

Process Improvement of Distribution Protective Relays Coordination

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Abstract—This paper discusses the improvement of protection settings reviews performed by protection engineers in utilities regularly. It highlights common process inefficiencies, shows the improved deployment of data sources and proper use of software tools, and demonstrates filling gaps with automated routines. The rapid expansion of renewable energy resources and evolving regulatory requirements have increased the demand for these studies and necessitated a quicker turn-around time. The paper presents three practical examples implemented in a real power network. The solution presented in this paper results in considerable time savings and forms one of the major building blocks for adaptive protective schemes in the future.

Keywords—power system analysis; power system protection; power distribution faults; power system simulation; substation protection; and power distribution.

I. INTRODUCTION

With the advent of renewable resources, changes in customer demands, and more strict regulatory requirements, the need for quick evaluation of system changes has become increasingly important. In addition to time constraints, the existing study routines, methodologies, and processes require an update to ensure systems' safety and security with modern loads and generation. These two factors have initiated a move to modernize the grid and improve the use of digital technologies. These improvements involve processes and tools, which are this paper's focus, specifically in evaluating protection systems for distribution networks.

Utility engineers routinely study the protection systems from security and dependability perspectives. The studies are initiated by several factors such as changes in the system, unexpected operations, or routine preventive measures. In a perfect scenario, a system is continuously monitored, and any changes in the inputs, states, or output of it will initiate a study. This process will make it possible to detect and mitigate any contingencies that may compromise system safety or cause any disruption to the service preventively.

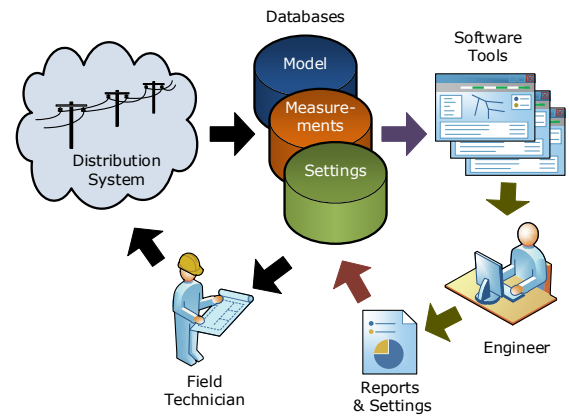


Fig. 1. A generic protection system study and review process

A generic process is depicted in Fig. 1, showing the full cycle of modeling, reviewing, and implementing settings changes. Depending on the quality of data, complexity of the system, and strictness of study conditions, a protection study can take between hours to days to perform manually. Such study requires several data sources, the knowledge of various software tools, and knowledge and expertise in reviewing protection systems issues.

Improvement of such process, which is the focus of this paper, is a comprehensive task. It involves identifying data sources, improving study routines and software tools, automating small tasks when possible, and documentation. Making improvements can significantly reduce the time and effort needed for protection engineers.

Several other publications have considered the improvement of various steps of the process, such as modeling [1], specialized studies [2], and settings data management and interpretation [3]. Previous efforts have been mostly focused on transmission systems. In distribution systems studies, which is the focus of this paper, often data sources and models have less accuracy and certainty, making process improvement more

challenging. For such systems, while working on improving data availability and quality, the existing processes can gradually be improved, as shown in this paper.

Three practical studies are considered in this paper as follows:

- Damage-curve and arc-flash
- Relays pickup settings comparison with actual load (historical values)
- Substation relays coordination

In these studies, on average, the study time is reduced from hours to minutes while improving accuracy and allowing a more thorough investigation than can be done manually.

II. DATA INTEGRITY FOR POWER SYSTEM STUDIES

Four aspects of data integrity required during a power systems study process are shown in Fig. 2 and discussed in this section. There are several other data integrity concerns (such as security, storage) which are not in the scope of this paper.

A. Data Availability

In a move toward more digital solutions, data availability and data quality have become a bottleneck. Traditionally data collection has been performed by utilities from the beginning. For example, the record of relay settings changes, and their reasoning, was stored on paper. These paper records were located in the substation and potentially other places. Today, almost all recordings are digital, allowing for quality checks before the data are accepted.

For a protection study multiple data types are required and often the distribution departments do not own the data sources. Different groups or departments (e.g., Distribution Planning, Asset Management, Operations, etc.) maintain the data sources (such as system models, customer data, and protective device settings) with inconsistent naming conventions and various data quality levels. Even if the data are available in the sources, the filtering and interpretation of the data may be challenging.

