Challenges in Analyzing SPOF Based Tripping Sequence and Fault Clearing Time for TPL-001-5.1 Compliance

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Introduction

- Transmission planning teams have relied on protection engineering teams for protection system performance data for the steady-state and transient stability studies performed as part of NERC TPL-001-4 standard compliance
- With the upcoming NERC TPL-001-5.1 revision (effective July 1, 2023), the study requirements for determining the impact of non-redundant protection systems have been expanded
- This has resulted in a more detailed protection system performance analysis to generate the data required for the planning studies
- This paper discusses the challenges related to this new requirement and strategies to tackle these challenges

Upcoming Changes in TPL-001-5.1 Standard

- In the upcoming TPL-001-5.1 revision, the P5 category is expanded from failures of non-redundant relays to failures of non-redundant components of a protection system
- As per the latest revision, the following can be considered a non-redundant component of a protection system:
  - A single protective relay that responds to electrical quantities without an alternative (which may or may not respond to electrical quantities) that provides comparable Normal Clearing times
  - A single communications system associated with protective functions necessary for the correct operation of a communication-aided protection scheme required for Normal Clearing (an exception is a single communications system that is both monitored and reported at a Control Center)
  - A single-station DC supply associated with protective functions required for Normal Clearing (an exception is a single-station DC supply that is both monitored and reported at a Control Center for both low voltage and open circuit)
  - A single control circuit (including auxiliary relays and lockout relays) associated with protective functions, from the DC supply through and including the trip coil(s) of the circuit breakers or other interrupting devices, is required for Normal Clearing (the trip coil may be excluded if it is both monitored and reported at a Control Center)

New Challenges – Increased Effort

- Identifying protection systems with non-redundant components or single points of failure (SPOF) across the entire BES system
  - Requires detailed drawings and data management
- Determining the delayed fault clearing times accurately
  - Increasingly difficult to estimate clearing times due to the increased complexity of the protection systems, especially for ground faults
- Feeding protection study results into planning studies
  - Need to translate protection study results into outage files for steady-state and transient stability studies

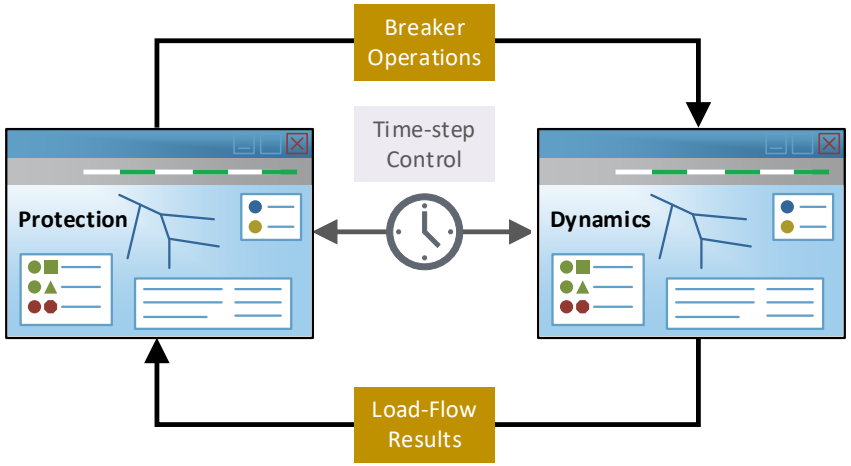
Planning Analysis Dependent Upon Protection Analysis

- Power system stability analysis (transient and steady-state) and protection analysis are performed using separate specialized analysis tools
- Planning tools specialize in analyzing power system stability by efficiently simulating the slow power system transients
- Planning tools typically work with pre-defined protection system operating times when analyzing impact of network outages
- However, when the protection system has been compromised due to the failure of a non-redundant component, its impact on protection coordination and fault clearing times cannot be generalized, and requires a more detailed analysis

Integrated Analysis Approach

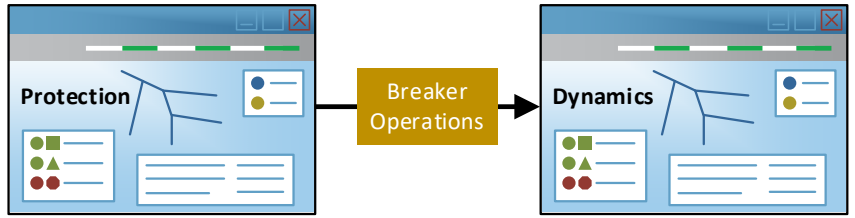
Co-simulation

- Requires both simulation tools to interact in small time steps
- Requires a perfect alignment (identical topology) of the protection and planning network models

