Modeling and Simulating Single Points of Failure for TPL-001-5.1 Compliance

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Overview

- Introduction
- Modelling & Simulation Approach
- Implementation Challenges & Solutions
- Summary & Conclusions

Introduction

The TPL-001-5.1 standard and new requirements

Introduction

- NERC TPL-001-4 standard: planning studies rely on generic protection performance data often categorized based on voltage for steady-state and transient stability studies NERC TPL-001-4 standard compliance
- NERC TPL-001-5.1 standard: expands study of non-redundant protective relay to non-redundance protective system elements (effective July 1, 2023)
- Generalized protection performance data is not sufficient and more accurate protection modeling and simulation is required now
- Accurate model is always good to have! But the challenges are
  - Collecting data
  - Loading data to protection models
  - Enabling simulation of contingencies
- This paper presents the solution using commonly used software tools

Identifying Single Points of Failure

- 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 is 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 Modeling & Simulating Requirements

- Identifying non-redundant components of protective system that can become single points of failure (SPOF)
- Collecting such data and storing it
- Loading SPOF data into model
- Simulating both the protection model and dynamics model, simultaneously

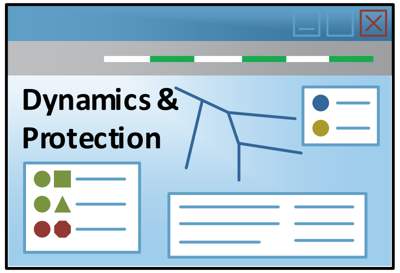
Challenges of the New Requirements

- Many different SPOF condition may exist and must be determined even in one utility’s network due to different designs
- Collecting SPOF data can be long and tedious
- Some SPOF data cannot be readily incorporated in protection, e.g. loss of DC supply
- Most simulation tools specialize in one area:
  - Planning tools specialize in analyzing power system stability by efficiently simulating the steady-state conditions and slow electromechanical transients
  - Protection tools specialize in modeling relays during short-circuit conditions assuming no dynamics during protection system operation

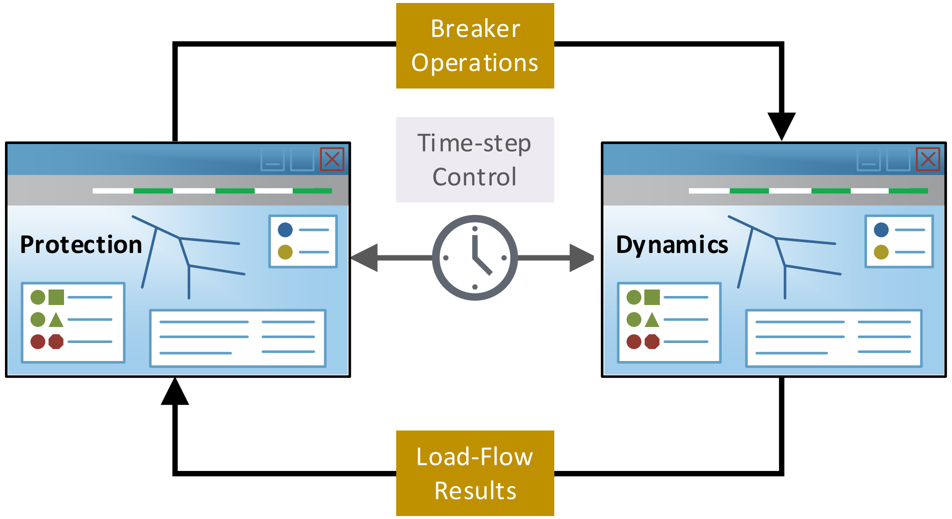
Modeling & Simulating Approach

Software tools and how to connect them for simulating dynamics and the protection systems

