Developing Network and Protection Model Maintenance Approach for NERC PRC-027

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I. Introduction

PRC-027-1 is an upcoming NERC Protection and Control Reliability Standard that is intended to ensure the continual maintenance of protection system coordination associated with Bulk Electric System (BES) elements. The PRC-027-1 Reliability Standard will require electric utilities that are subject to NERC, to establish formal procedures in a range of aspects to support the maintenance of protection system coordination performance. Furthermore, the growing complexity of modern protective devices with dozens of integrated functions, and hundreds of settings, as well as the evolving nature of power grids poses significant challenges in the design and evaluation of protection settings performance.

Numerous utilities around the world are investing in advanced protection system analysis software to aid in the design of protection settings and evaluate the coordination performance of the surrounding protection devices. Although automated protection settings evaluation studies have the potential to greatly reduce the analysis effort, they require accurate network and protection models that are ready for simulation. The main challenges in preparing or maintaining an accurate model are: 1) System evolution, 2) Complexity of modern protection systems, 3) Time sensitive nature of process, 4) Data availability, and 5) Data integrity.

Therefore, it becomes essential to have a systematic and sustainable approach for continual model maintenance that can support the need for periodic protection coordination analysis, such as compliance with NERC PRC-027.

Most utilities have already established processes for maintaining a short circuit model. Such processes may comprise manual methods of maintaining the network model or rely on automated methods such as those based on IEC CIM standards. However, preparing a simulation-ready protection model is still a challenge in the industry due to the complexity of modern protection devices and a wide range of protection functions. The model preparation process is still primarily manual as it relies on the information that is typically stored in different non-integrated databases, such as asset management systems, relay settings files, network drawings, DC logic diagrams, etc.

The manual modeling approach is not only time consuming but is also prone to human error. Historically, this has been a barrier for utilities wanting to build a protection model with enough detail to take advantage of modern protection system analysis tools. To eliminate such barriers, new automated tools need to be developed for accurate, repeatable, and efficient protection modeling in advanced computer programs. This paper discusses approaches and processes for maintaining and updating the network and protection modeling using a short circuit program and discusses challenges related to their practical implementation. It presents processes and challenges related to data gathering, aligning network and protection data, handling device settings from utility data sources, and accurately modeling complex functions such as tele-protection schemes.

The presented model maintenance approaches are intended for network model preparation, protection modeling, simulation, and analysis in a real-world large-scale system. Besides offering a significant amount of time and budget savings, the proposed approaches and processes can effectively reduce modeling error, thereby increasing confidence in the model and subsequent analysis.

II. Utility Processes for Protection Model Maintenance

The short circuit model needs to fulfill two major utilization requirements. First, the model shall be able to represent the in-service system, which is used for analyzing the present state of the system; second, it shall be able to represent the future system, which is used for analyzing the state of the system once new construction projects are commissioned. The model maintenance processes need to satisfy both requirements.

The model maintenance process approaches can be fundamentally categorized into the following: a centralized approach and a distributed approach.

The centralized approach consists of having dedicated resources for managing the model. This type of approach requires less training overhead and ensures a model with better quality. However, it can introduce a constraint in the model preparation timeline and may result in delayed release of updated models for the engineering group. A typical centralized model maintenance approach will result in publishing the model at set periodicity, such as monthly, quarterly, etc.

The distributed approach consists of requiring all users of the model to also modify the system model concurrently. This type of approach requires larger number of resources to be trained and poses a greater risk to maintaining the integrity of the model. The distributed approach may however result in more up-to-date model at a given point in time, as the model updates are applied more frequently.

While both approaches can satisfy the utilization requirements, the centralized approach is generally preferred due to the lower training burden and better control over the model quality.

In the practical implementation referenced in this paper, a combination of centralized and distributed approaches is adopted. While the centralized approach is adopted to fulfill the utilization requirement for having a model of the in-service system, the distributed approach is adopted to fulfill the utilization requirement for having a model of the future system. An overview of this process is provided in Figure II-1 and described below.

