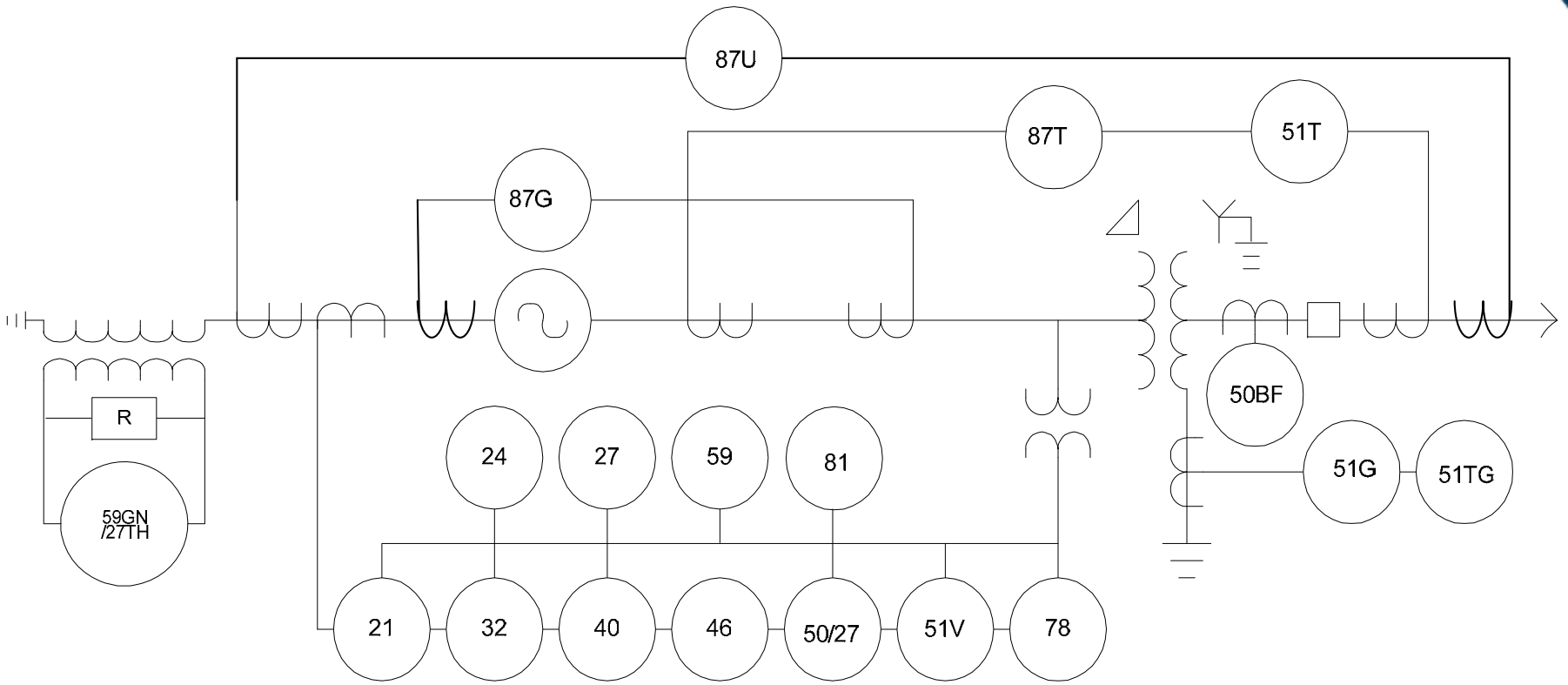
August 14, 2003 Blackout

- The record of generator trips (290 units, about 52,745 MW) during the North American disturbance on August 14, 2003.
- Included thirteen types of generation-related protection functions that operated to initiate generator tripping.
- There is limited information available that directly addresses which of those generator trips were appropriate for the Bulk Electric System (BES) conditions, and which were undesired trips.
- Some undesired generator trips contributed to expanding the extent of the blackout.