Lately, many utilities have considered collecting all data sources under one umbrella, and the concept of a “data lake” has become attractive. Such a system improves data availability and security.

B. Digitization

A first step toward improving data availability and quality is converting data sources into digital formats. Most utilities have already implemented changes or have ongoing efforts to convert paper-based records (such as relay settings, substation drawings, etc.) to digital formats. Since data recorded on paper did not have the same quality control as digital records, data converted from paper records are usually not vetted. Also, digital conversion is not always accurate, and some losses are expected. To minimize data loss and inaccuracies, a combination of automated and manual work is usually necessary to convert, clean, and store data in a reliable format.



Fig. 2. Data integrity for protection systems modeling and studies

C. Quality Assurance

After the data become available in a digital format, the next step is to ensure data quality is acceptable for users and automation tools. Each data source shown in Fig. 1 has quality concerns that need to be investigated separately. For example:

- An accurate model of the distribution systems connectivity is required for short-circuit studies.
- The source impedance model should be updated based on a transmission network model.
- The latest settings for protective devices and whether they are as found in the field are needed.

Data quality control is often a large effort performed immediately after data conversion. However, this effort must be considered an ongoing task, requiring the reporting of quality issues and fixing them as they are found.

D. Standardization

Even if all data is available in a digital format, one of the challenges for a system study is the linkage of data from different sources. Often the network model is accurate from the planning group, and the latest settings files are available within the protection group. However, due to the different naming conventions used by different units in the utility, locating the system’s protective devices may not be simple. An experienced user may know the conventions, but this would be difficult for someone facing it for the first time.

The long-term solution for such discrepancies is standardizations across the utility, which can be considered during data conversion and data migration or when a centralized data solution is implemented. In the meantime,

translation tables and procedures can guide users and software applications to link data between different sources.

III. STUDY PROCESSES, SOFTWARE TOOLS, AND AUTOMATION

A. Process Optimization

Power systems experts have developed processes for each study, such as a distribution protection study. These processes are sometimes written or embedded in study tools or documents. These processes need to be updated when data structure, availability, and sources change, or to accommodate system changes such as addition of distributed energy resources or volt-var optimization techniques.

A study process needs to be aligned with software tools and designed for available data types. Ideally, users would need one tool to help them complete a study's steps with adequate error checks, minimizing the need to go back and forth between documentation and multiple tools.

B. Software Tools

Like many other power systems engineering studies, a protection study involves multiple steps, usually using several tools. The user makes connections between different study results, manually transfers data between simulation tools and calculation sheets, analyses the results, and creates reports. This process depends on the knowledge of power systems and protection systems and requires expertise in using many software programs.

Specifically, in protection studies, due to each software application's limitations or unavailability of data in the required formats, only one function of each tool may be used. For instance, a short-circuit study program is needed to calculate fault duties. Then one or more protective device vendor tools are used to extract protection settings. Another tool is used to create or update the protection model and draw device curves to compare operation time and evaluate coordination. The tools' full functionalities are not being used, but users still need to learn their basic operation.

In the process above, a single study usually requires multiple software licenses, which must be purchased. Also, using several tools to perform one study makes the process prone to human errors. Data accuracy may be affected when users manually transfer data between tools.

Most of today's software applications can potentially be used as the main tool where most of the study steps are performed, eliminating the need to switch between applications. These tools have functionalities that assist users by automating steps (i.e., macros) and connecting to other tools through application programming interfaces or other means.

A comprehensive study of the tools available and intended functionalities for a specific utility system is recommended to be completed before designing and implementing any automation routines.

C. Use of Automation

Automation techniques are widely used in utilities, especially where data quality and availability are less challenging. An example is transmission planning, where a model of the network is more stable, and the required data, such as load and generation sizes, are more readily accessible. In distribution systems, however, the availability of data and ensuring their quality is difficult and expensive. Therefore, certain assumptions are made by engineers during the study.

The complexity of power systems and the additional layer of protection systems make it difficult to automate some study process steps, such as interpreting settings and modeling protective devices and determining relationships (primary vs. backup protection). Many software vendors have included automation routines to assist users in protection studies and other general study types. Due to protection study process variances among utilities, providing an off-the-shelf solution is usually impossible, with at least some customization required.