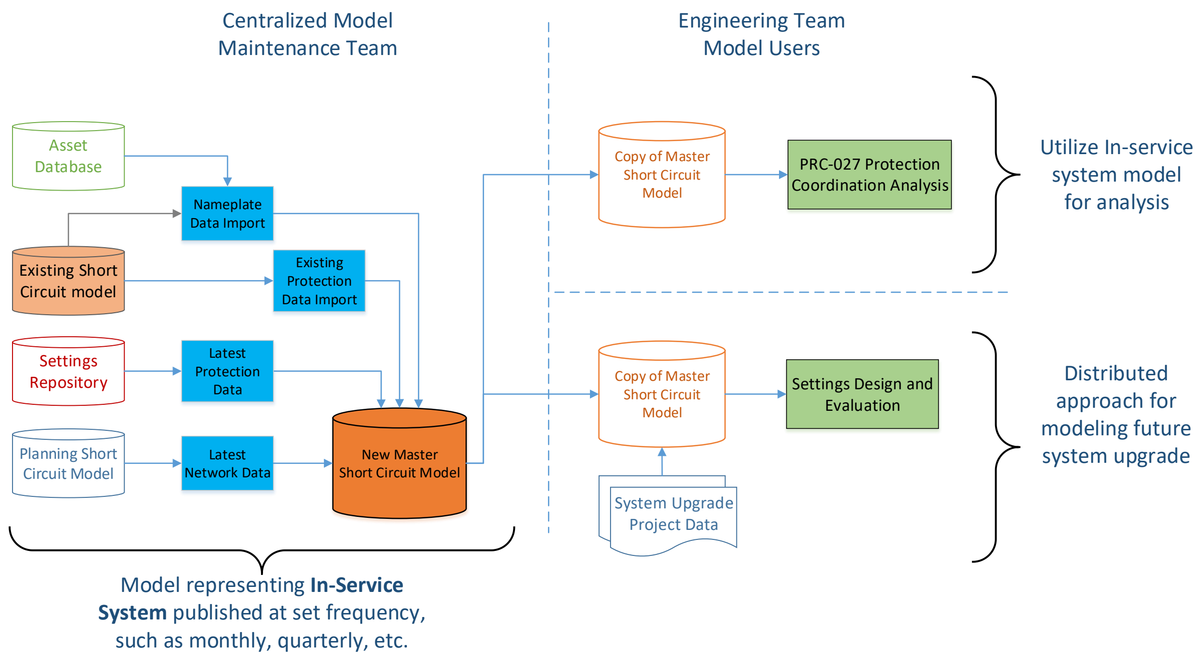

Figure II-1. Typical process flow for updating a protection model using a short circuit program.

The database preparation process shown in Figure II-1 includes the following stages:

1. **Acquiring Data** – Acquiring data from the planning database, obtaining the latest protection settings and logic diagrams, single line diagrams, etc.
2. **Conversion of Planning Model to Short Circuit Model** – Converting the planning base-case model into a new short circuit model via utilization of intermediate tools.

3. **Nameplate Data Migration** – Running an intermediate tool that will update the new short circuit model with the latest nameplate data from the asset database and performing network model updates to prepare it for Protection Data Merge.
4. **Protection Data Merge** – Merging protection data from the existing protection model into the newly created one.
5. **Data Comparison between Settings Database and Existing Protection Model** – Performing a comparison of protection settings data using an intermediate validation module which will provide a list of protection devices that require protection model update.
6. **Protection Model Updates** – Updating protection model to ensure that it reflects the latest protection settings for the complete network.
7. **Database Quality Assurance (QA) Check** – Performing data and operational QA checks on the new short circuit model, including a fault current comparison check with the original planning base-case that is used for creating the new short circuit model.
8. **Future Projects Updates** – Updating a copy of the published master short circuit model with future system upgrades using project data for new settings design

In the centralized approach for model maintenance, the frequency and timeline for updating the short circuit model could vary for each utility. However, a typical timeline for execution of the process in Figure II-1 is depicted in Figure II-2 and described below.