Table 1 — 2003 Blackout Generation Protection Trips

Device Type	21	24	27	32	40	46	50/27	50 BF	51V	59	78	81	87T	Unknown	Total
Number of Units Tripped	**8**	**1**	**35**	8	**13**	5	7	1	**20**	**26**	7	**59**	4	96	290

Relay One-Line Showing All Generator Protection Functions



Subsequent Events

- In some of the subsequent events the following concerns have been observed and analyzed:
  - Improper coordination between Power Plant and Transmission System protection
  - Trips due to auxiliary systems
  - Power Plant design concerns

Specific Concerns Regarding Generators and Power Plants

- Some Specific Examples of Concerns:
  - Auxiliary system voltage protection and motor contactor actuation
  - System-fed versus generator bus-fed auxiliaries

What is Coordination for Purposes of this Technical Reference Document

Coordination Definition

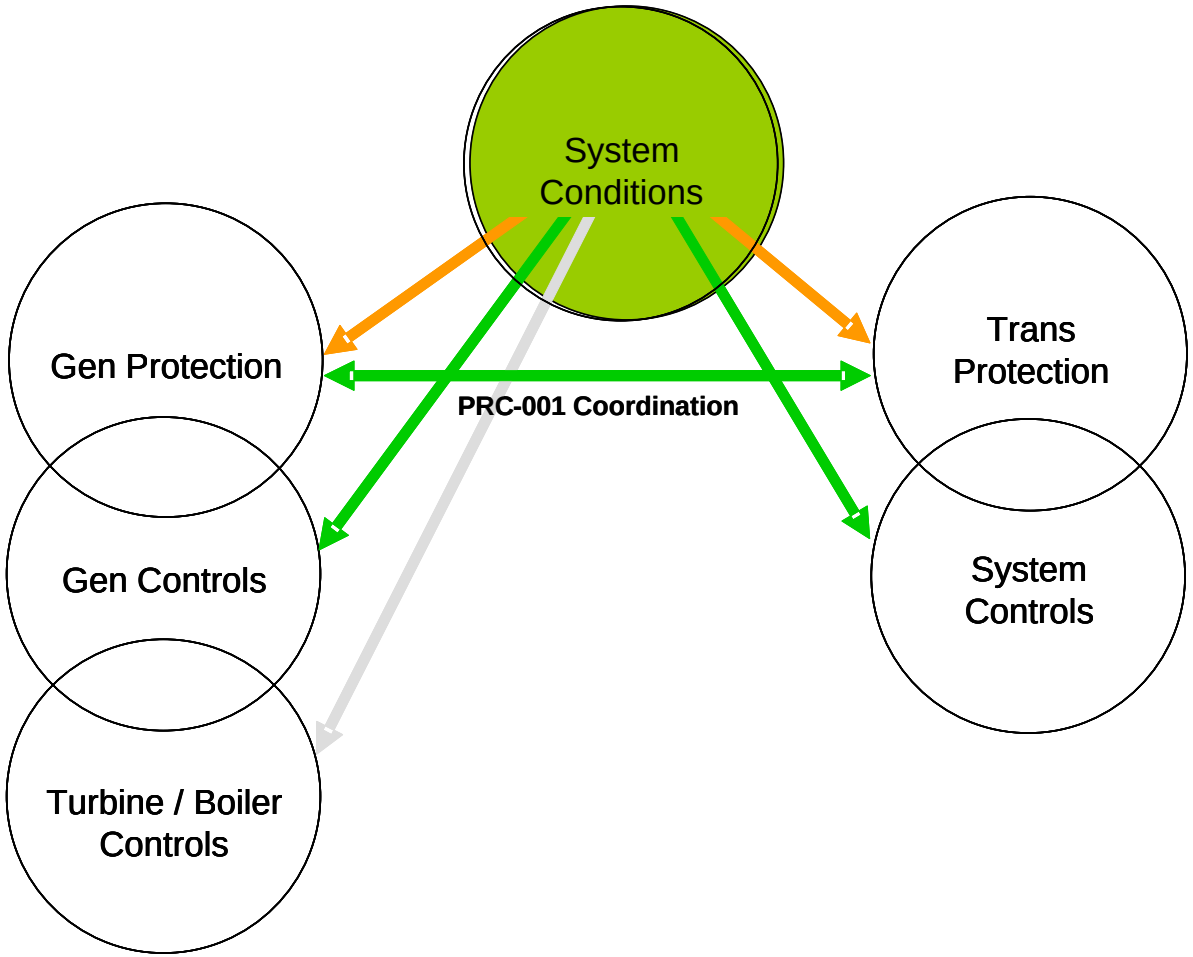
Coordination of generation and transmission protection systems (for events external to the plant), means that power plant protection and related control elements must be set and configured to prevent unnecessarily tripping the generator prior to any transmission protection and related control systems acting first, unless the generator is in jeopardy by exceeding its design limits due to operating conditions, generator system faults, or other adverse potentially damaging conditions.

