An Innovative and Automated Solution for NERC PRC-027-1 Compliance

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1. ABSTRACT

Compliance with NERC PRC-027-1 has brought increasing stress to utilities as they work to establish a defined process for performing relay setting development and coordination at regular intervals. While current software programs attempt to aid utilities in complying with this new standard, they only offer an overwhelming and unmanageable report of coordination study results. None of the current programs provides a work flow from relay setting development to wide area coordination, which is what utilities desperately need. In this paper, we present an innovative process to comply with the R1, R2, and R3 requirements of PRC-027-1 through the use of an automated solution.

2. INTRODUCTION

To reduce the probability of mis-operations caused by mis-coordination and human error, NERC has introduced PRC-027-1, requiring utilities to have a well-defined relay setting development process and to perform a time or fault base coordination study on a recurring basis to account for changes in the power system.

In our previous publication [2], we demonstrated that the current relay settings development process is laborious and difficult to complete in an accurate manner with today's tools. This process requires the setting engineer to manually transfer vast amounts of data from short circuit programs to calculation sheets and finally to relay setting files. We also demonstrated that an automated solution for relay setting development could eradicate errors introduced during the manual transfer of data. East Kentucky Power Cooperative (EKPC) acknowledged the advantage of using relay setting automation in this way.

A more pressing challenge for all utilities is performing a Wide-Area Coordination study. The industry has begun developing software tools and example workflows to help utilities meet the requirements of PRC-027-1 in a more efficient manner. Short circuit programs[3] are introducing functionality specific to the standard, allowing users to make some basic selections about the study. The subsequent execution produces an enormous amount of data which the user must individually examine for violations, categorize, and finally, resolve[3]. Other solutions[4] target the processing of this data, usually providing a data import functionality from a short circuit program into an Excel template, which provides some basic mechanism for managing the vast amounts of data. *However, none of these approaches automate the entire workflow under a common interface, nor do they provide continuous feedback from the short-circuit program during the violation resolution phase as to how proposed solutions will affect the remaining issues in the protection scheme.*

Building upon the automation advances in systems protection presented in[2], we present a new, unified framework for PRC-027-1 that provides a complete workflow process for compliance, including automation of coordination studies and relay setting development. Without the need for macros or other programming, users can customize their coordination study to include different tests such as sensitivity studies, CTI, Zone reaches, etc. In this solution, data automatically flows from the short circuit program into a dashboard with all violations categorized as major, moderate or minor. It then gives a path to resolve all issues, followed by automatic generation of reporting artifacts and relay configuration files (e.g., SEL rdb). This removal of human management of data (i.e., copy and paste, categorization) eliminates a significant source of errors in this process. Furthermore, we present a novel approach to violation resolution that prioritizes the order issues for the engineer and incrementally updates the short-circuit model, giving continuous feedback to the engineer on the progress made toward correct system coordination. The software also drastically improves the relay setting development process, allowing the engineer to automate the process and eliminate human error resulting from copy and paste functions. We believe this system will not only reduce the effort and errors made during the process itself, but will also provide a simplified system for utilities' to have a well-defined process for PRC-027-1 compliance.

Although EKPC currently has a manual process in place for relay setting development and coordination checks, automation software will drastically improve these processes, resulting in a higher quality of settings.

3. CURRENT RELAY SETTING PROCESS

EKPC currently calculates and reviews transmission line relay settings on a rotating five-year basis for all protective line relays on the system, as well as new or upgraded relays as part of capital or maintenance projects. These five-year reviews are completed to ensure the adequacy of the line settings as the system changes, to check coordination between relays, and to bring older settings to the new standard settings philosophy if any changes have been made. The settings process begins with a standard EKPC document outlining the criteria for transmission line settings on the system for several different arrangements, including two-terminal lines, three-terminal lines, and radial lines. EKPC utilizes several different high-speed pilot schemes on lines above 100kV and on several foreign utility interconnections.

The EKPC standard document outlines the settings requirements for each of the transmission line setups and describes the optimal setting criteria for each element that will be utilized. EKPC standardizes on three zones of phase distance and two zones of ground distance protection with a directional residual ground overcurrent. The engineer calculating the settings will initially verify the fault study model is correct by verifying line impedances and the general model setup. Once the model is verified, the engineer will utilize a standard settings calculation template, currently in a spreadsheet format. The spreadsheet incorporates the settings criteria philosophy outlined in the standard document through the use of user inputs such as line impedances, CT/PT ratios, and fault current magnitudes. It then calculates the values through user defined equations.