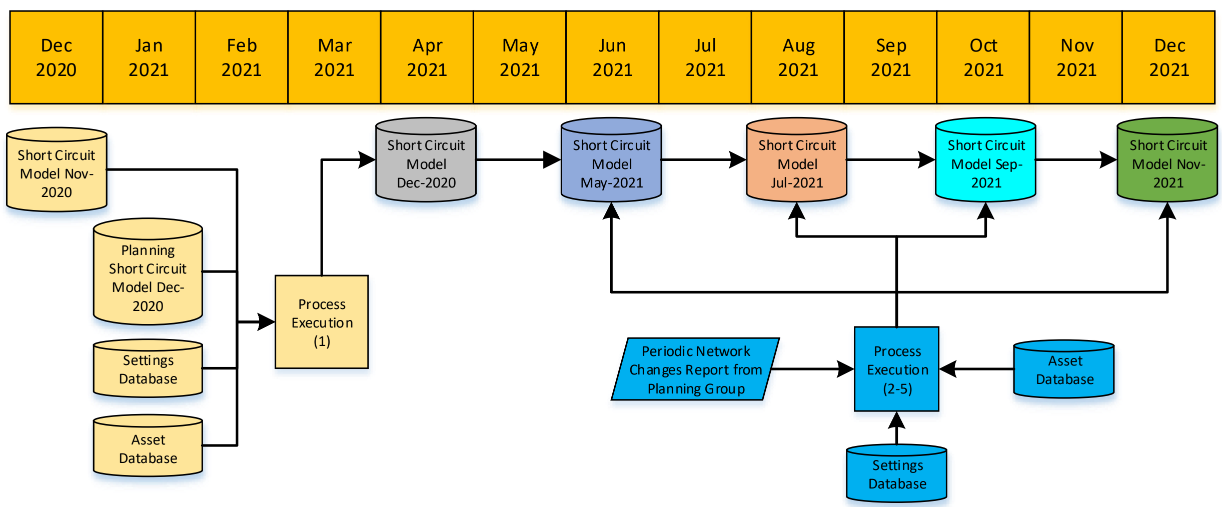

Figure II-2. Frequency and timeline of protection model update for a typical utility over one year.

The annual process and timeline shown in Figure II-2 for a typical year, e.g., 2021 includes the following stages:

1. **Preparing the December 2020 Short Circuit Model:** The December 2020 short circuit model update will ensure that both the network and protection model are current as of December 2020. It will be based on a new network model converted from the December 2020 planning model and merging all the existing protection model data into the newly created network model. This update involves greater effort and therefore is performed only on annual basis.
2. **Performing Bi-Monthly Short Circuit Model Updates:** Upon completion of the December 2020 short circuit model, four bi-monthly network and protection model updates are completed during the 8-month period from May 2021 to December 2021. These updates will utilize incremental changes in the planning model to update the network of the existing master short circuit model. These updates entail lesser effort and thus can be completed faster.

III. DATA MERGE PROCESSES FOR A SHORT CIRCUIT MODEL

A. Short Circuit Model Data Requirements

Power system data typically comes from various sources, and while several groups may have access to such data, ownership and maintenance of the data are generally the responsibility of a single group. For a protection study (e.g., a PRC-027 compliance study), network model data, protection data, and other information (e.g., ownership of assets) are required. All these sources are constantly changing due to modifications to the network, its operation, or upgrading of the protection systems. To ensure that protection engineers have access to the most recent data, a process should be in place to update the model from various data sources.

The two major sources of data required for protection studies include:

- Network Data: includes nodal models of the system, impedances, and nominal voltages
- Protection Data: includes protection schemes, relays, and instrument transformers

1) *Basic Short Circuit Model*

Network data is often maintained by the planning department. The planning department may obtain most network data from a larger asset database and add future developments to it. This model is then converted to a short circuit model for protection studies. The process to handle such a conversion is shown in Figure III-1; this process should be well documented and performed regularly by an experienced engineer.

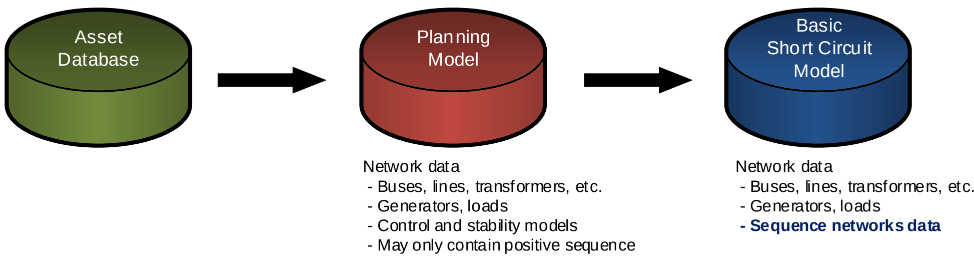

Figure III-1. Process for creation of short circuit model.

2) *Complete Short Circuit Model*

Traditionally, short circuit models were only used for short circuit calculation, and other studies were performed separately. However, modern tools allow for modeling of protection system elements to be added to the basic short circuit model. Including these additional elements have become a requirement of PRC-027 compliance studies.