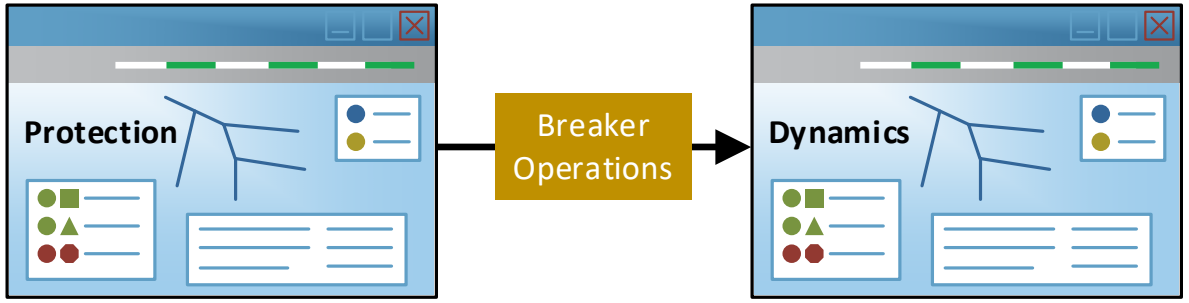


Feed-forward

- Operation of the system components is translated from protection system to planning system and finally fed forward for stability simulation
- Does not require complete alignment between the two models and instead relies on an external mapping table for converting results from protection to dynamic model



Feed-forward Integrated Approach – More Practical



Key Drivers–

- Complete alignment between protection and planning models is not required
- The approach works with all available protection and planning software tools

Single Points of Failure Identification (1/3)

- Identifying and recording SPOFs can be tedious and pose a significant challenge for a utility
- SPOF data is not traditionally readily available and requires detailed review of the protection system design and performance
- Broad expertise level required across protective relay function, communication systems, and protection system circuitry
- Need to be completed periodically and recorded for future use
- Warrants coordination across different departments– Planning, Protection, Communication, Asset Management, Commissioning and Testing

Single Points of Failure Identification (2/3)

- Protective Devices
  - Challenging to provide evidence of comparable fault clearing times when the alternative relays are different
  - Further complicated by the presence of electromechanical protection schemes
- Communication Systems
  - SPOF identification of communications systems requires a full redundancy assessment of the many communication system components and the communication medium

Single Points of Failure Identification (3/3)

- DC Supply
  - DC connections to all components of the protection systems need to be reviewed together to determine if failure of the DC Supply can result in delayed fault clearing
- Control Circuitry
  - Requires an extensive review of the critical protection trip paths in the protection circuit designs
  - Seemingly redundant protection systems can have shared control circuitry components resulting in non-redundancy

Strategy on Collecting and Managing SPOF Data (1/2)

- Develop a strategy and a documentation format for data collection based on a sample set of substations
- Consider making the SPOF information a required field in asset management systems, and updated as assets are added to the system or modified
- Building controls (processes and tools) to ensure that SPOF data is kept up-to-date, which is often spread among multiple repositories – Relay Database, SCADA Alarms, Asset Management Database, etc.

Strategy on Collecting and Managing SPOF Data (2/2)

- Ensure communication systems, DC supply, and trip coils are properly monitored and reported to the Control Center to significantly reduce SPOF identification burden
- Invest to improve and standardize the protection systems and monitoring systems to minimize the number of SPOF and reduce TPL-001-5.1 assessments

Tripping Sequence and Fault Clearing Time Calculation (1/2)

- Protection evaluation involves applying an SLG fault on an equipment combined with the failure of a non-redundant component of the protection system protecting the faulted equipment
- Requires the study of EHV and HV network equipment of the following types:
  - Transmission circuits
  - Transformers
  - Bus sections
  - Generators
  - Shunt devices
- Variations in the protection system design, possible fault locations, and response from backup protection systems
- Unique challenges in determining the worst-case delayed fault clearing time

Tripping Sequence and Fault Clearing Time Calculation (2/2)

- Complexity of the protection systems has grown
- Difficult to accurately predict the protection system tripping sequence for a given contingency scenario without simulations
- Protection simulations require accurate and detailed modeling of short circuit network and the protective device functions
- Need to be define an optimal modeling detail level
  - Higher model detail, such as node-breaker network model, breaker failure protection model, etc. can be advantageous, but can require higher maintenance effort

Stepped Events Analysis (SEA) Based Protection Simulations (1/2)

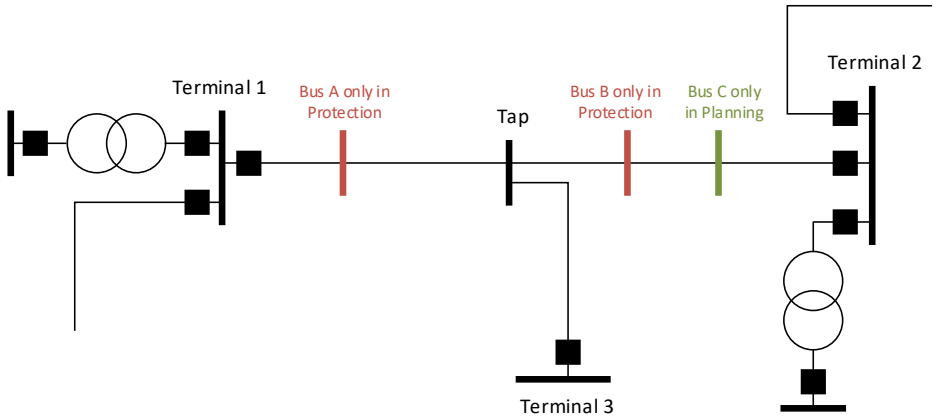
- Although manual simulation can be tried for a small number of cases, the simulation of the entire system is impractical without some automation
- The preferred method for analyzing tripping sequence and fault clearing times is stepped-events analysis (SEA); it is commonly used for coordination analysis, but is directly applicable to the SPOF studies
- SEA-based simulations break down the fault simulation into different events, which are defined by the opening of one or multiple breakers at the same time
- At each event, the voltages and currents seen by the protective devices around the faulted element are recalculated, and their steady-state operation is predicted