The standard calculation spreadsheet is a living document that is updated as the EKPC settings philosophy is changed. It requires a large amount of user entered data to perform the calculations required to obtain the settings. The majority of these values come directly from the fault study program. Once the settings have been calculated and adjusted as necessary by the engineer, the settings enter a peer review process which is integrated into the relay settings database software. The settings are entered as a new entry for the existing relays and sent to a second engineer for review. The peer review will consist of using the calculation spreadsheet and running all the faults a second time to verify that the numbers are the same. In the event that settings values do not agree, the peer reviewer will be able to make comments on the spreadsheet and document what changes they recommend. The peer reviewer will then sign off on the calculation sheet as well as the relay database software, which provides a way of tracking and documenting the peer review.

Finally, once the settings have been peer reviewed and approved, the relay engineer will take the calculated settings and apply them to the correct standard relay settings file. The calculation sheet auto populates a coversheet where all of the settings are extracted and printed to a PDF. Relay set points are manually entered into the relay files and sent to the peer reviewer as a second check before deploying the settings to the field. Field personnel also act as a peer review as they verify the relay file they receive matches the set points on the coversheet. Once the settings are applied to the relay in the field, the relay technician downloads the as-left relay settings and uploads them to the relay database for a final review by the engineer. This process is also tracked in the database to show the final approval of which settings have been left in the field.

4. AUTOMATED RELAY SETTING PROCESS

For compliance with PRC-027 Requirement 1, EKPC plans to roll the whole settings philosophy and calculation process into one standard process. EKPC reviews and updates the standard settings philosophy document, at a minimum, on an annual basis. This document provides written documentation of standard settings criteria and coordination intervals required to achieve proper coordination. The current peer review process also incorporates several peer checks that are documented in our relay database software as the process moves from start to finish. EKPC also includes coordinating and documenting the settings with a foreign utility through the use of a coversheet in the event that the settings are calculated for an interconnection, which is currently used for PRC-001 compliance.

The EKPC process has been standardized through the System Protection group and has incorporated several peer reviews. The process, however, still has many areas to improve due to the high amount of manual entry into the calculation sheet and the relay settings files. An automated settings process can have many advantages that directly impact the performance and reliability of protection schemes, especially by eliminating human error from manual data entry. Moving data from the fault study to the calculation sheet, as well as from the calculation sheet to the relay file can result in the application of incorrect settings and ultimately lead to a mis-operation of the protection scheme. An automated solution can eliminate manual data entry by the engineer through automatically running fault simulations using a fault study program and extracting the data to be used for calculations. Once the settings are reviewed and approved by the engineer, the settings can be automatically transferred into a standard relay file and reviewed, again removing the manual entry aspect that can result in incorrect settings.

An automated process not only has the ability to reduce human error through removing the manual entry of settings to relay settings files, but it can also save time during the settings calculation process. Instead of spending time on a tedious process, the relay engineers can instead focus their time on reviewing and examining the settings, looking at different scenarios for the protection scheme that may be unique to each line. The fundamental aspect of automated settings is not to take the place of the engineer, but to assist in retrieving the correct information to study, allowing the engineer to make an informed decision on how to manipulate the set points and achieve the best coverage of the protection scheme. The automated process can provide the engineer with the initial calculations up front, saving time that would be used to obtain the fault information, and providing the engineer with more time to review different contingencies and line setups that may need to be inspected.

Another significant function of an automated solution for calculating settings is the ability to easily adapt the existing settings process and standard philosophy into the solution. An automated solution should be able to provide the functionality and ease of defining a settings philosophy as easily as defining equations in a spreadsheet program. The functionality to make changes to the user defined variables and equations is also required to be able to update the settings philosophy as it is modified. This is shown in the Figure 1 below, a screenshot of the existing relay setting template philosophy from the pilot program:

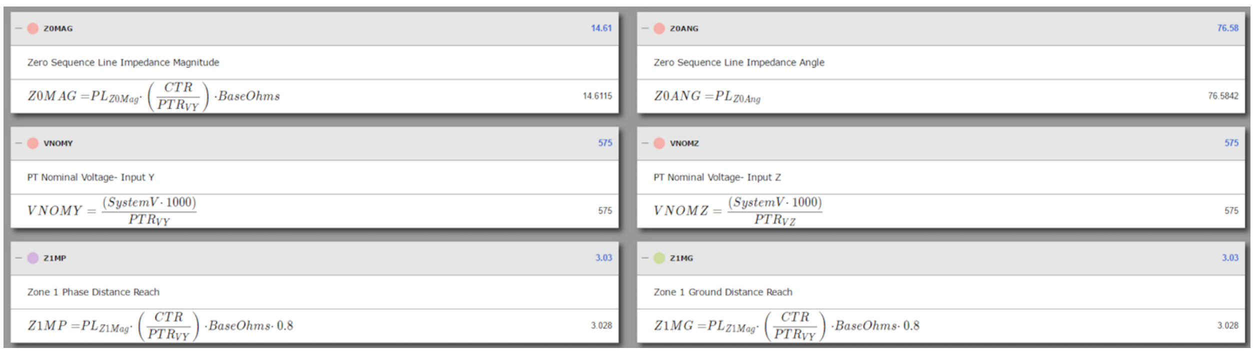

Figure 1: SEL-421 Relay Setting Automation Card

It is also a necessity to be able to export the relay settings to an existing standard relay file that is already designed. EKPC uses several different relays with standard relay files utilizing the same logic and displays. It is critical to be able to modify the relay file with set points as they change or add new set points for new capital installations and to make these changes without having to modify or change the logic in the relay file.

In addition to the need for an automated relay setting development process, EKPC must also consider the even greater issue of wide area coordination. As the implementation of PRC-027-1 approaches, EKPC must determine how they will meet the coordination requirements in a timely manner while maintaining the quality of their system.

5. WIDE-AREA COORDINATION

As previously described, performing a Wide-Area Coordination will present crippling effects in utilities due to the PRC-027-1 coordination requirement. This requirement can be extremely laborious and expensive if external consulting resources are used.

In this section, we unveil a solution that allows utilities to easily implement their own coordination studies at an economical cost without requiring expensive external consulting solutions. This new software framework, which works in conjunction with ASPEN, allows utilities to both standardize and automate the coordination study (and to some extent short circuit model verification) portions of PRC-027-1 compliance. First, utilities must describe their criteria or their approach to coordination in a coordination template using an intuitive graphical user interface, which draws on our experience in template specification for relay settings development. Next, the short circuit model must be verified, aided by automated checks and reports automatically generated by inspection of the case file against common / expected values. The utility must then decide on a section of the grid where the coordination study is to be performed. Next, the relay coordination study is run, and a database of violation errors is created that are then visualized and presented graphically to the user for resolution. This is where the violations are automatically classified as major, moderate or minor, and a path to fixing all issues is easily framed for the engineer to start fixing issues. Finally, reporting artifacts are generated along with software configuration files to update affected relays and the short circuit model. By unifying the specification and execution of the coordination study, the resolution of violations, and artifact generation under a single software framework, the possibility for errors in data transfer is significantly reduced, leading to better and faster completion of the required compliance activities. This process is shown below in Figure 2:

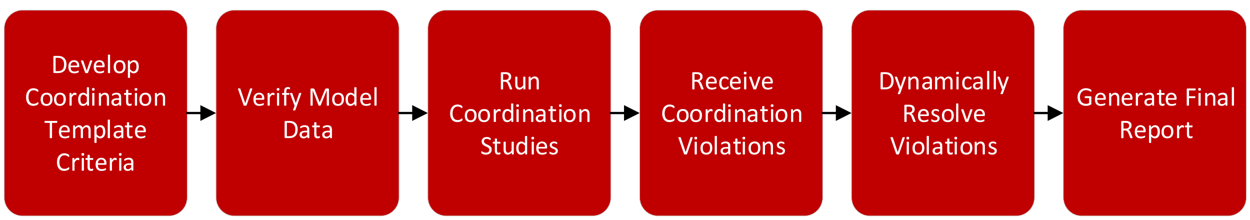

Figure 2: Wide Area Coordination Automated Process

5.1. Develop a Coordination Template.

Our previous work in the automation of relay settings development[2] addresses a large part of the requirements for R1 of PRC-027-1, providing utilities with a methodology to express their standardized protection philosophy through a series of symbolic system protection equations. An example of such an equation was shown in Figure 1. These customizable settings equation templates are created once and then repeatedly evaluated for each settings application via an automatic interface to the fault simulation program, ensuring uniformity in the process.