Protection data is usually maintained by a utility's protection department. The process of adding protection data to the network model to create a complete short circuit model can be very time consuming due to the complexity of protection systems and the frequent irregularities in the data. This process is shown in Figure III-2. Automation tools can assist in this process; however, a fully autonomous solution is not yet available. Therefore, expert involvement in this process is a must.

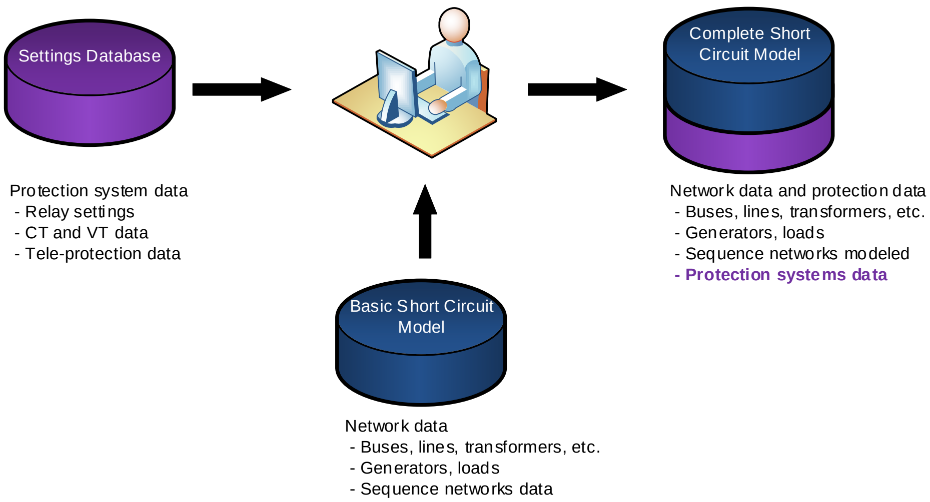

Figure III-2. Process for creation of complete short circuit model.

3) *Short Circuit Model Maintenance*

As shown in Figure III-1 and Figure III-2, two different data sources are used to create a complete short circuit model with network details and protection data all in one place. Any changes to these sources should be reflected in the model. Utilities have two options for maintaining their short circuit model:

- Continual Maintenance: update the model as soon as any changes in planning or settings data occur
- Periodic Maintenance: update the model based on a schedule, such as annually or quarterly

a) Continual Maintenance

Some utilities may choose to update their short circuit model as soon as any change in the system is issued or any mistake is spotted. However, for the network model, any changes made by a different department that are not explicitly communicated to the department in charge of the model can hinder such maintenance.

b) Periodic Maintenance

A utility may decide to follow a periodic routine for updating their short circuit model (including the network and protection settings data) for any number of reasons (e.g., available resources, the complexity of the organization, etc.). Even quarterly maintenance will likely require resolving substantial changes in the two sources of data (planning and settings). Rather than performing a manual update, the data merge approach explained in the next section can be adopted.

B. Data Merge Process

1) *Protection Data Merge*

Figure III-3 illustrates a case where protection data from an older model is merged with protection data from a newer model created from the latest planning database (see Figure III-1). This requires a mapping algorithm to identify conflicts between the two models and to replace older data with newer data. Because such algorithms typically rely on bus numbers or bus names, some models may need to be “cleaned up” prior to a data merge. When there is a discrepancy in the network data, a merge conflict should be highlighted that needs to be manually fixed.

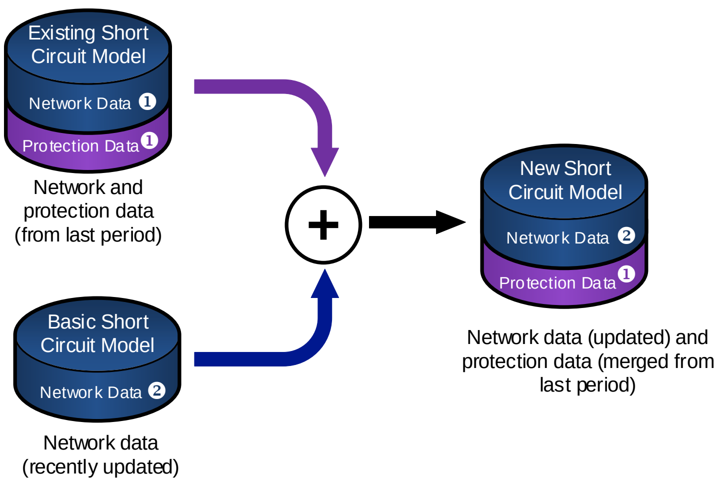

Figure III-3. Process for merging protection data into a new short circuit model.