Multi-Function Protection Devices

- Proper and adequate system and equipment protection is paramount and of highest priority.
- However, it is important to overall system reliability that generation and transmission are not tripped unnecessarily.
- The application of a protective function to trip a unit should be based on a specific need to protect the turbine-generator. **If that protection function is not needed, *DON'T USE IT!***

Interrelationships - Protection and Controls Coordination Goals

"A reliable electric system requires: proper protection and control <u>coordination</u> between power plants and transmission system."



Power Plant and Transmission System Coordination Objectives

- The goal of this document is to explore all generating plant protection schemes and their settings, which might be contributing to undesired trips during system disturbances or extreme stressed system conditions.
- To identify power plant protections that are required to coordinate with the transmission system.
- Information exchange requirements between the Generator Owner and Transmission Owner or Planning Coordinator.
- Technical basis to evaluate the coordination between generating plant protection and system transmission protection with an example.
- This self-examination and coordination process will significantly reduce the number of undesired trips in future events to improve system reliability.
- Technical Reference Support for the named NERC Protection and Control (PRC) Standards.

Scope

- Focus is on the reliability of the Bulk Electric System.
- This Technical Reference Document is applicable to all generators, but concentrates on those generators connected at 100 kV and above.
  - Note that the Technical Reference Document was developed with a focus on synchronous generators, and discussion for some protection functions may not be applicable to asynchronous generators.
- Distributed Generation (DG) facilities connected to distribution systems are outside the scope of this document.
- Information exchange requirements between Generator Owners and Transmission Owners to facilitate coordination between their protection schemes.

PRC Standards Support

- Support of the Following Standards
  - PRC-001 – NERC Project 2007-06: System Protection Coordination
    - Purpose: To ensure that System Protection Coordination is achieved and to ensure that real-time operating personnel have the information needed to react to the operations of Protection Systems and Transmission Planners have Protection System information to perform planning functions.
  - PRC-006 – NERC Project 2007-01: Automatic Underfrequency Load Shedding
    - Purpose: To establish design and documentation requirements for automatic underfrequency load shedding (UFLS) programs to arrest declining frequency and assist recovery of frequency following underfrequency events.
  - PRC-023: Relay Loadability
    - Purpose: Protective relay settings shall not limit transmission loadability; not interfere with system operators' ability to take remedial action to protect system reliability and; be set to reliably detect all fault conditions and protect the electrical network from these faults.
  - PRC-024 – NERC Project 2007-09: Generator Frequency and Voltage Protective Relay Settings
    - Purpose: Ensure that generator frequency and voltage protective relays are set to support transmission system stability during voltage and frequency excursions.