We have extended this general approach to customization to include wide area coordination, providing protection engineers the flexibility to compose a coordination template from an extensive collection of common studies (i.e., sensitivity studies, zone reaches, CTI, etc.). Any number of these can be included by the engineer to construct their customized specification of coordination for the utility. For example, Figure 3 shows the template card added to include a Zone 1 reach test in the coordination study. Each test has user-provided parameters such as, in this case, the target reach specified by the protection philosophy. Furthermore, the card summarizes the way in which errors will be categorized by the system. While we include several common studies in the framework now, this will continue to grow over time as it has in our automated relay settings development tool. This growing availability of studies will provide utilities even more flexibility in creating sophisticated coordination studies through this simple yet powerful template-based methodology.

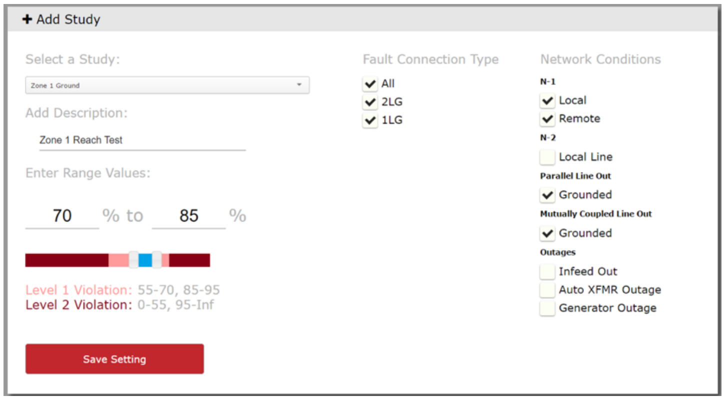

Figure 3: Coordination Card for Zone 1 Ground Reach Verification

5.2. Verifying the Short Circuit Model

One of the requirements in R1 of the standard is to maintain an accurate short-circuit model of the power system. While no automated tool will be able to catch all possible errors in the model, we believe that software can play an important role in finding common errors and identifying areas of the grid for more careful review by the protection engineer. The framework provides a series of simple, sanitizing checks that aid in finding common errors such as missing line impedances and missing relays as well as incorrect voltages, and CT and PT ratios. This tool must be run and issues resolved in order to ensure that subsequent runs of the coordination study are drawing from an accurate system model. While we expect that this workflow will benefit from an interactive graphical user interface, we currently generate a report of issues identified for the engineer to review and address, if necessary.

We chose to make our sanitization inherently conservative, perhaps generating false positives in cases where model parameters are uncommon but still correct for the given usage. Although this means that the engineer will have to evaluate whether action should be taken or not, we believe this is preferable to silently allowing possible errors to persist in the model.

Simple as the checks may be, they do indeed find mistakes in the model inadvertently caused by the regular use of engineers. For example, in one ASPEN case, we found a CT ratio incorrectly set to 1. This is often done in settings development to determine the primary impedance of the line. While this change can be quickly undone by the engineer to return the model to a correct state, such errors must be regularly checked for to ensure they do not cause a misconfiguration of the protective system.

5.3. Running Wide Area Coordination Study

After verifying the short circuit model, the engineer can request that a coordination study be run using the utility's coordination template, the creation of which was described earlier. They can then choose to do the entire utility model by area, zone, a selection of buses, or only on buses where a fault base current comparison is above a certain threshold such as the 15% standard requirement. Exactly which option is selected will be based on the frequency of study chosen to comply with PRC-027-1, the sizes of both the power system and protection team, and other factors. For instance, larger utilities may run a study on the entire grid and generate a summary report, after which the grid is broken into areas for individual engineers to address. These engineers will rerun the study for their area and proceed to the resolution phase, which is described in the next section.