2) *Network Data Merge*

In some cases, network data changes between the update cycles are small, and thus, a network data merge approach would be preferred. In such a case, network data from the newer model is merged with the older model that includes the protection data. Then, the discrepancies between the two network models should be resolved until the complete short circuit model replicates the model with the new network data. This process is shown in Figure III-4.

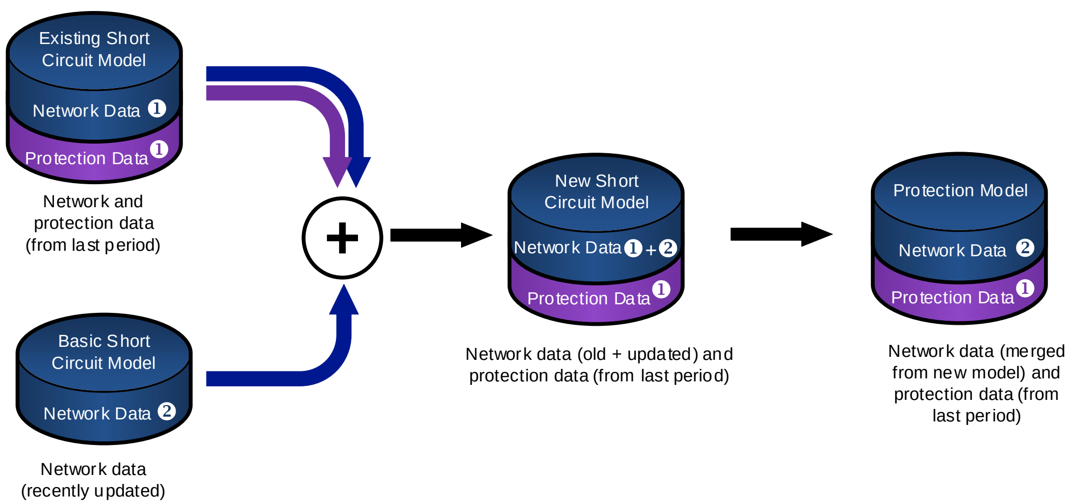

Figure III-4. Process for merging network data into a complete short circuit model.

3) *Choosing Merge Process*

The choice of merging protection data versus merging network data depends on several factors including:

- Number of changes in the network model from the last period
- Complexity of the short circuit model
- Availability of tools for performing either of the approaches

In both cases, a careful examination on the network model before and after the merge is needed.

- A network comparison prior to merge helps identify the changes and would indicate if and where a merge conflict can happen. The comparison results should be stored for manual QA check after the merge.
- A network comparison after the merge ensures that the updated network is still intact. An easy check for this step is a fault comparison on all system buses. All discrepancies should be resolved and noted for a protection model check at the end.

Considering the recent developments in detailed modeling of protection systems, a network data merge is often the preferred approach because it results in less manual effort.

IV. Protection Modeling Processes

The application of automation for data entry and validation can offer these advantages:

- Alleviate the human error that could result from manual entry
- Reduce the burden on protection engineers for protection modeling
- Holistically check for model deficiencies
- Considerable amount of time and budget savings due to faster completion of the model

Modern protection simulation software can leverage automation to conduct comprehensive protection studies such as sensitivity, coordination, regulatory compliance, etc.

Figure IV-1 shows the process flow for automated protection modeling using a short circuit program. As shown in the figure, the following stages are performed:

- Automated data extraction from various data sources and data population in the protection data management tool
- Data review and push to the database of the short circuit model where network parameters exist

In addition, extensive data and operational QA-check should be performed on the database after modeling to ensure the accuracy and validity of the protection model.