Benefits of Coordination to the Generator Owner

- Continuing to generate energy and produce revenue during these system events instead of unnecessarily tripping the unit.
- Avoiding a unit trip and start-up as well as associated costs.
- Not placing undue burden on other generating units in the fleet with the unnecessary loss of a given unit – both MW and Mvar loading.
- Reduction in start/stop cycles potentially reducing maintenance cycle frequencies.

Benefits of Coordination to the Transmission Owner

- Reduce loss of revenue due to reduction in power transfer.
- Improved reliability of generator var support to system.
- Reduction of transmission line overloads.
- Reduce unnecessary breaker and other equipment operations.
- Reduce likelihood of islanded system conditions.

Benefits of Coordination to the Planning Coordinator

- Improved accuracy of simulated system response.
- Increased confidence in results of planning studies.
- Achieved by:
  - Reducing the likelihood of generation tripping during stable system swings and other recoverable system conditions, and
  - Identifying conditions for which generators may trip, allowing proper modeling and accounting for the consequence of such trips.

Reliability of the Bulk Electric System and Reliability of Power Delivery to the Customer

- Reduce the number and extent of significant system events and associated impacts to lost production and power utilization.
- More reliable infrastructure and power supply.

Review of Technical Reference Table 2

- Table 2 provides an executive summary for the protection system function coordination described in this technical document. The three columns provide the following information:
  - Column 1 — the protective functions that require coordination by the Generator Owner.
  - Column 2 — the corresponding protective functions that require coordination by the Transmission Owner.
  - Column 3 — the system concerns the Transmission Owner and Generator Owner must, as a minimum, jointly address in their protection coordination review.

Table 2 Excerpt — Device 21 Protection Coordination Data Exchange Requirements		
Generator Protection Device	**Transmission System Protection Relays**	**System Concerns**
21 – Phase distance	21 87B 87T 50BF	Both 21s have to coordinate, Trip dependability, Breaker failure time, System swings (out-of-step blocking), Protective Function Loadability for extreme system conditions that are recoverable System relay failure Settings should be used for planning and system studies

Review of Technical Reference Table 3

- Table 3 provides the detailed information required from each entity to be exchanged for each function, such as the protection set points, time delays and other detailed data. The three columns provide the following information:
  - Column 1 — the detailed data the Generator Owner must provide to the Transmission Owner
  - Column 2 — the detailed data the Transmission Owner must provide to the Generator Owner
  - Column 3 — concerns that need to be addressed with the Planning Coordinator

Table 3 Excerpt — Device 21 Data To be Provided		
Generator Owner	**Transmission Owner**	**Planning Coordinator**
Relay settings in the R-X plane in primary ohms at the generator terminals.	One line diagram of the transmission system up to one bus away from the generator high-side bus[1].	Feedback on coordination problems found in stability studies.
Relay timer settings.	Impedances of all transmission elements connected to the generator high-side bus.	None
Total clearing times for the generator breakers.	Relay settings on all transmission elements connected to the generator high-side bus.	None
None	Total clearing times for all transmission elements connected to the generator high-side bus.	None
None	Total clearing times for breaker failure, for all transmission elements connected to the generator high-side bus.	None

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

General Data Exchange Requirements – Transmission or Distribution Owner Data and Information

- 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

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
- Setting Validation for the Coordination
  - 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

Functions Covered in the Technical Reference Document

- Phase Distance Protection (Function 21)
- Overexcitation or V/Hz (Function 24)
- Undervoltage Protection (Function 27)
  - Generator Unit Protection
  - High Side Protection Applied at Point of Common Coupling
  - Generating Plant Auxiliary Power Supply Systems
- Reverse Power Protection (Function 32)
- Loss-of-Field Protection (LOF) (Function 40)
- Negative Phase Sequence or Unbalanced Overcurrent Protection (Function 46)
- Inadvertent Energizing Protection (Function 50/27)
- Breaker Failure Protection (Function 50BF)