The result of the coordination study is not a raw text dump of data and violations. Rather, we either create an archive with several files for use by subsequent steps of our framework or even for use by other software tools as we aim for interoperability through using common file formats. The files included in the archive are:

- The coordination template, which is a JSON formatted file.
- An SQL database file, for which all violations are stores along with related information (e.g., timing information for CTI tests).
- A copy of the short circuit model file (e.g., ASPEN olr). Including this allows us to maintain the original state of the model at the time of the study for future use (e.g., baseline comparison). It also provides a copy that can be changed during intermediate checks in the violation resolution phase without introducing unwanted changes into the original version maintained by the utility.

In addition, all data is elegantly organized in a coordination study dashboard that allows the user to quickly view all violations in the entire system. Furthermore, violations are shown per coordination study as defined in the template. From here, the user can start fixing issues per substation, which are prioritized based on the maximum violation score. The substation with the most critical violations will be shown first on the list. In addition, the user can choose to fix violation per study by going directly into the study tile. Part of the main dashboard is shown in Figure 4 below.

As can be observed, the results can be classified by coordination study or by priority. The graph on the left shows the percentage of substation issues by study and the graph of the right shows the percentage of substation by priority. This allows the user to easily see the substation that have the most critical issues in the system.

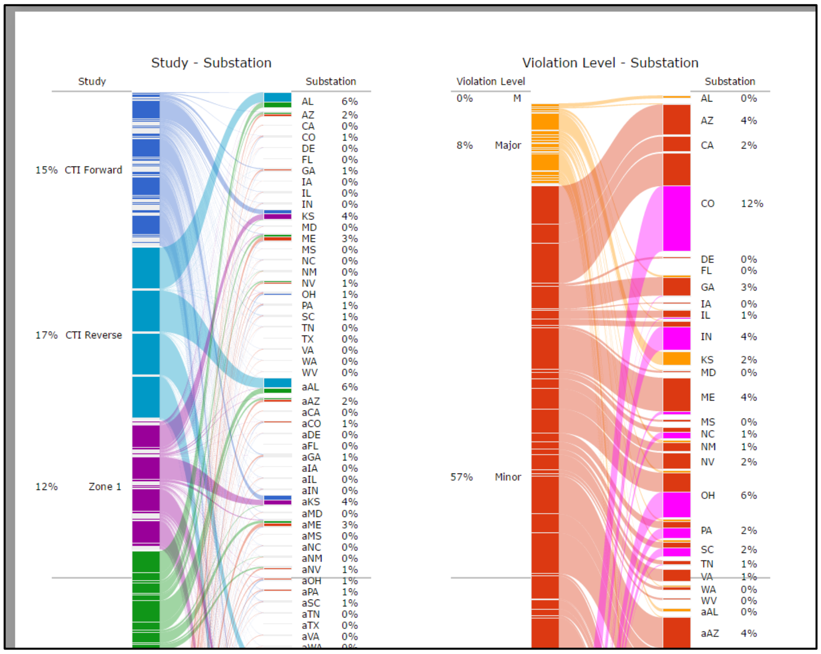

Figure 4: Coordination Studies Results Main Dashboard

5.4. Violation Resolution.

Much of the time spent on PRC-027 compliance will be focused on resolving any violations uncovered by a coordination study. To this end, we aim to ease the burden of this step for the protection engineer by providing rich visualization of information about the nature of the violations so that they have a big picture overview of the state of the grid. This will allow them to determine a clear plan of attack to resolve issues according to their priority. Next, feedback needs to be gathered about the effect of the proposed changes in order to determine if they actually resolve the issue. Currently, this requires the engineer to manually update the short circuit model with the proposed change to see whether it fixes the issue. Instead of this tedious and error prone process, the automation software dynamically updates the stored copy of the model and can provide immediate feedback on how the given change affects the power system. We believe that this unique ability of the framework will greatly improve the compliance workflow for protection engineers.

The interface summarizing the violations is shown in Figure 5 below.