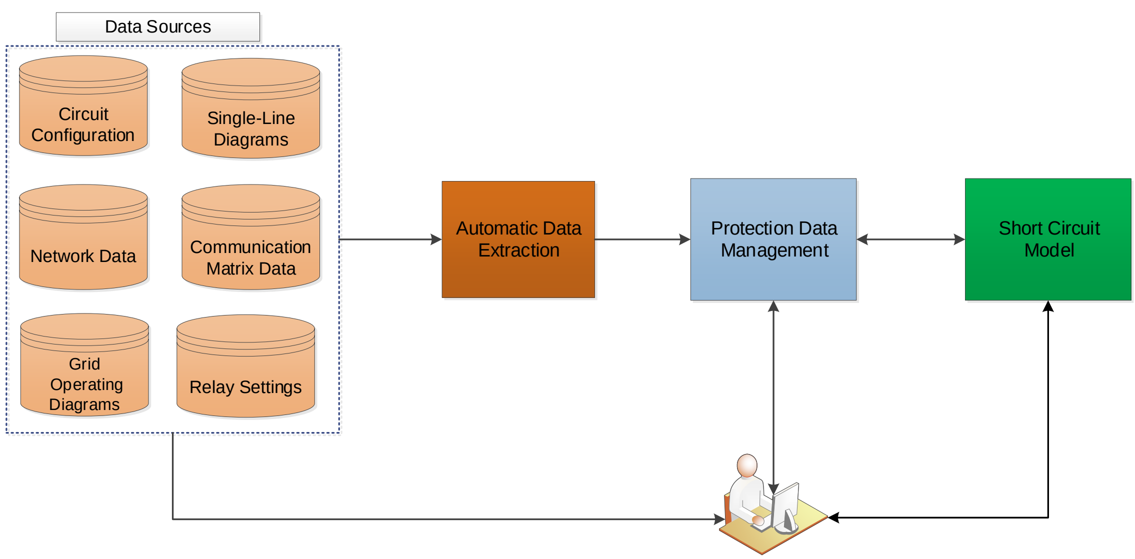

Figure IV-1. Automated protection modeling in the database of short circuit program.

A. Automated Data Import for Protection Settings Update

The automated process for protection modeling in a computer program using relay setting files in the setting repository is shown in Figure IV-2. As shown in the figure, the automated modeling process involves using information from the working database and the extracted relay settings to model protection in a short circuit model. This process is usually triggered by an engineer for a set of lines that have been marked as being prepared to be modeled. The topological data in the working database is used to determine where in the short circuit model protective devices should be placed. After determining the position where the protection should be modeled, the next necessary step would be to parse the relay settings file associated with the selected protection and load the settings values into the memory. Different short circuit programs have varying levels of complexity regarding how relays are modeled in their software and often offer several different relay models for the same protective function. The first decision that would need to be made by an automated solution is which model to use for each actual real-world relay. The automated solution should take into consideration the accuracy as well as try to maintain the protection model in the future when deciding which relay model to use. Depending on the short circuit program used, it might also be necessary for the automated solution to set up objects other than a relay such as a breaker, CT, or VT.

The database of the short circuit model can also be used to store comments and annotations an engineer might need to make during the modeling or analysis process. The protection scheme information can also be modified by an engineer if the data extracted from the relay repository or other protection scheme databases are not completely accurate.

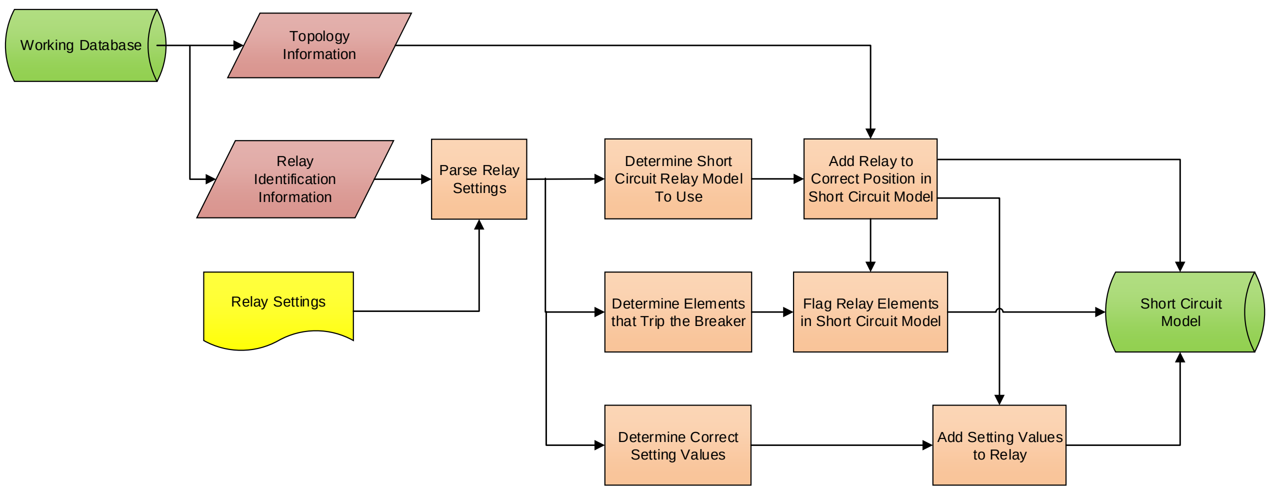

Figure IV-2. Protection setting push from the working database to a short model.