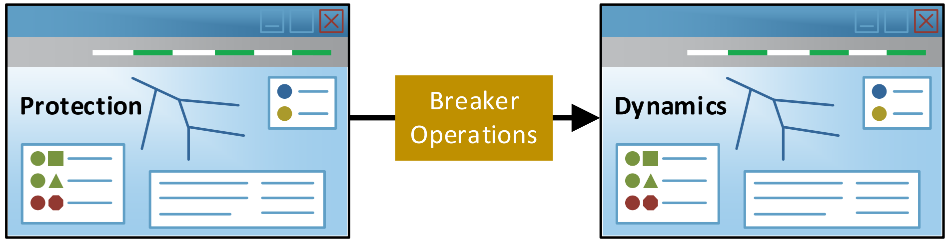
Defining Simulating Approaches



1. **Single-tool**
- Simulating both models in a single application



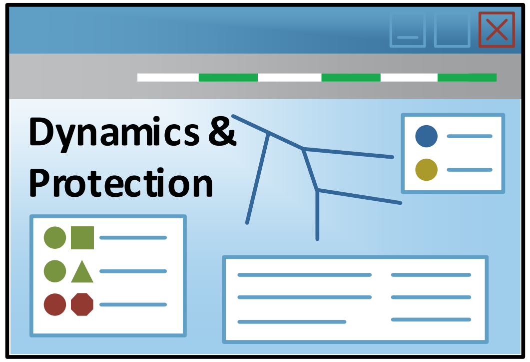
2. **Co-Simulation**
- Closed-loop simulation using 2 applications



3. **Feed-forward**
- Open-loop simulation using 2 applications

Single-tool for Protection & Dynamics

- Same network model
- Simulation tool capable of
  - Power-flow calculation
  - Dynamic models
  - Short-circuit calculation
  - Relay models



✓ Properly simulates the interoperation of protection systems during dynamics events

✗ Not used by North American utilities

Co-Simulation of Protection & Dynamics

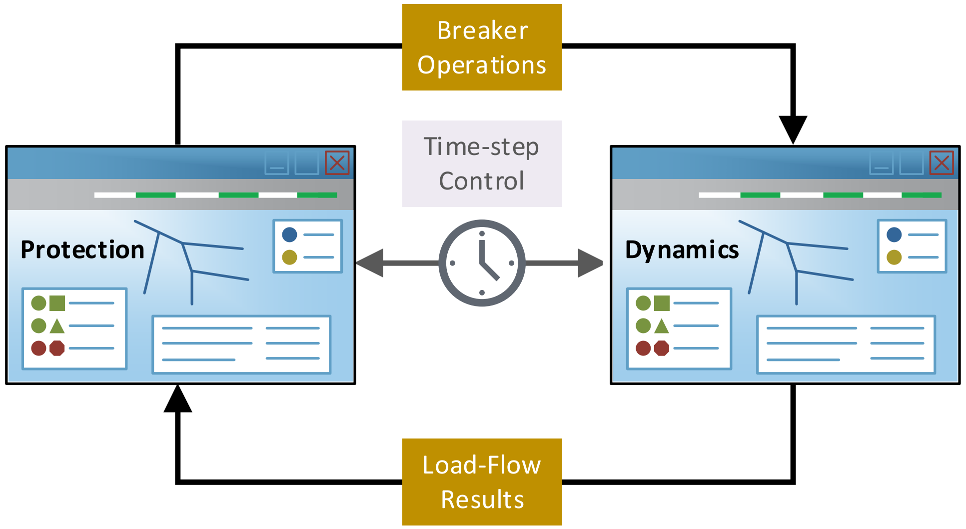
- Dynamic model and protection model separated in two specialized software tools
- In small time-steps, information is transferred between the two

✓ Properly simulates the interoperation of protection systems during dynamics events

× Limited to one pair of tools only

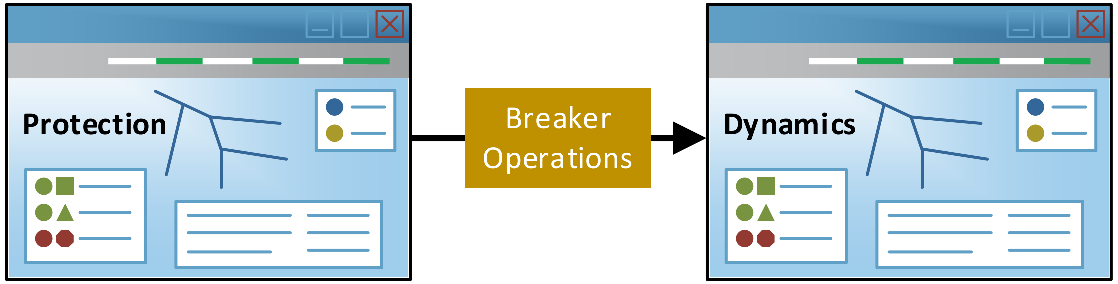
× Network models should closely match both ways