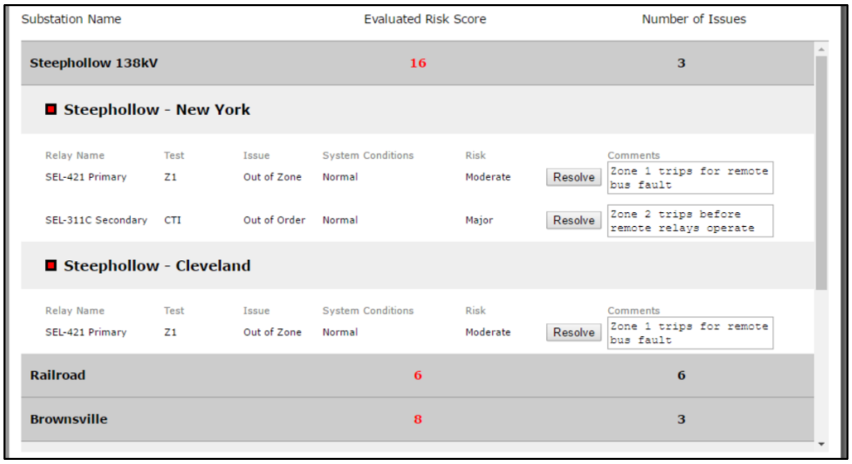

Figure 5: Violation Resolution User's Console

In the user console, violations are categorized both by severity and by the tests (e.g., Zone reaches, CTI timing, sensitivity checks) that generated them. An overall count of violations along with the progress towards resolving them is also shown. Violations can then be viewed and resolved by progressing through one of the tiles, which are categorized by substation (and then terminal), or by filtering down by test type. Next, an individual violation is selected, presenting a screen to resolve the violation (see Figure 6). Note that this screen changes based on the test type.

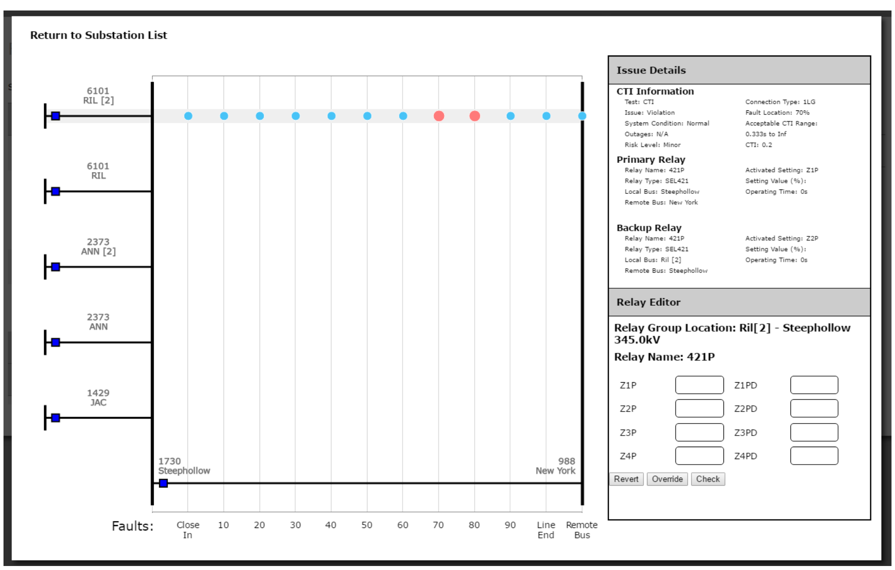

Figure 6: Settings Resolve Window

Along with visualization and a description of the violation, an input box will appear to enter the proposed resolution, which will then be verified to resolve the issue with the short circuit program. If accepted, this resolution is stored in the resolution database, and the engineer may proceed to the next issue. After all violations are resolved, the coordination study should be rerun to verify that no new violations have been introduced. The engineer can then move on to generating reports and updated configuration files.

5.5. Reporting Artifacts and Configuration File Generation.

As with the relay setting development module, our framework can automatically generate reports summarizing the violations found and their resolution. In addition to the report, we also generate files to automate the relay update process. This removes the need for engineers to copy and paste this information, resulting in fewer errors. We can generate new rdbs for the affected relays in addition to an updated short circuit file. For ASPEN specifically, we provide a standardized change file which can be used to update the ASPEN case with the changes required for proper coordination.

6. CONCLUSIONS AND FUTURE WORK

This paper represents initial efforts to bring a new level of automation to PRC-027-1 via bidirectional interaction with the short circuit program as well as advanced interface customizability and visualization. We believe there is great potential to improve this software further to aid utilities in their PRC-027-1 compliance efforts. Immediate areas for improvement are to add additional tests that can be selected in the coordination template as well as refine how the violation summaries are visually presented to the engineer

7. REFERENCES

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8. BIOGRAPHY

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9. ACKNOWLEDGEMENT

The authors would like to thank Elizabeth McGee for her contributions to this paper.