IV. STEPS TOWARD EFFICIENT SYSTEMS STUDIES

Before any automation to improve the system studies process, three major steps are required, as shown in Fig. 3:

1. Ensuring data integrity and availability
2. Documenting current processes, planned changes, and predicted needs
3. Examine available tools and evaluate potentials for improvement

A. Data Integrity

Data digitization, data quality assurance, and data availability require major work but have benefits extending far beyond this paper's focus. These activities should be initiated before the automation effort, as tool and process design are highly dependent on available data, their format, and their quality.

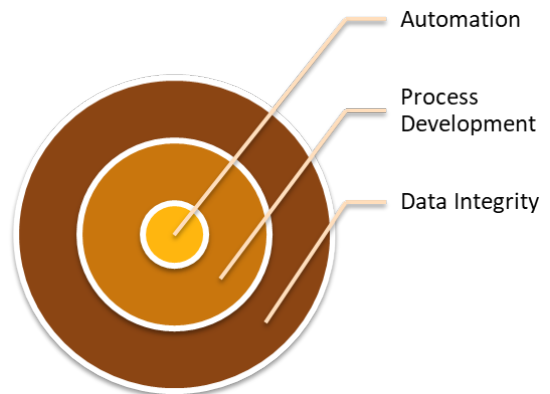


Fig. 3. Automation and prerequisites

B. Process Development

1) Build Automation Team

The automation team to develop and implement automation should have diverse knowledge and skillset to understand both power systems and software development challenges.

2) Review Processes

Most utilities already have processes well developed for regular engineering study routines. However, many complexities and exceptions make it difficult to record all details for distribution systems protection studies. Revising those documents and recording “tribal knowledge” is another requirement. Experts should be interviewed to record best practices, identify deficiencies, and plan for the future. Such plans should have provisions for changes and emerging technologies, such as DER integration, Volt/VAR optimization techniques, and different customer load profiles due to transportation electrification.

3) Study Software Tools

Power systems tools are constantly improving to accommodate new emerging technologies and utility’s needs. Existing software tools may already have automation capabilities at no extra cost to the utility. Creating the list of software tools and their used and unused functions can highlight overlapping functionalities to help select the best tools for each application.

4) Prepare Documentation

Documentation availability for standards, guidelines, and general practices is essential for protecting workflow quality. With today’s agile workforce habits, utilities, like other industries, face more frequent changes due to retiring, position changes, and moves. Therefore, the need for a robust process for day-to-day tasks that can be implemented with minimal training and supervision has become more pronounced. Proper documentation is a one-time effort that can relieve the management and staff of inefficiencies and avoidable quality control activities.

C. Automation Approaches

The approach suggested in this paper is the continuous integration of automation into an existing process. This approach allows utility engineers to have “quick wins” and a fast return on investment. This approach has little to no interruption to the existing processes and facilitates knowledge transfer between experienced engineers, the IT department, and automation developers.

An alternative approach is to develop an entire solution and implement it all at once. In this way, the development phase is expedited, but the testing deployment phases are prolonged considerably.

V. IMPLEMENTATION EXAMPLES

In this section, three examples of a continuous automation integration approach are presented. The automation functions are developed individually but with consideration for various

processes with similar needs. The examples show this approach as implemented in real systems.

Fig. 4 illustrates a user’s interactions with several data sources and software tools to perform a protection study. Normally, the expert user spends considerable time extracting data, modeling, running studies, and transferring data between the tools. Comparatively, little time is spent reviewing protection situations, test solutions, and suggest changes.

In the three examples below, one or more of the arrows are automated, relieving the user from mundane tasks and saving time while improving quality.

A. Damage-Curve and Arc-Flash Studies

For this study, the operation time of protective relays under a fault condition is compared with the withstanding capabilities of the personal protective equipment and the conductor’s ampacity. This type of study is an important study directly related to the safety of the personnel and the public. A few of the arrows shown in Fig. 4 are automated, reducing the study time from hours to minutes for each substation.

The automated function implemented in this example are as follows:

- Automatic extraction of protective data from settings files (which is a major improvement) relieves users from interpreting protective device settings. A prerequisite to this step is the accurate naming convention for device identification.
- Creating a library of damage curves and protective relay curves
- Automatic drawing of protective device curves and damage curves and comparing them
- Automatic importing of fault-duties from the short-circuit program

An example automatically generated comparison curve is shown in Fig. 5.