Functions Covered in the Technical Reference Document

- Backup Phase (Function 51T) and Backup Ground Overcurrent Relay (Function 51TG)
- Voltage-Controlled or -Restrained Overcurrent Relay (Function 51V)
- Overvoltage Protection (Function 59)
- Stator Ground Relay (Function 59GN/64G)
- Out-of-Step or Loss-of-Synchronism Relay (Function 78)
- Over and Underfrequency Relay (Function 81)
- Transformer Differential Relay (Function 87T), Generator Differential Relay (Function 87G) Protection and Overall Differential Protection (Function 87U)

Description and Introduction of Each of the Detailed Coordination Modules

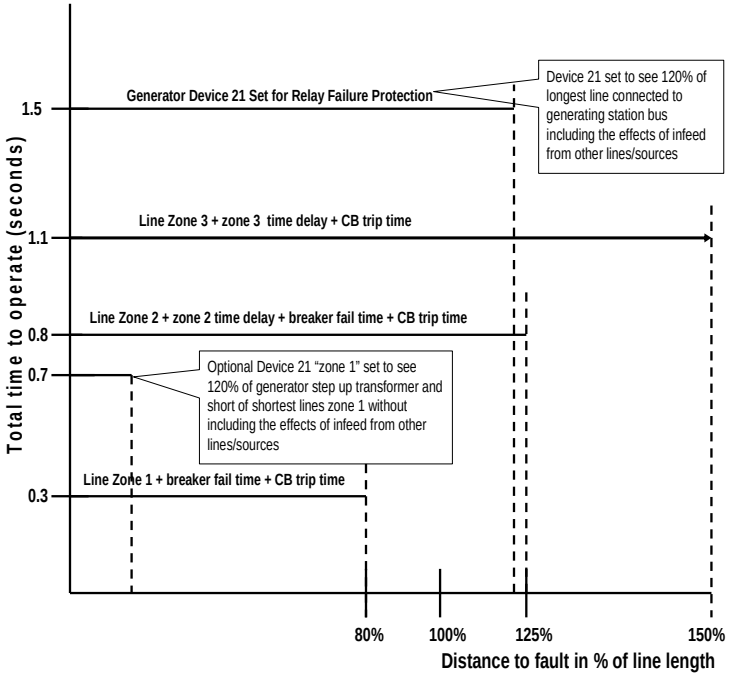
- Overview of generator and transmission system protection fundamentals
- Detailed discussion on coordination of Functions 21 and 51V
- Detailed discussion on coordination of Functions 40 and 78
- Detailed discussion on coordination of Functions 24, 27, 59, and 81
- Detailed discussion on coordination of Functions 50BF, 51T, 51TG
- Detailed discussion on coordination of Functions 32, 46, 50/27, 59GN/27TH, 87G, 87T, 87U