B. Tele-Protection Modeling Process

The importance of accurate protection modeling has grown significantly. With poor or incomplete software models, protection engineers are unable to reliably assess telecommunication-based logic in their systems. However, existing tools in the software environment to model advanced telecommunication-based schemes are limited in their scope as well as their ease of implementation. Alternatives to software evaluation often require costly equipment and may not be easily available. Thus, it is common to avoid the modeling of advanced protection and telecommunication-based logic altogether. This could translate into misoperations in the real world, caused by hidden issues stemming from deficiencies in telecommunication schemes. The long-term value of an accurate software model comes from being able to find such hidden issues.

In order to effectively model and evaluate telecommunication-based protection schemes, an auxiliary relay must be created in the software environment that can accurately represent the diverse logic of a conventional relay. Furthermore, this relay should be flexible enough to have applications in the modeling of adaptive and complex logic-based protection schemes. There should also exist automation-based tools to efficiently transfer the data within the utility data sources to a software model with pilots. With the use of this auxiliary relay and accompanying modeling tools, protection engineers should be able to complete studies that reveal hidden issues they would be unable to detect otherwise.

The creation of this auxiliary relay in the software environment must be accomplished using resources native to the software environment, such that it does not necessitate the use of additional software in its functions. The design should also be automation-friendly and well-integrated with the automatic approaches for protection modeling and analysis.

The most apparent application of this relay, referred to as the pilot relay in this paper, is in the modeling, analysis, and design of standard telecommunications-based protection schemes. The pilot relay will house several elements used as the components of protection schemes, including permissive over-reaching transfer trip (POTT), permissive under-reaching transfer trip (PUTT), directional comparison blocking (DCB), etc. Within the pilot relay, there is internal logic between these components that is activated based on the scheme that the user selects to use.

The pilot relay itself, as discussed, does not include protective elements. These elements operate in the local protective relay and are mapped to elements within the pilot relay. The communication elements in the pilot relay are mapped to communication elements in other pilot relays at the remote terminal(s) to simulate telecommunication signals. Both types of elements are processed inside the pilot relay, and a trip signal is issued to the local circuit breaker as per the internal logic expression.

Figure IV-3 shows an example communication matrix between the pilot relays at the line terminals and the transformer station on a two-terminal line with one load tap.