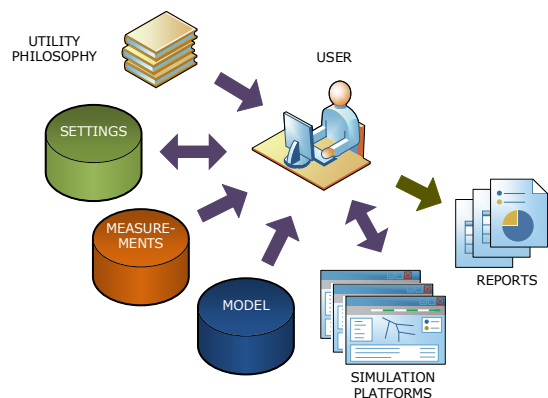


Fig. 4. User interaction with software tools and data sources to perform a system study based on the utility’s processes and philosophies

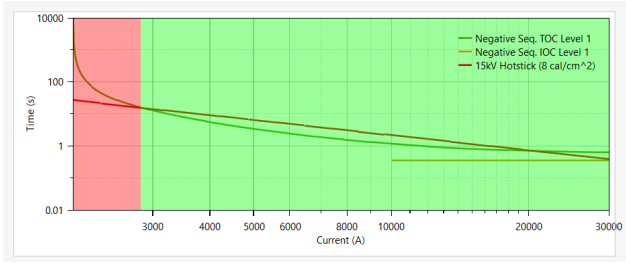


Fig. 5. Comparing time-over-current curves with personal protective equipment withstanding curves; the red area is where protective relay needs to operate faster

B. Relay Pickup Settings Comparison with Historical Load Values

Comparing protection settings with actual load values is a preventative study performed on the entire system to flag possibilities of misoperation before it happens. This study is hardly manageable to do manually due to the number of devices in a utility network. With an automated process, studies can be performed on schedule, flag issues, and send results to engineers for review.

The automated functions, which are reused in this example with minimal changes, are:

- Automatic extraction of protective data from settings files
- Comparing maximum possible load values with existing pickup settings and creating a flag when the value exceeds the settings or lacks enough security margin

The only additional function for this study is:

- Automatic analysis of historical load value, filtering bad data, and estimating maximum possible load for the future

An example automatically generated comparison curve is

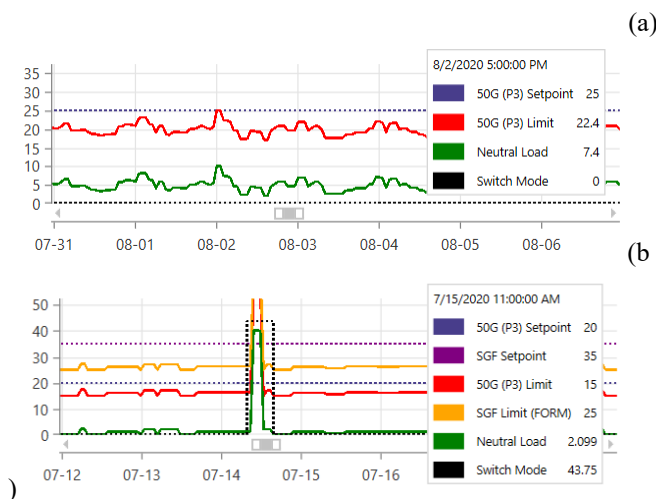


Fig. 6. Comparing ground pickup value with measurement; (a) Peak load current has not enough margin with ground pickup settings. (b) Condition ignored due to an abnormal situation flag (Switch Mode).

shown in Fig. 6. The graph on top (a) shows a condition where load current is getting too close to the pickup value and touches the maximum allowed value shown with dotted line. The graph at the bottom (b) shows another situation which is expected as an abnormal system condition (Switch Mode) was detected.

C. Substation Protection Coordination Studies

Distribution substations usually have a simple structure, consisting of one or more parallel transformers connected to feeders. There may be one or more buses and bus-ties, but (assumedly) there are no loops, and the power's direction in the example system is from the high-voltage side to the low-voltage side. Having these properties makes it an attractive next candidate for automation.