Overview of Generator and Transmission System Protection Fundamentals

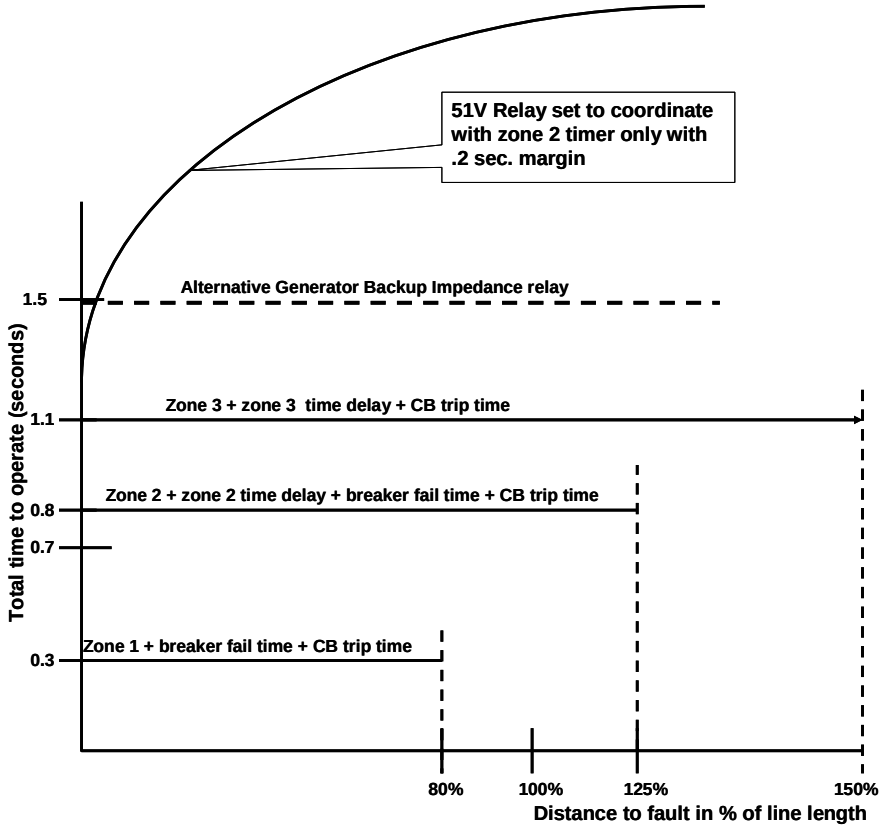
- Discussion of generator and transmission system protection fundamentals.
- Identify specific protective functions involved.
- Focus on areas required to perform the required exchange and protection coordination.
- Current protection schemes using best industry practices and extensively referenced to industry guides.
- Intended for the new engineer or engineer interested in developing knowledge in these areas for purposes of accomplishing the requirements in the PRC Standards .

Detailed Discussion on Coordination of Functions 21 and 51V

- This group of protective functions require both loadability and fault coordination with the transmission system.
- The graph below illustrate examples of time coordination from their respective sections.