× Simulation stability is more difficult



Feed-forward Protection Model Events to Dynamics Model

- Protection system operates independently without dynamics
- Operation of the breakers is translated from protection system to dynamic system



✘ Accuracy is reduced in an open-loop approach

✓ Alignment of models is one-way only and can be done externally

Detailed protection model can be reduced and transferred to the dynamics model but converting simple bus to detailed may not be possible without additional information

✓ Can be implemented for all protection and dynamics applications pairs

✓ Simulation time is reduced, and simulation stability is less concerned

Implementation Challenges & Solutions Part 1

How to get data, how to model, and how to define study criteria

Basic Modeling Requirements

- Dynamics Model
  - Detailed model of breaker configurations can be omitted with the chosen approach. However, recommended to take advantage of it if possible
  - Same high-quality dynamics modeling is required as always
- Protection Model
  - Detailed model of network and breakers may be required
    To model specific elements affected by loss of DC supplies, control circuitry, etc.
    Increased effort for locating protection model on the network
  - Event-based simulation features of protection tools is a must
    Complexity of protection systems and relays is growing
    Prediction of tripping sequence and clearing time requires detailed model

Single Points of Failure – Part 1: Identification

- SPOF data is not traditionally recorded nor readily available
- Detailed review of the protection system design and estimating its performance during contingencies is needed
- Such review requires broad expertise level across protective relaying, communication systems, and control circuitry
- Collection and storage of SPOF data warrants coordination across different departments – Planning, Protection, Communication, Commissioning and Testing

Single Points of Failure – Part 2: Data Management

- 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 in the chosen data repository
- Improve standard to reduce SPOF numbers, e.g., with better monitoring of DC supplies, and increased redundancy of communication and control circuitry

Single Points of Failure – Part 3: Modeling

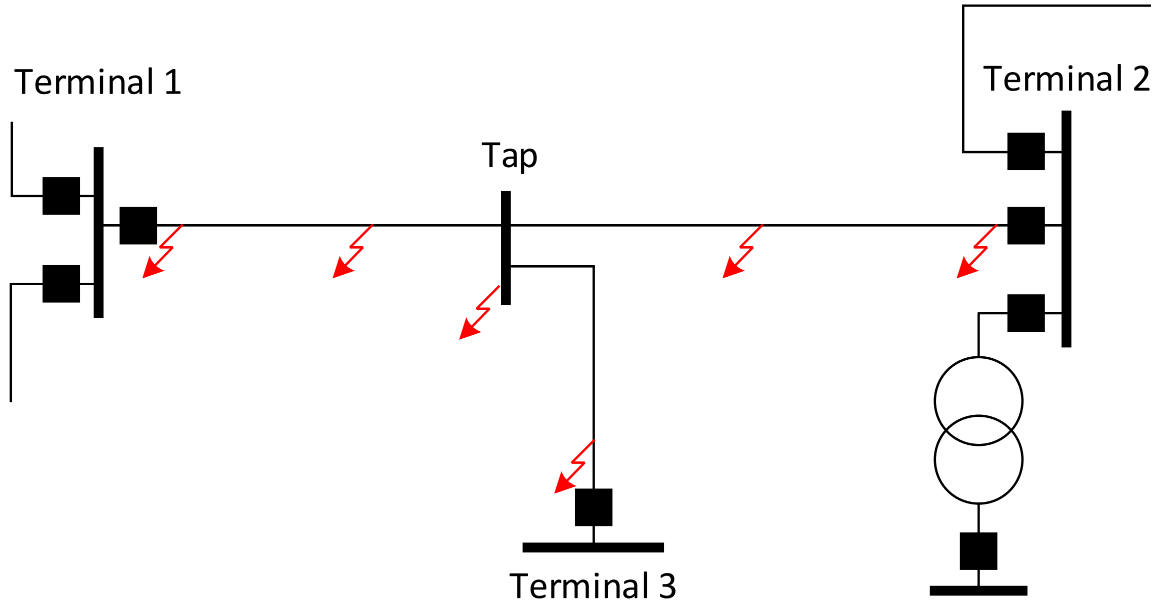
- Protective Devices
  - Modeled in protection tools
  - Models in a wide-area, preferably entire system is needed
  - Automation helps to interpret settings and create models
- Communication Systems
  - There may be shared components between schemes that should be carefully considered
  - Requires a full redundancy assessment of all the communication systems components
  - Limited modeling options in protection tools
  - May be modeled by outaging the entire teleprotection
- DC Supply
  - Generally, cannot be modeled in protection tools
  - Loss of DC may be modeled externally by disabling all affected protective devices
  - Can be avoided, e.g., if redundancy is available or proper alarm is set up
- Control Circuitry
  - Generally, cannot be modeled in protection tools
  - Loss of control circuitry elements may be modeled externally by disabling affected protective devices
  - Be mindful that seemingly redundant protection systems can have shared control circuitry components resulting in non-redundancy