The automated functions, which are reused in this example with minimal changes, are:

- Automatic extraction of protective data from settings files
- Automatic drawing of protective device curves and comparing them
- Automatic importing of fault-duties from the short-circuit program
- Comparing maximum possible fault values with existing settings and creating a flag when there is a chance of misoperation

The additional functions for this study are:

- Automatic identification of relays and their functionalities (A prerequisite to this step is the accurate naming convention for identifying devices.)
- Automatic identification of substation configurations (This step requires an accurate naming convention to identify a device's location.)
- Development of fault scenarios, including outages for all known system configurations
- Development of a generic study to fall back on if the substation configuration is not available (This is one of the steps to ensure automation applicability with minimal data.)

Automation helped this study by significantly improving study time and criteria by considering all possible scenarios, which is difficult to do manually, and providing a simplified visual model of the system under study.

This automation was supported with a one-time manual effort to digitize distribution substation configuration details. An example is shown in Fig. 7 where all detected relays are well coordinated for the fault scenario.

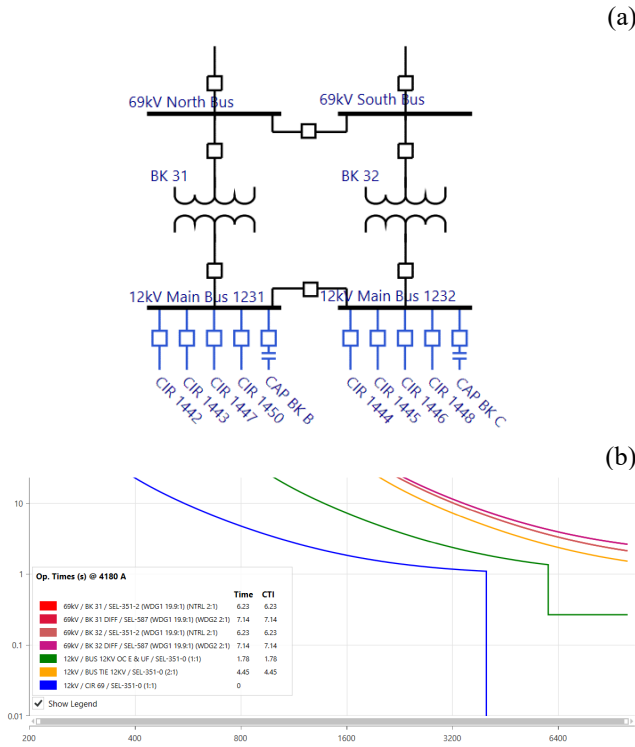


Fig. 7. Automatic distribution substation coordination; (a) Automatically detected substation configuration. (b) Protective relays curves with no coordination issues for single-line-to-ground fault.

VI. CONCLUSIONS AND FUTURE WORK

This paper suggests an approach to improve protection study processes, especially in distribution networks. The requisite data availability and quality constraints are described, available tools and software applications are reviewed, and different automation approaches are considered. With three practical examples, a gradual implementation of automation is shown as an effective approach. The new processes using automation resulted in substantial gain due to reduced routine tasks, improved quality, and a significant reduction of turn-around times (from hours to minutes). To make the solutions robust, they are designed to work with minimum available data, but additional data sources can be added to obtain better accuracy and detail.

Depending on the utility's needs and identified deficiencies, developed functionalities must be planned with future development in mind.

Notably, the improved results presented in this paper were possible due to good quality data due to the utility's prior initiatives. Automation tools can help identify minor data errors, but data cleanup and/or an integrity check are required if the data sources are not accurate.

Currently, the automation tool can identify issues conservatively. With software improvements and better data availability, more advanced automation futures can be

developed to detect issues more accurately and to suggest corrective actions. With real-time operational and measurement data, study routines can be initiated automatically when a system change is identified. Adding more intelligence to the detection and solution process will make enable a fully autonomous system.

With advancements in automation capabilities and increased data availability, many routine processes, like those described in this paper, are expected to be automated in the next several years.

VII. SUMMARY

This paper presents a practical approach to improve a distribution protection study process. It presents the prerequisites, data integrity challenges, documentation needs, and an effective implementation methodology. Three examples of practical implementation of automation approaches show more than a 90% improvement in study time while improving quality. This paper exemplifies a few steps toward an adaptive protection system of the future where changes are automatically detected, studied, and possible misoperations are prevented.

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