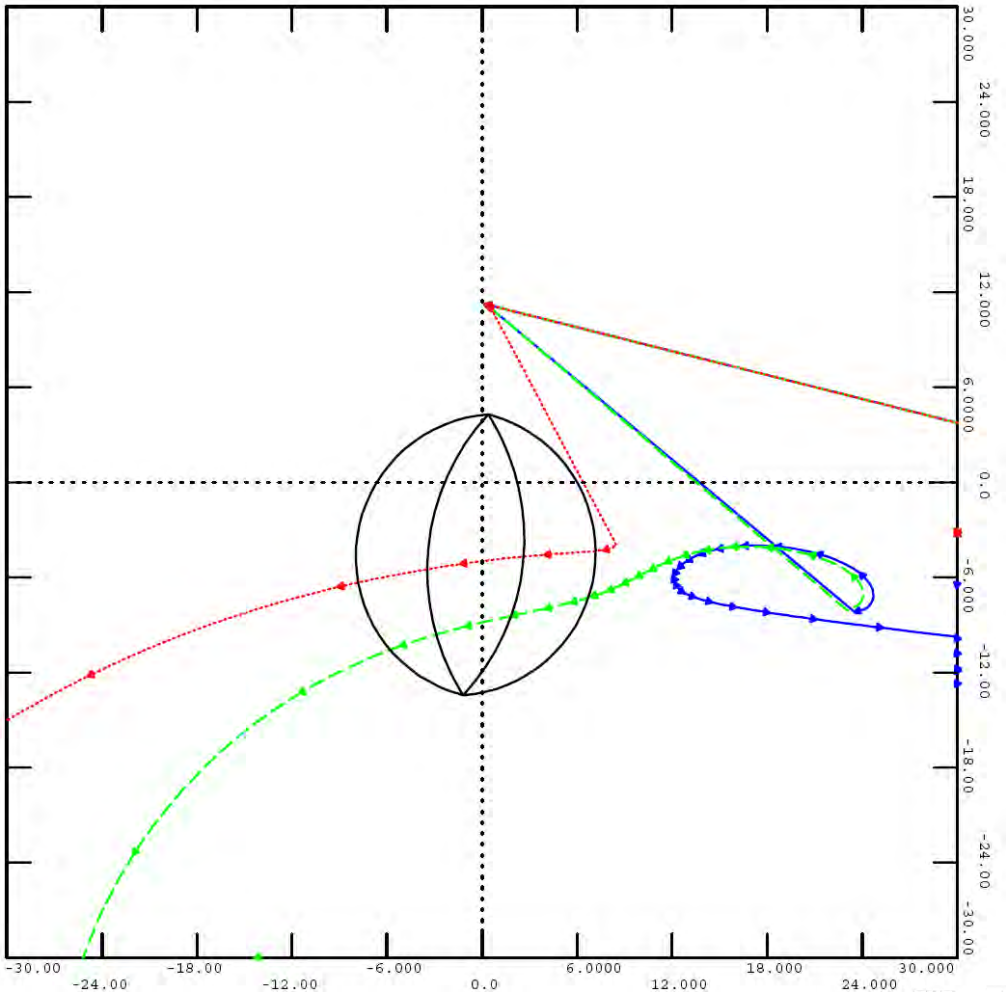
Function 21 – Section 3.1



Function 51V – Section 3.10

Detailed Discussion on Coordination of Functions 40 and 78

- This group of protective functions needs to be validated against transient stability studies to insure that tripping does not occur for stable impedance swings.



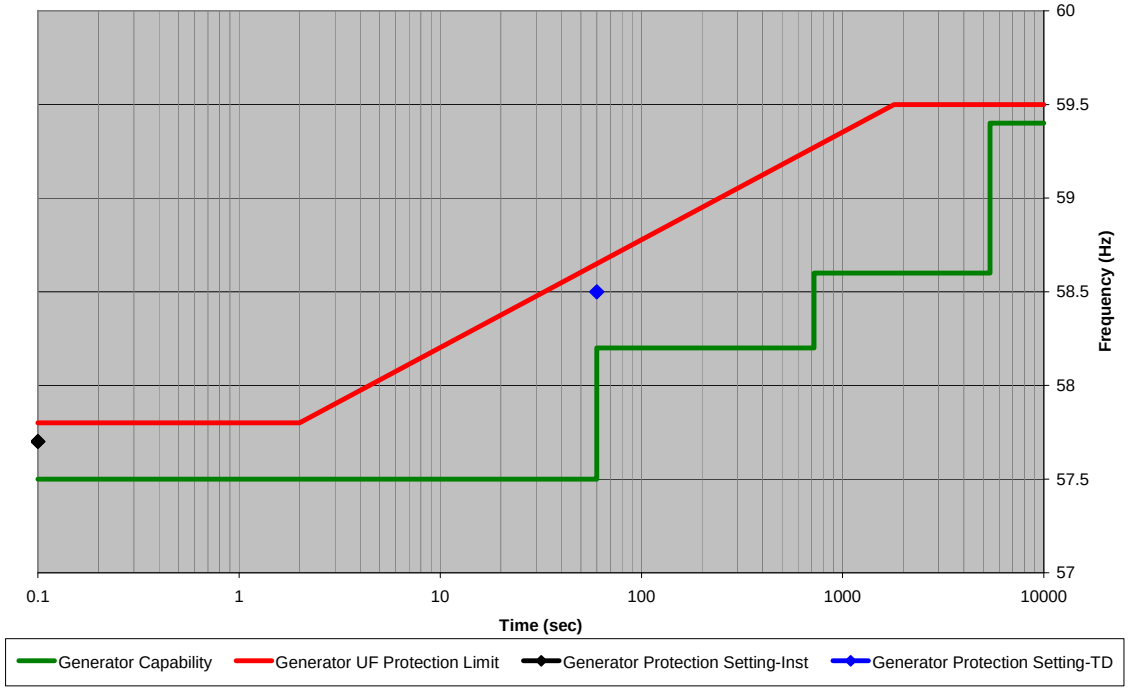
Sample apparent impedance swings are presented in this figure for a dual lens characteristic out-of-step relay. In this figure the time interval between markers is 100 ms (6 cycles) such that the faster swings have greater distance between markers. The three traces represent marginally stable and unstable swings for fault clearing at and just beyond the critical clearing time, and a trace for the worst credible contingency representing the fastest unstable swing