Implementation Challenges & Solutions Part 2

How to simulate protection operation on dynamics model

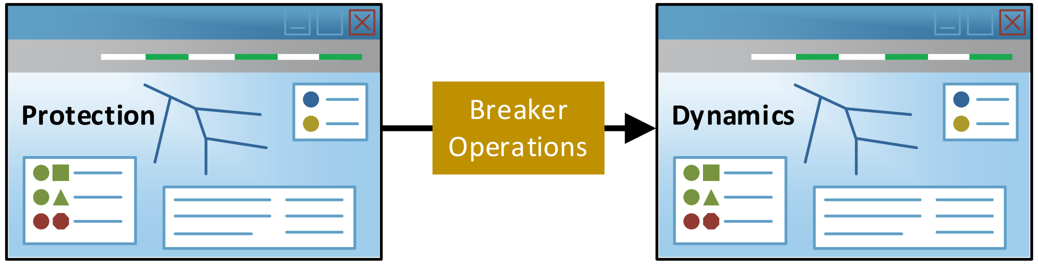
Fault & Contingency Scenarios

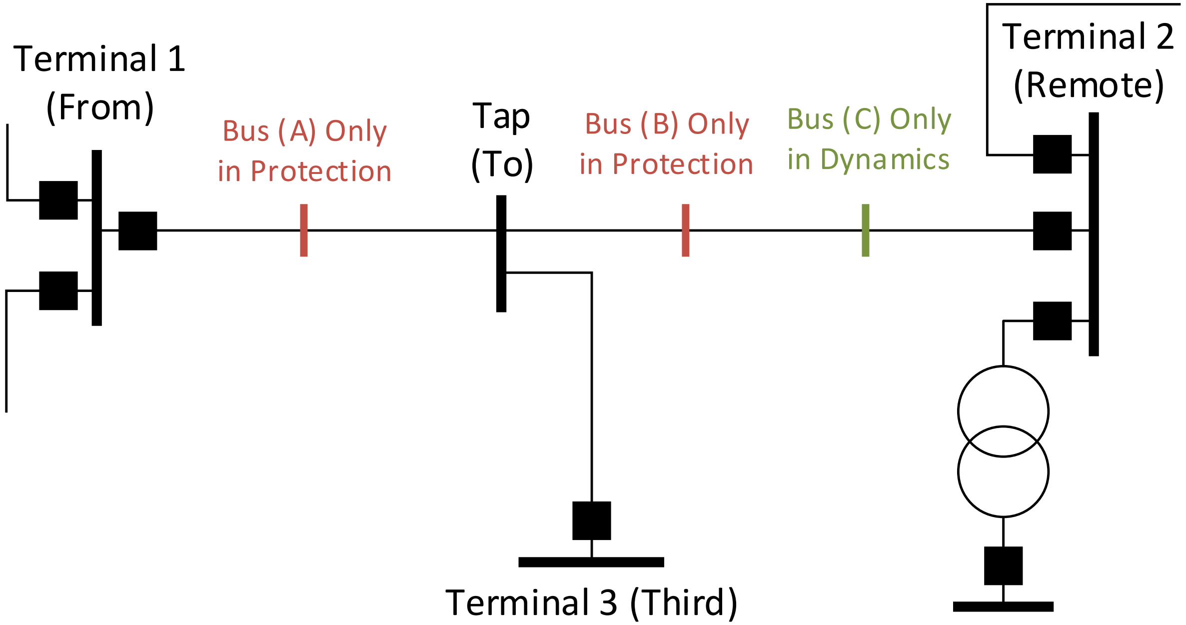
- Worst case of delayed fault clearing should be determined
  - Multiple locations can be considered
  - Consider automating the simulation of fault scenarios
- P5: single-line-to-ground faults
  - Each fault is combined with the failure of a non-redundant component of the protection system protecting the faulted equipment