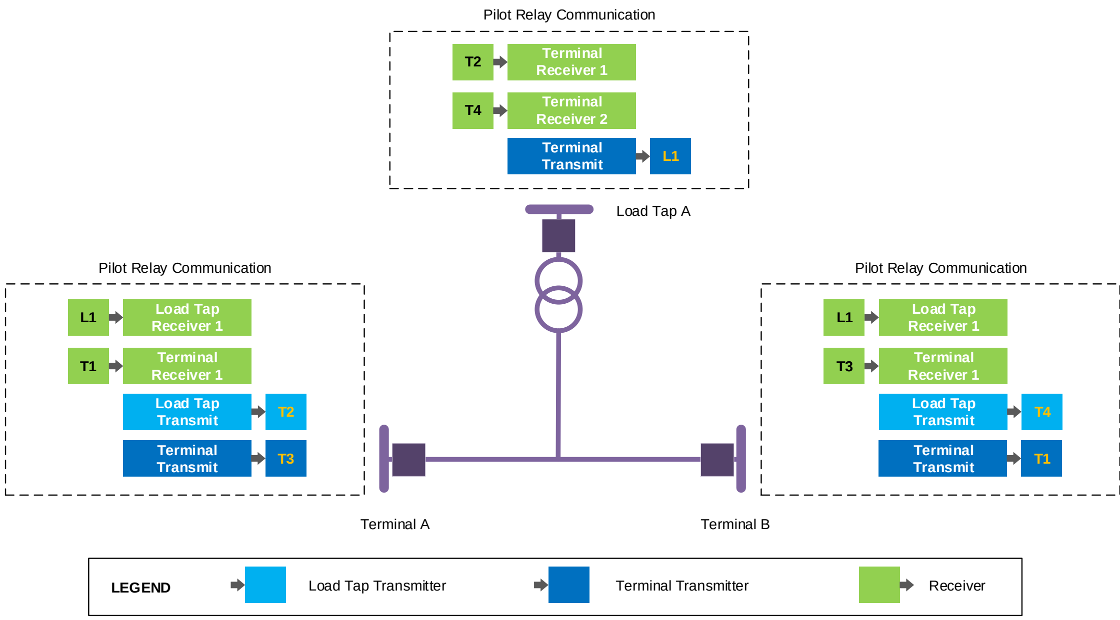

Figure IV-3. Communication matrix among pilot relays in a short circuit model.

The illustration in Figure IV-3 could be a model for a transfer trip scheme, where the circuit breakers on the line as well as the low-side circuit breaker of the transformer must trip in order to clear a fault at a location anywhere on the line. The local elements in the pilot relays are mapped to protective relay elements.

All pilot relays have multiple transmitters and receivers, allowing for multi-terminal communication as well as different signals between different types of stations (e.g. load tap vs. line terminal). The receiver at each pilot relay is connected to the transmitter of the other pilot relay that has the same number as the receiver (e.g., L1, T1, etc.). The transmitted bit is produced through internal logic with the local elements, which in the case of transfer trip would correspond to the operation of any instantaneous local tripping element. The received bit at each pilot relay is connected to a transmitter of another pilot relay. There is tripping logic internal to the pilot relay, depending on the active scheme, which uses the received signals for evaluation.

For transfer trip, simply receiving a transfer trip signal is enough to cause the pilot relay to issue a trip to the circuit breaker.

For a close-in fault on the line at Terminal A, the local Zone 1 distance relay will trip the circuit breaker. The pilot relay, which Zone 1 is connected to, will read the trip signal and transmitters T2 and T3 will issue a trip signal for load tap and terminal stations, respectively. At Load Tap A, the Terminal Receiver 1 in the pilot relay will read the transfer trip signal after a programmable delay meant to simulate the communication delay. Similarly, at Terminal B, Terminal Receiver 1 in the pilot relay will read the transfer trip following a time delay. Both pilot relays will trip their local circuit breakers.

V. DISCUSSIONS

A. Protection Merge

Commonly, the network model is updated at least once a year. Depending on the size of the utility, dozens of changes may have occurred in the system by the end of the year. These changes are often for new developments (i.e., the areas requiring fresh protection modeling). Therefore, merging such changes with an existing model will result in fewer conflicts than the actual number of changes.

After the network merge is performed, the elements removed from the system should be identified and carefully eliminated from the short circuit model. If any protection model relies on those elements, that should be noted and considered for protection model update. An automation tool can facilitate the network comparison and identify the added and removed elements, thereby reducing the effort of merge from days to hours.

Modern protection software tools can store a lot more information in addition to the network and protection data. Such data is often lost in the processes that create the network model. A data management tool can merge the data from other sources (such as maximum loading capacity, ownership information, etc.) that can facilitate protection studies. The presence of such data can significantly reduce the investigation time required to find information about a protection issue and its resolution.

B. Protection Modeling

The proposed approaches in this paper have been applied for protection modeling and analysis for several years and in multiple utilities. The results and experience demonstrate that the proposed automation-based approaches can save a significant amount of time and budget as compared to the manual approaches. In addition, the modeling accuracy can significantly increase if the modeling is performed automatically. The authors in this paper argue that in order to come up with a reliable protection design, tele-protection schemes need to be accurately modeled in a software environment and analyzed thoroughly before being issued to the field. To that end, approaches are presented that can handle complicated tele-protection schemes in an advanced software environment and allow the user to replicate the behavior of the real-world protection system.

It is worth noting that this paper suggests that protection modeling can be used for NERC PRC-027 compliance checks. However, the scope of protection modeling can be enhanced over time based on the future expectations. In addition, the future advancement in short circuit simulation technologies can help leverage more complex protection modelling. As such, the approaches proposed for automated protection modeling and database maintenance can become even more important in the future to handle complex problems. More protection elements can be included in the model as the simulation engines improve in terms of accuracy and speed that would allow a user to conduct more comprehensive studies and capture hidden protection issues that would have not been identified otherwise.