Marginally Stable Swing
Marginally Unstable Swing
Worst Case (Fastest) Unstable Swing

Notes: Time between markers (◄) is 100 ms
Scale is apparent impedance in secondary ohms

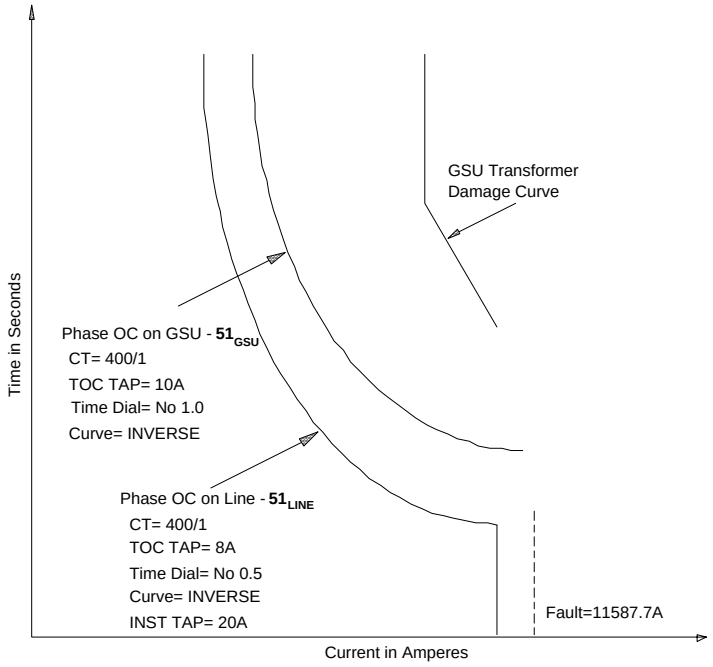
Detailed Discussion on Coordination of Functions 24, 27, 59, and 81

- This group of protective functions require coordination with transmission system performance, UFLS, and UVLS for stressed voltage conditions.
- Settings should be used for planning and system studies either through explicit modeling of the function, or through monitoring frequency performance at the function location in the stability program and applying engineering judgment.
- The graph below illustrates underfrequency set points coordination with an UFLS Scheme.



Detailed Discussion on Coordination of Functions 50BF, 51T, 51TG

- This group of protective functions requires coordination with system phase and ground fault protection.
- The graph below illustrates an example of time current coordination for the 51T, GSU transformer phase protection with system phase overcurrent protection.



Detailed Discussion on Coordination of Functions 32, 46, 50/27, 59GN/27TH, 87G, 87T, 87U

- These protective functions do not present significant coordination concerns but each should be checked for specific issues identified in the Technical Reference Document.
- Some examples are:
  - Checking overlapping zones with system protection on the transformer and overall differential protection (87T and 87U),
  - Undervoltage supervision set point on the inadvertent energizing protection (50/27)
  - Negative sequence current protection (46) coordination with system protection for unbalanced fault condition as well as any unusually high level of continuous negative sequence current due to system unbalances such as un-transposed lines.

Session Summary

- The Technical Reference Document:
  - Identifies the specific plant protection functions that need to be coordinated.
  - Lists plant, system, and planning data to exchange.
  - Provides a seven step process for each of the individual functions.
  - Provides examples of plant and system coordination.
  - Provides specific areas of concern with regard to the reliability of the system to be addressed between the entities.
- A basic protection primer will be provided in the next session.
- Further details will be provided in subsequent sessions with protective functions grouped according to similar coordination concerns.

Question & Answer

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