Feeding Protection Results into Dynamics Studies

- Reminder: SPOF is modeled in the protection software tool, then feed-forward to dynamics model
- Challenge 1: Dynamics model may not have breakers
- Challenge 2: There may be buses that are missing from each model – see picture ➔
- Protection model breaker operation should be converted to dynamics model branch outage





Breaker Operation Conversion (1)

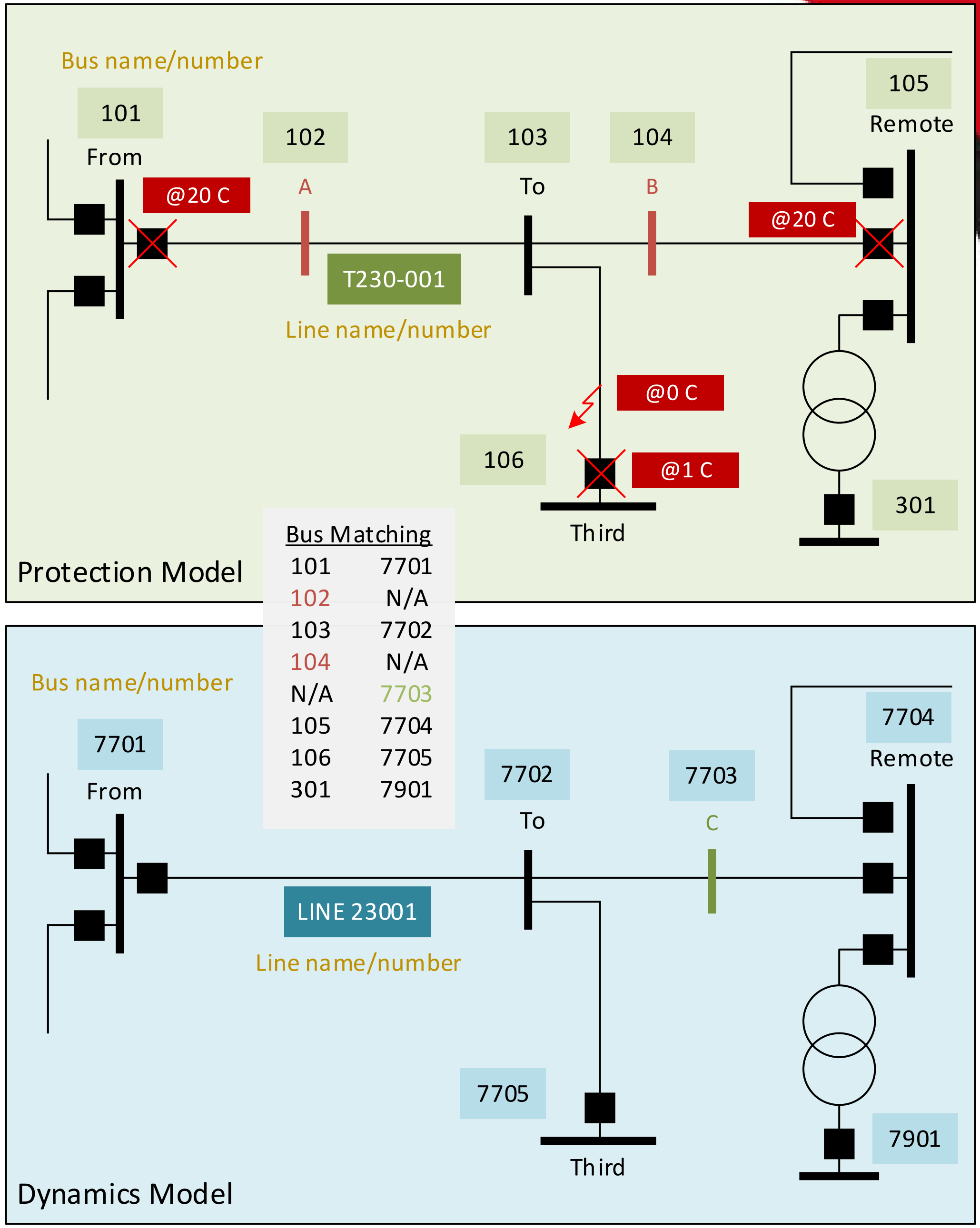
Node Breaker to Branch Outage

- Protection simulation results

```
@1 cycle      Open 106 to 103
@20 cycle     Open 105 to 104 &
              Open 101 to 102
```