Stepped Events Analysis (SEA) Based Protection Simulations (2/2)

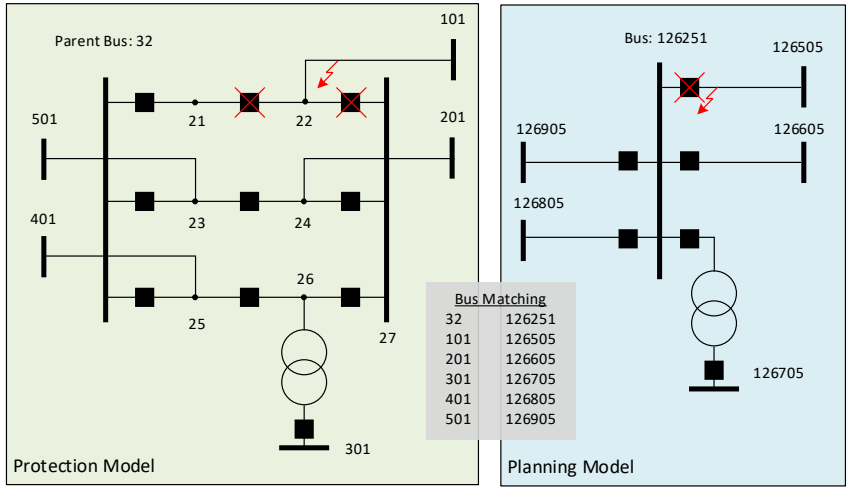
- The SEA is dependent upon an up-to-date simulation-ready protection model
- To reduce the model maintenance effort and timeline, utilities need to invest in an automation-based protection modeling solution
- Some contingency scenarios that are dependent upon complex protection modeling may require manual analysis
  - As automated analysis and related special modeling requirements may not be worth the effort
- Manual analysis may also be more applicable for SPOFs with a lower system occurrence rate

Feeding Protection Results into Planning Studies (1/2)

- The protection study results need to be translated to the corresponding outages of planning model components
- Accurate and comprehensive mapping of network components between protection and planning models is required, due to the difference in network modeling practices



Differences in number of buses in protection and planning models



Comparison of bus configuration representations in protection and planning models

Feeding Protection Results into Planning Studies (2/2)

- Planning and protection tools can have different methods of defining breaker operations
- Protection typically record breaker operations in their actual sense– such as at the end of a line, or at one winding of a transformer, etc.
- Presently, available planning tools could allow outage of an entire equipment, such as a line section, a tie, a transformer
  - Newer versions of planning software tools may soon be capable of simulating a virtual breaker operation
- These requirements can add to the complexity of feeding protection results into planning studies

Transforming Protection Study Results for Planning Analysis (1/2)

- Planning and Protection model alignment is critical to converting the protection study results into outage files for planning analysis
- Alignment is achieved using a bus mapping table between the two models by using automated and manual comparison of the models
  - Mapping should be designed to support both one-one, and one-many relationship between buses
- Investing in reducing differences between planning and protection models will reduce the effort of future maintenance of the mapping table

Transforming Protection Study Results for Planning Analysis (2/2)

- Protection study results need to be fed into two types of planning analysis
  - Transient – Requires breaker operation with timing, and zero and negative sequence Thevenin impedance at the faulted bus
  - Steady-state assessment– Requires only the breaker operations
- Outage files need to be created for both types of assessment
- Specially customized scripts were created to generate outage files for steady-state and transient studies using the bus mapping table and protection analysis results as inputs

Summary (1/2)

Tackling the Present

- TPL-001.5.1 will require protection and planning teams to work even more closely
- Identification of SPOFs in the protection system can pose a significant effort initially; develop a strategy for data collection and documentation
- Careful review required when determining automated vs manual analysis for complex contingency scenarios
- Integrated Analysis Approach – performing SEA-based protection simulations and generating outage files for planning analysis saves engineering time and effort

Summary (2/2)

Future Improvements

- Utilize asset management systems to maintain SPOF data going forward
- Strong case for upgrading older protection systems, and establishing monitoring and reporting automation where possible
- Need for aligning the network models used by planning and protection engineering, and move towards centralized Network Model Management solution

Thank you!

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