- Convert to dynamic model outage using bus matching table

```
@1 cycle      Open 7705 to 7702
@20 cycle     Open 7704 to 7703 &
              Open 7701 to 7702
```



Bus Matching

101	7701
102	N/A
103	7702
104	N/A
N/A	7703
105	7704
106	7705
301	7901

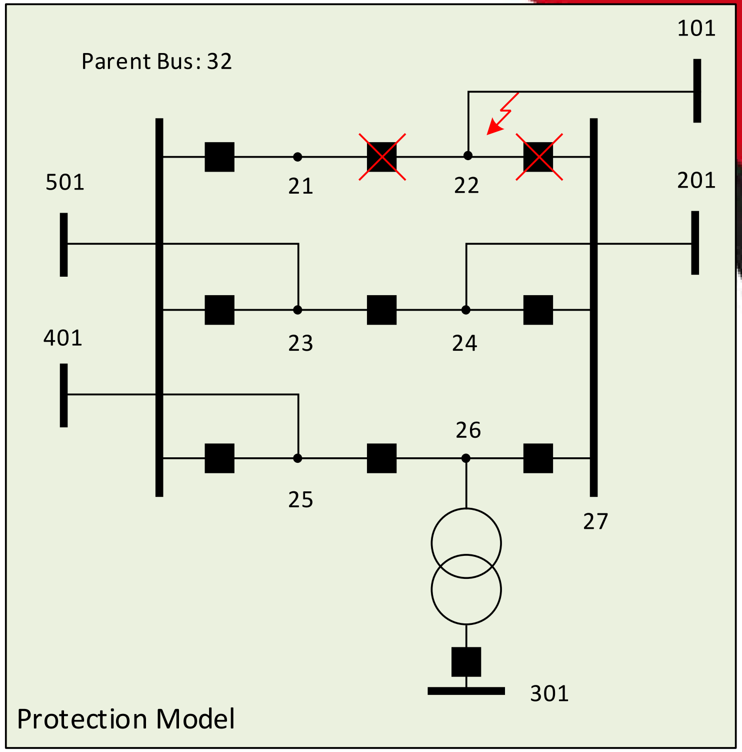
Breaker Operation Conversion (2)
Detailed Bus to Branch Outage

- Protection simulation results

```
@1 cycle      Open 21 to 22 &
              Open 22 to 27
```

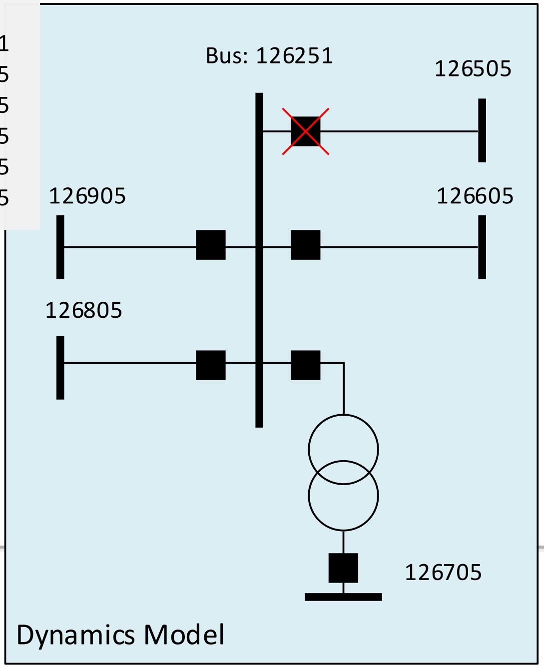
- Convert to dynamic model outage using bus matching table

```
@1 cycle      Open 126251 to 126505
```



Bus Matching

32	126251
101	126505
201	126605
301	126705
401	126805
501	126905



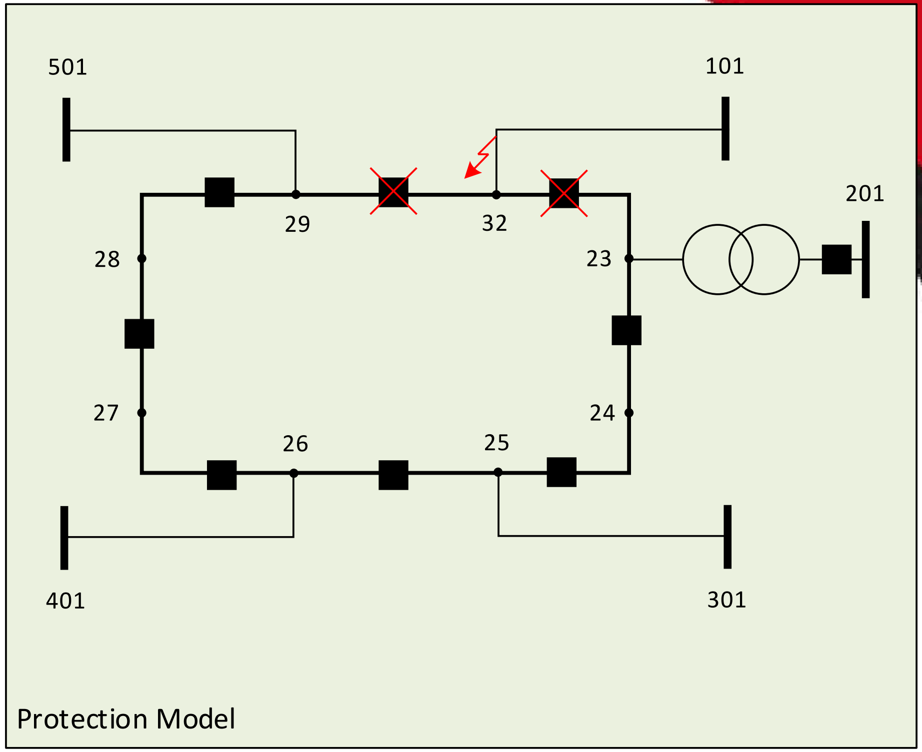
Breaker Operation Conversion (3)
Detailed Bus to Branch Outage

- Protection simulation results

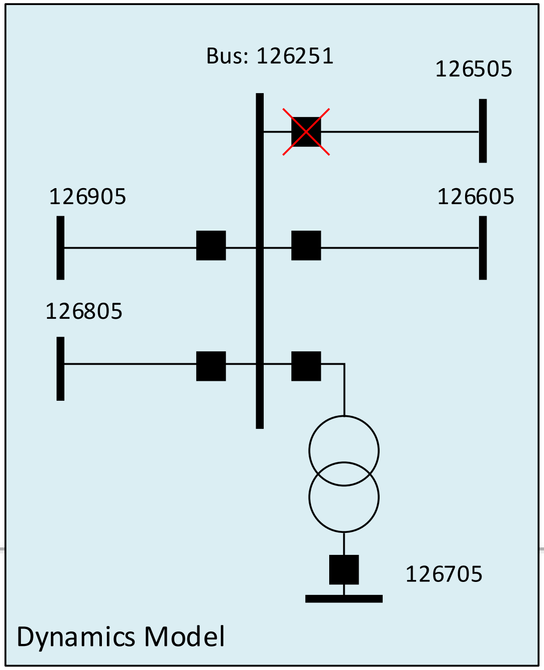
```
@1 cycle      Open 29 to 32 &
              Open 32 to 23
```

- Convert to dynamic model outage using bus matching table

```
@1 cycle      Open 126251 to 126505
```



Bus Matching	
32	126251
101	126505
201	126605
301	126705
401	126805
501	126905



Steady-state and Transient Dynamics Stability Analysis

- List of faults, delays, and translated breaker operations available at this point
- All breaker operations used for steady-state stability analysis
- The sequence of operation is translated to contingency scenarios (outage files) for transient dynamics simulation
- Zero- and negative-sequence Thevenin impedances needed at fault location to estimate single-line-ground fault in a positive-sequence model
- Detailed breaker operation may result in split bus that should be modeled
- Temporary (dummy) bus and zero-impedance branch may be needed to model breaker if not supported by tool

Summary & Conclusions

Summary & Conclusions

- TPL-001-5.1 highlights the need for upgrading outdated protection systems and improving redundancy
- Requires protection and planning teams to work even more closely – requires better modeling practices
- Identification of SPOF in the protection system can pose a significant effort initially – requires data management systems
- Not all SPOF can be modeled in protection, and simultaneous simulation may not be an option
- Alternative solution is to create another tool that integrates both dynamics and protection simulation functionalities under a single software application

Summary & Conclusions (Continued)

- Consider unifying network models and improve model maintenance, i.e. better network model management
- Future tools should support the simulation of transient dynamics and protection schemes, simultaneously
- Until then the open-loop method presented greatly improves the protection system simulation accuracy and fault clearing time calculation

Thank you!

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